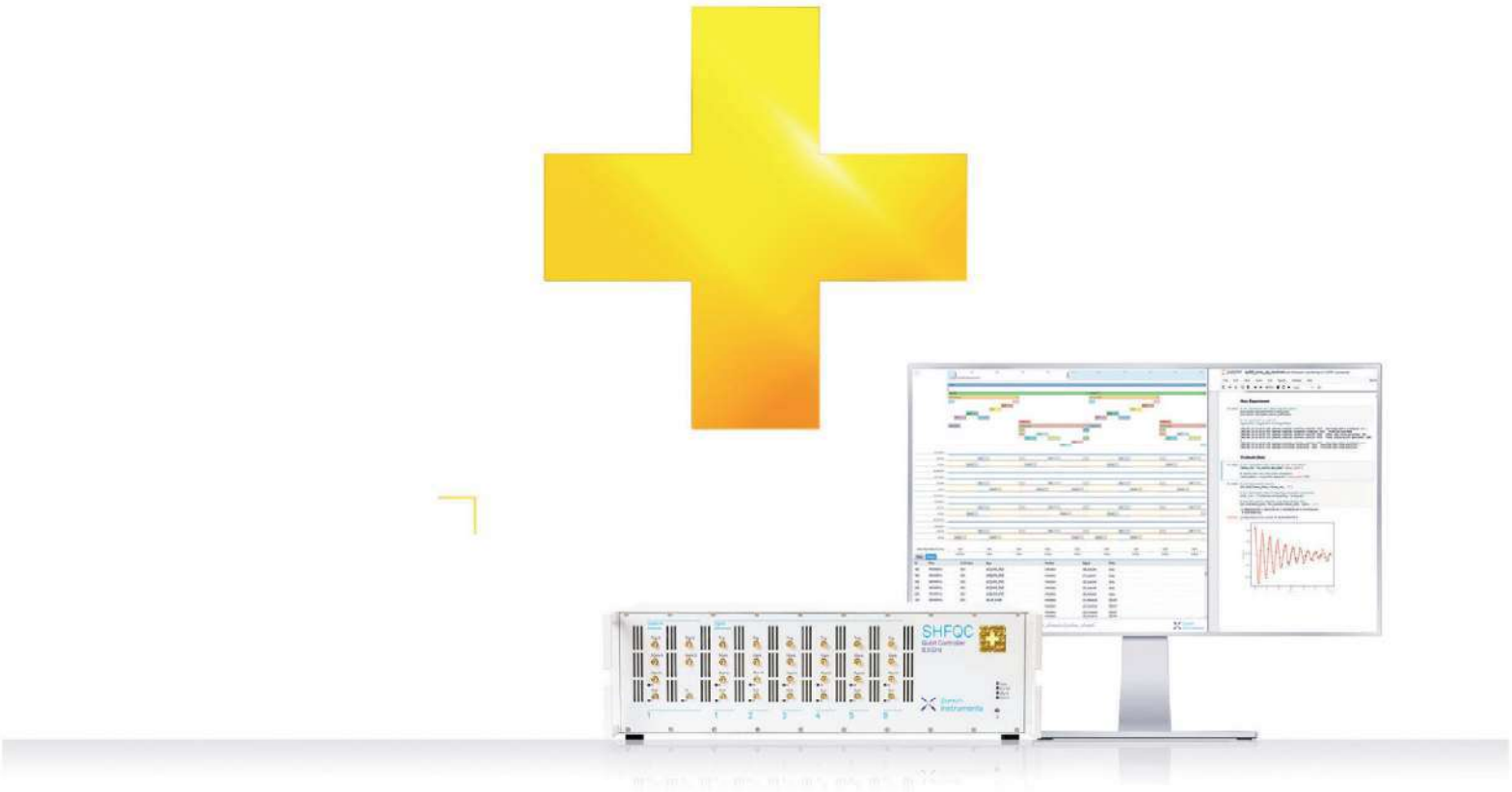

QUANTUM MATTER
2024
International Conference on Science & Technology of Quantum Matter
MAY 07-10 • San Sebastián (Spain)
ORGANISERS
PHANTOMS foundation
CSIC
Consejo Superior de Investigaciones Científicas
DIPC
Donostia International Physics Center
ICN2
Institut Català de Nanociència i Nanotecnologia
SCAN ME



Higher Fidelities
Faster Workflows

Reach new levels of performance on your quantum processor with the new SHF+ line of products.

- Higher SNR, lower phase noise, and fast muting functionality
- Ideal for measurements on even the most sensitive and long-lived of qubits
- Scalable software with extensive example libraries
- Tested at top labs worldwide

Zurich Instruments

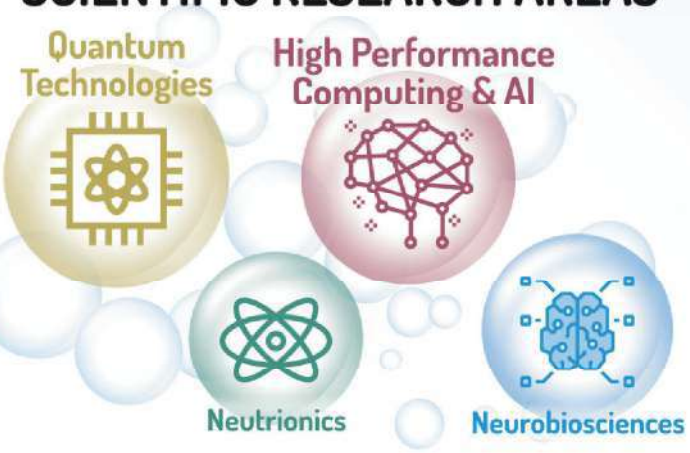
Unleash your quantum lab

INDEX

ikur estrategy

IKUR 2030 is the Strategy to position the Basque Country as a scientific pole of international reference.

SCIENTIFIC RESEARCH AREAS

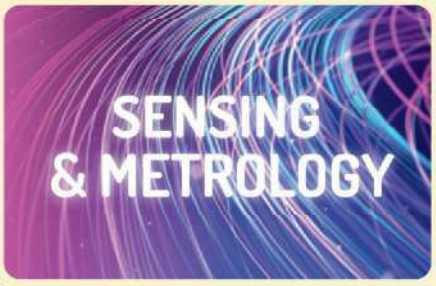


TOTAL INVESTMENT +282 M€

- BG Education department: 100 M€
- Companies: +139 M€
- Administrations: +18 M€
- International: +25 M€

ikur qt quantum technologies

RESEARCH TOPICS



2021-2024

- 8 Basque research and technology centers
- Over 2M investment in equipment
- More than 15 collaborative projects
- 65 New researcher hires

PROJECTS *some examples*

- A coordination chemistry approach for quantum computers.
- Quantum algorithms for quantum chemistry.
- Superconducting spintronics: fundamentals and applications.
- Analogue quantum simulators in moiré low-dimensional materials.
- Plexitonic quantum nanostructures as a source of entangled photons for parcial photonic quantum technology.
- Hydrogen vacancy centers in diamonds for hyperpolarization and advanced nmr detection.
- Quantum gyroscopes exploiting rotational doppler quantum metrology.
- Quantum optical hardware, applications and sources based on anti-resonant optical fibres.
- Quantum behaviour of artificial spin ice lattices.
- Shortcuts to adiabaticity for quantum computation.
- Non-linear transport and spintronics phenomena in low-dimensional materials with broken symmetries.
- Quantum register based on molecular spins and graphene nanostructures.

+info contact: ikur@euskampus.eu

ikerbasque Basque Foundation for Science
EUSKO JAURLARITZA GOBIERNO VASCO
euskampus
Plan de Recuperación, Transformación y Resiliencia
Financiado por la Unión Europea NextGenerationEU

FOREWORD

On behalf of the Organising and the International Scientific Committees we take great pleasure in welcoming you to San Sebastian (Spain) for the 4th edition of the Quantum Matter International Conference & Exhibition (QUANTUMatter2024).

This event aims at gathering the various communities engaged in the science and technologies of quantum information and quantum matter, to foster the incubation of new ideas & collaborations at the forefront of quantum technologies, emerging quantum materials and novel generations of quantum communication protocols, quantum sensing and quantum simulation.

Quantum Information and Quantum Matter are two components of revolutionary treatments of information, which are becoming cornerstones for discovering and implementing disruptive paradigms in quantum computation and quantum technologies.

QUANTUMatter2024 Highlights:

- Nearly 560 participants in-person
- 61 Plenary, Keynote & Invited Speakers
- More than 185 posters
- Nearly 180 oral contributions
- 25 Exhibitors and 23 Sponsors
- 7 Parallel Workshops
- 2 days Industrial Forum in parallel to get an updated understanding of latest technology developments from worldwide industries.

We are also indebted to the following Scientific Institutions, Companies and Government Agencies for their help and/or financial support:
IKUR estrategia, CFM/CSIC, DIPC, Quantum Machines, Zurich Instruments, Qruise, QTEP/CSIC, QBLOX, Keysight, Multiverse Computing, QuantrolOx, Kiutra, PASQAL, Maybell, QCentroid, Delft Circuits, attocube, IBM Quantum, UAM/IFIMAC, Tecnalia, Frontiers in Quantum Science and Technology, Nature Reviews electrical engineering and Royal Society of Chemistry.

We also would like to thank all the exhibitors, partners, speakers and participants that join us in-person this year.

We truly hope that QUANTUMatter2024 serves as an international platform for communication between science and business.
Hope to see you again in the next edition of QUANTUMatter in Grenoble (France): May 20-23, 2025.

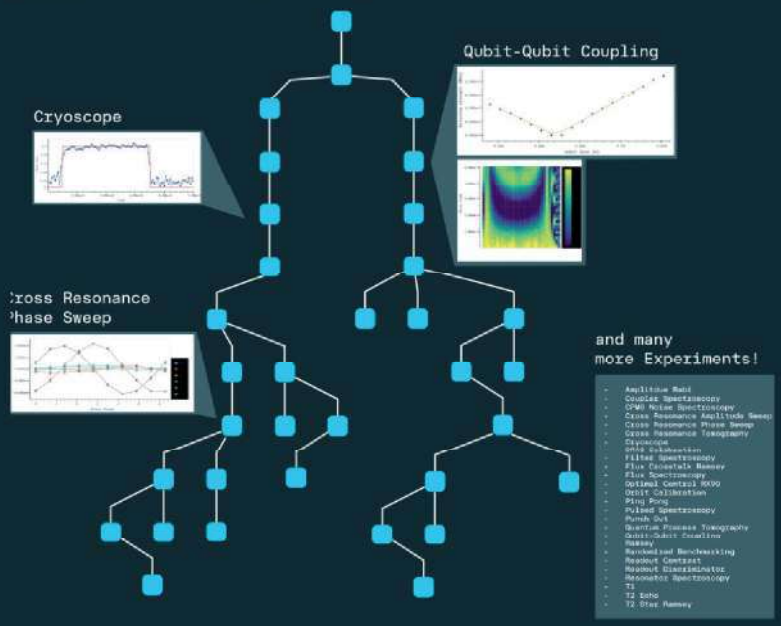
QUANTUMatter2024 Organising Committee

PRODUCT LAUNCH

Qruise OS

THE RAPID AUTOMATED BRING-UP FRAMEWORK

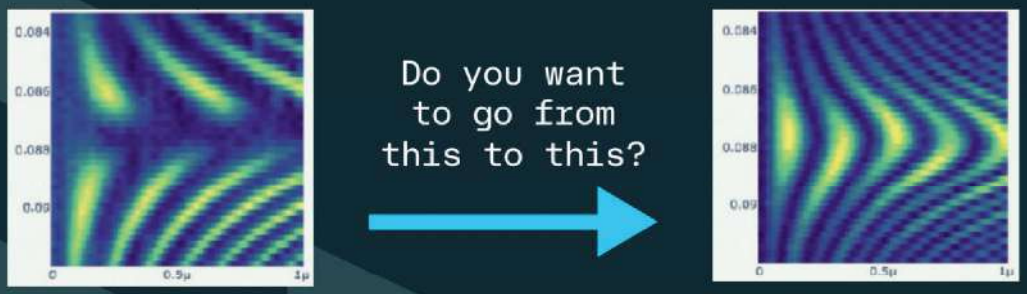
From in-depth characterization to enhancing the design process, seamlessly integrated experiments and interactive debugging, QruiseOS has it all!



NEW PRODUCT

Qruise ML

LEARNING PREDICTIVE MODELS



How can QruiseML help?
The generated models provide invaluable insights for R&D by producing detailed error budgets and simulating potential outcomes, vastly improving the efficiency and efficacy of quantum device design and optimizing the performance.

Want to learn more?

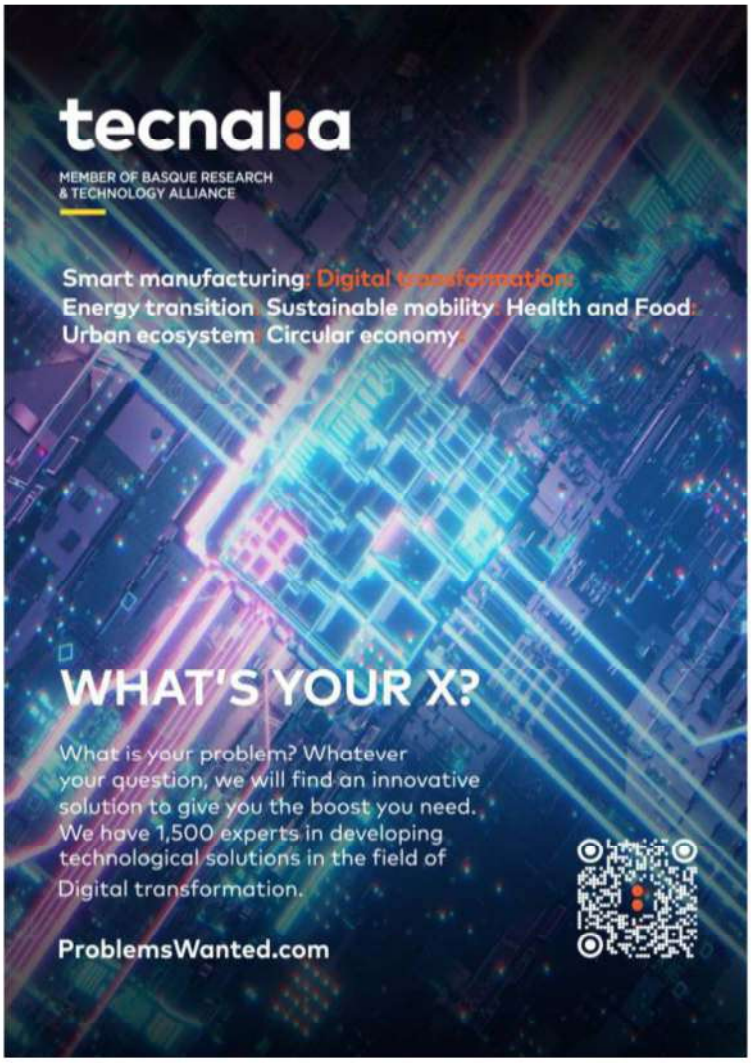
GENERAL INFO

FREE WIFI
Username: QM2024
Password: 24quantum24

EXHIBITION & POSTER AREA
Banquet Hall (Level -1)

COFFEE BREAKS
Check the program for timetables
Location: Exhibition & Poster Area

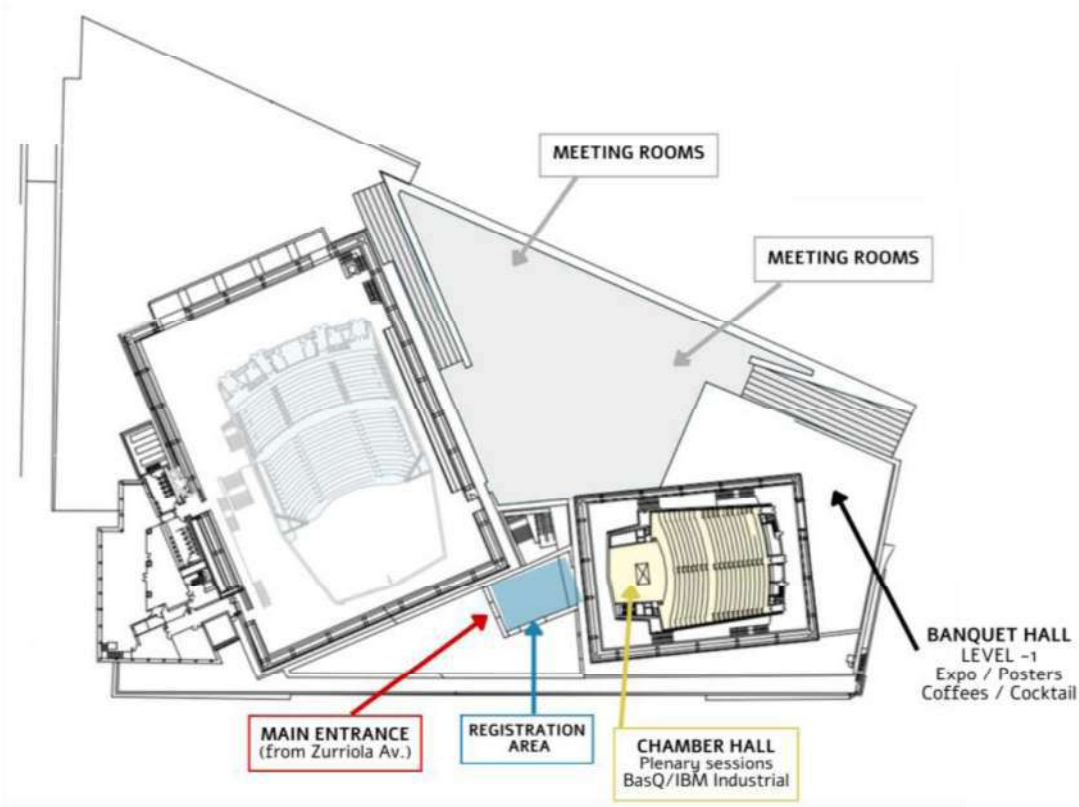
COCKTAIL LUNCH
Offered by QUANTUMatter 2024 organisers
Tuesday May 07
Thursday May 09
Location: Exhibition & Poster Area



CONFERENCE DINNER*
Wednesday May 08, 21:00
Restaurant PETRITEGI SAGARDOTEGIA
Petritegi Bidea, 8; Astigarraga, 20115, Gipuzkoa
Shuttle transfer info provided onsite
* Conference dinner NOT included in Exhibition Passes. Included only in FULL conference passes.
If you wish to attend, contact the organisers at the registration desks.

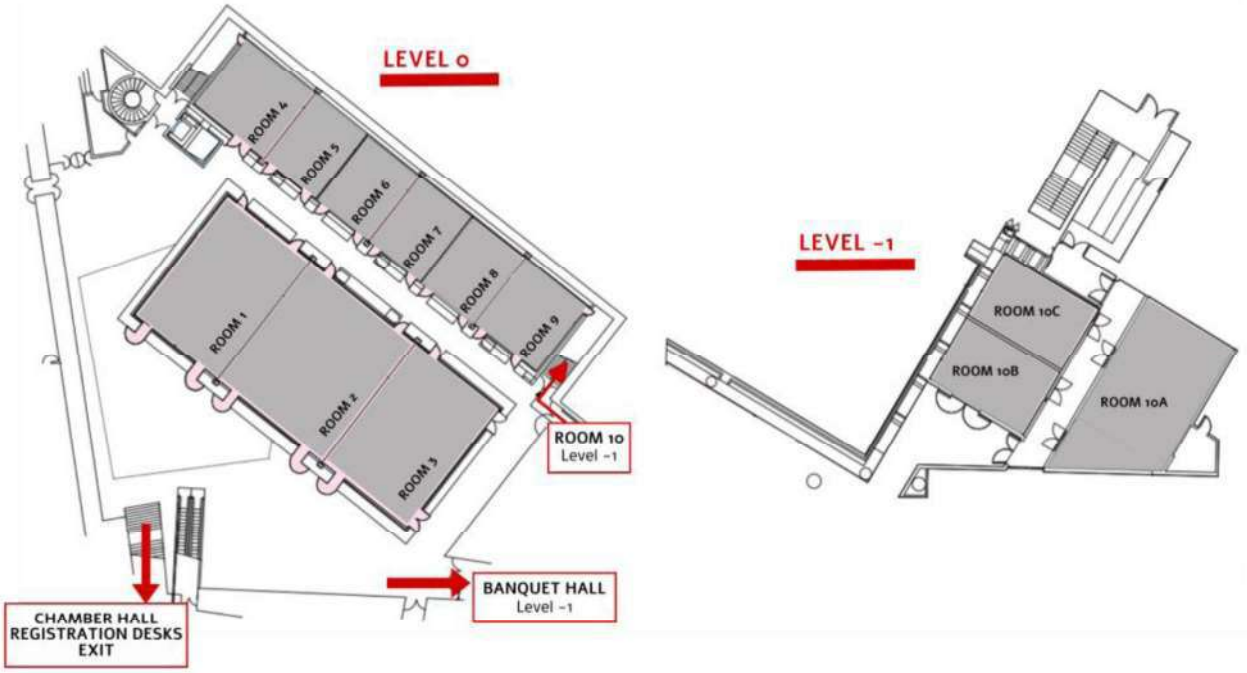
POSTERS SCHEDULE
Session I Tuesday May 07 to Wednesday May 08
You need to make sure you remove your poster after the morning coffee break on May 08
Session II Wednesday May 08 & Thursday May 09
You need to make sure you remove your poster after the afternoon coffee break on May 09

LOCATION



MEETING ROOMS

Workshops & Students // Sessions Industrial Forum & B2B



AGENDA & LOCATION

Monday – May 06	Room	Time
Tutorials	Room (6+7)	13:30 – 18:00
Tuesday – May 07	**Room**	**Time**
Plenary Session	Chamber Hall	08:45 – 17:45
Poster Session 1	Banquet Hall	12:30 – 13:00
Exhibition & Posters	Banquet Hall	–
Cocktail Lunch	Banquet Hall	13:00 – 14:00
Wednesday – May 08	**Room**	**Time**
Industrial Forum	Room 2	09:00 – 18:45
Workshop 01	Room 1	09:00 – 18:00
Workshop 02	Room 3	09:00 – 18:15
Workshop 03	Room 4+5	09:00 – 18:15
Workshop 04	Room 6+7	09:00 – 18:00
Workshop 05	Room 8+9	09:00 – 18:15
Workshop 06	Room 10A	09:00 – 17:45
Workshop 07	Room 10 (B+C)	09:00 – 17:45
Exhibition & Posters	Banquet Hall	–
Thursday – May 09	**Room**	**Time**
Plenary Session	Chamber Hall	09:00 – 13:00
B2B Brokerage event	Room 6	09:00 – 13:30
Industrial Forum	Room 2	09:00 – 12:45
Industrial Forum (BasQ/IBM Session)	Chamber Hall	14:30 – 18:30
Students 1: Quantum Matter	Room 1	14:30 – 16:00
Students 2: Quantum Info & Computing	Room 2	14:30 – 16:00
Students 3: Quantum Tech	Room 3	14:30 – 16:10
Exhibition & Posters	Banquet Hall	–
Poster Session 2	Banquet Hall	14:00 – 14:30
Cocktail Lunch	Banquet Hall	13:00 – 14:00
Conference dinner	Petritegi restaurant	20:00
Friday – May 10	**Room**	**Time**
Plenary Session	Chamber Hall	09:00 – 13:10

Quantum control stacks

Integrated.
Scalable.

QBLOX

COMMITTEES

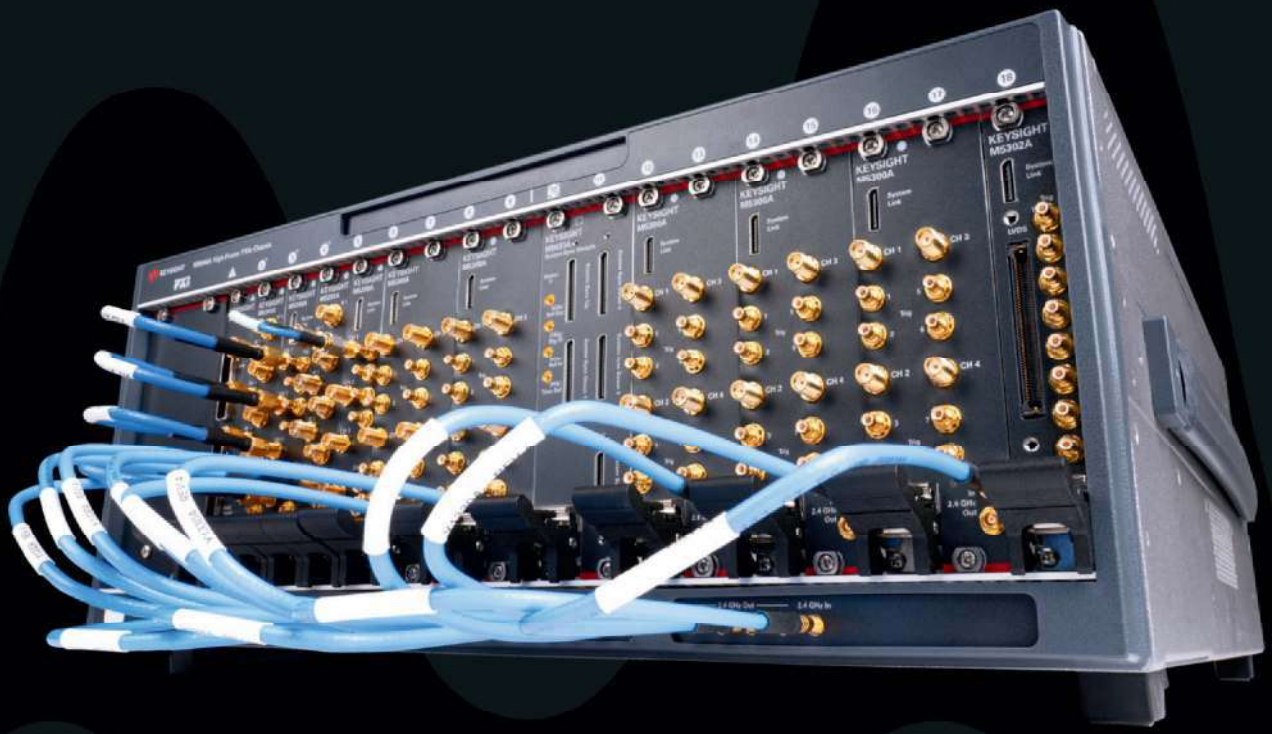
Organising Committee
Antonio Correia (Phantoms Foundation, Spain) - Chairperson
Ricardo Díez Muiño (DIPC & Ikerbasque, Spain)
Juan Jose Garcia-Ripoll (IFF-CSIC, Spain)
Stephan Roche (ICREA / ICN2, Spain)
Daniel Sanchez-Portal (CFM, Spain)

Local Organising Committee
Javier Aizpurua (DIPC & Ikerbasque, Spain)
Nacho Pascual (CIC nanoGUNE, Spain)
Enrique Rico (UPV-EHU, Spain)
Celia Rogero (CFM/CSIC - UPV/EHU, Spain)

International Scientific Committee
Silvano de Franceschi (CEA/UGA, France) - Chairperson
Sergio Valenzuela (ICN2, Spain) - Co-Chairperson

Ramon Aguado (ICMM-CSIC, Spain)
Sonia Conesa Boj (Delft University, The Netherlands)
Andrea Ferrari (Cambridge Graphene Centre / University of Cambridge, UK)
Yvonne Gao (NUS, Singapore)
Carmen Garcia Almudéver (UPV, Spain)
Giorgios Katsaros (IST, Austria)
Jelena Klinovaja (University of Basel, Switzerland)
Alfredo Levy Yeyati (IFIMAC / UAM, Spain)
Fernando Luis (UNIZAR, Spain)
Zlatko Minev (IBM Quantum Research, USA)
Mikko Möttönen (Aalto University, Finland)
William Oliver (MIT, USA)
Gloria Platero Coello (ICMM-CSIC, Spain)
Tommaso Roscilde (ENS, France)
Pascale Senellart-Mardon (C2N-CNRS-Université Paris Saclay, France)
Giordanno Scapucci (TU-Delft, Netherlands)
Juan F. Sierra (ICN2, Spain)
Christoph Stampfer (RWTH Aachen University, Germany)
Maia Vergniory (MPI CPfS, Germany and DIPC, Spain)
Luca Tagliacozzo (IFF CSIC, Spain)

KEYSIGHT



Start simply. Scale easily.

The Quantum Control System (QCS) is the world's first fully digital quantum control solution, built for quantum from the ground up.

Innovators start here

www.keysight.com/find/quantum

SPONSORS

MAIN SPONSORS

IKUR (**www.science.eus/en/ikur**) is the Basque strategy promoted by the Education Department of the Basque Government to boost the Scientific Research in specific strategical areas and to position them at international level. Although its first focus is to enhance the generation of knowledge of excellence, in the medium and long term, it also seeks the technological development in these fields.

Born in 1999 as a joint initiative between Consejo Superior de Investigaciones Científicas (CSIC) and Universidad del Pais Vasco – Euskal Herriko Unibertsitatea (UPV/EHU), the long-term aim of CFM (**cfm.ehu.es)** is to push forward the frontiers of knowledge on advanced materials science research, by putting together stable teams with a record of excellence in scientific research. CFM quality work has been recognized by the Basque Government acknowledging its instrumental body MPC as a Basic Excellence Research Center (BERC).
CFM headquarters are located in Donostia-San Sebastián offering a well configured, high quality working environment with modern facilities, both for experimentalist and theoreticians.

The Donostia International Physics Center Foundation (DIPC – **dipc.ehu.es**) was created in 1999, the fruit of institutional collaboration between the Departments of Education and Industry of the Basque government, the University of the Basque Country, the Diputación Foral de Guipúzcoa, the San Sebastián City Hall, the Kutxa of Guipúzcoa and San Sebastián. Iberdrola S.A. also participated in the project from 2000-2003. In 2004, Naturcorp Multiservicios S.A, joined, followed by Telefónica S.A in 2005.
The DIPC was created as an intellectual centre whose main aim is to promote and catalyse the development of basic research and basic research oriented towards material science to reach the highest level. Since its creation, the DIPC has been an open institution, linked to the University

of the Basque Country, serving as a platform for the internationalising of basic science in the Basque Country in the field of materials.
The DIPC Foundation has become an international point of reference in basic research in the field of the Physics of Materials. This relevance shows in the quality of the researchers who have done research stays at the Foundation, the international level of the conferences held there, and, mainly, by the importance of the scientific contributions made as a consequence of the activities carried out at the DIPC.

DIAMOND SPONSORS

Quantum Machines accelerates the realization of useful quantum computers that will disrupt all industries. Supporting multiple Quantum Processing Unit (QPU) technologies, the company's Quantum Orchestration Platform (QOP) fundamentally redefines the control and operations architecture of quantum processors with unprecedented levels of scalability, performance, and productivity.
Our rich product portfolio, including full stack (hardware and software) quantum control and state-of-the-art quantum electronics, empowers academia and national labs, HPC centers, enterprises, and cloud service providers building quantum computers all over the world. To learn more, please visit **quantum-machines.co**.

Zurich Instruments **www.zhinst.com** makes cutting-edge instrumentation for scientists and technologists in advanced laboratories who are passionate about phenomena that are notoriously difficult to measure. The company's hardware offering includes lock-in amplifiers, quantum computing control systems, impedance analyzers, and arbitrary waveform generators.
Zurich Instruments brings innovation to quantum control systems in the form of efficient workflows, tailored specifications and feature sets, and a high degree of reliability. The company's goal is to support quantum researchers and engineers by allowing them to focus on developing and scaling up quantum processors and other elements of the quantum stack while benefiting from the most advanced classical control electronics and software.

PLATINUM SPONSORS

Qruise (**qruise.com**) develops software that helps scientists and researchers use Machine Learning tools in their day-to-day scientific workflows without having to worry about what's under the hood. ML has revolutionised how science is being done and taking advantage of this new numerical toolset should not require having a full time ML scientist on the team to design, develop and deploy systems. Qruise is developing ML for Science as a productised toolset making ML driven discovery accessible to all. Our first offerings address the growing pains of controlling current generation noisy quantum computers (NISQ devices) and provide improvements in operational fidelities through the use of ML & Quantum Optimal Control.

QTEP (**qst.csic.es**) is a CSIC Interdisciplinary Thematic Platform (PTI). The reference for QTEP is the quantum technologies community organised around the Flagship and the Quantum Community Network. This community works on four basic research lines with growing technological interest – Quantum Metrology & Sensing, Quantum Crypto & Communication, Quantum Simulation and Quantum Computing, and includes both research institutions as well as companies. QTEP represents a community of 22 groups on 11 research centers, with strong internal collaborations, remarkable international impact and scientific production. QTEP's research spans the main quantum technology pillars, plus a strong base working on enabling technologies.

Qblox (**www.qblox.com**) is a leading provider of scalable and modular qubit control electronics. Qblox operates at the frontier of the quantum revolution in supporting academic and industrial labs worldwide.

The Qblox control stack, known as the Cluster, combines key technologies for qubit control and readout with a modular solution ready to support customers using different qubit technologies. The Qblox team is 80+ members strong, and continues to innovate hardware and software that is device agnostic, sophisticated, and scalable to support operations on hundreds, and in the future thousands, of qubits.

MULTIVERSE
COMPUTING

ENERGY, LIFE- MANUFACTURING-
SPACE-FINANCE- HEALTHCARE-
DEFENSE- HIGHLY EFFICIENT LLM's

BE WILD JOIN US

TOP EU COMPANY

Largest Quantum Software company in EU

One of the TOP 100 companies in AI in the world

+150 employees,Fastest Growth Company, +40 nationalities,
30% women, Quantum & Tensor Networks

www.multiversecomputing.com

San Sebastián-Paris-London-Toronto-Munich-Milan

KEYSIGHT Keysight Accelerates Quantum Innovations to Connect and Secure the World (**www.keysight.com/find/quantum**). At Keysight, we inspire and empower innovators to build world-changing technologies. Serving as a global innovation partner, we deliver market-leading design, emulation, and test environments that help companies develop and deploy breakthroughs faster, with less risk, throughout the product life cycle. Our differentiated technologies, measurement expertise, and tailored solutions are built from a foundation of co-innovation with industry ecosystem leaders.

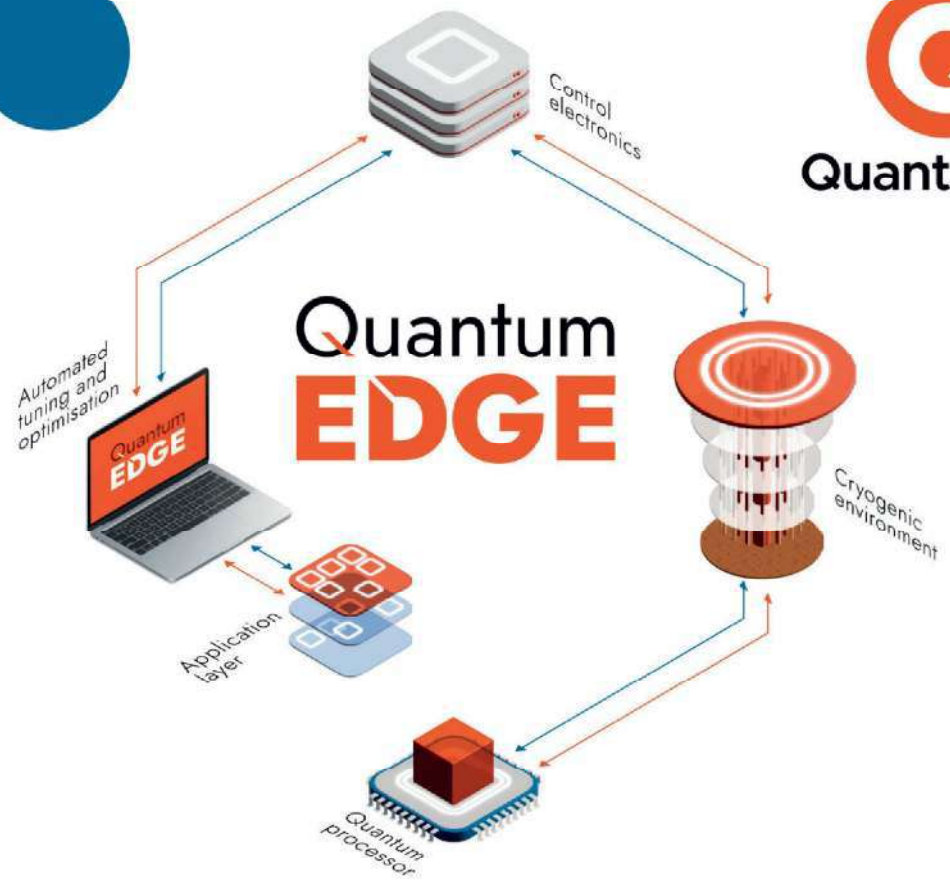
Keysight Quantum Engineering Solutions (QES) group enables your breakthroughs in quantum computing, sensing, and communications. As leaders in scalable quantum software and hardware solutions, our tools and expertise enable customer success. Keysight QES offers world-wide opportunities to connect and accelerate your quantum innovations.

Keysight Technologies (NYSE: KEYS) is an S&P 500 technology company, headquartered in California, with global offices and manufacturing. We've pioneered 3,800+ patents, ~15,000 employees connecting with 30,000+ customers to start technology revolutions.

MULTIVERSE COMPUTING

Multiverse Computing is a quantum and quantum-inspired software company, the largest in this segment in the EU by employees and capitalization. It prepares algorithms and additional complementary software that work for real-sized problems in more than 10 sectors, with finance, energy, manufacturing, logistics and space amongst them. Some solutions work in quantum computers, some in classical (traditional) computers and some others combine both. The best algorithms are included in Singularity, a product from Multiverse that anybody without quantum education can use (even from Excel!). Multiverse Computing is headquartered in San Sebastian (Spain), with offices in Toronto, Paris and Munich. It has more than 80 employees, 40% PhD, 30% women. Multiverse Computing successfully raised €10M in 2021, and in addition EIC Horizon Europe (EC) agreed to put €12.M more. Multiverse Computing has partnerships with most quantum manufacturers. Multiverse Computing filed 22 patents filed in 2021; 24/yr more in 2022. Multiverse Computing total contract value was €6.8M in 2021 and more than €10M in 2022. **https://multiversecomputing.com/**

QuantrolOx



MORE THAN 100X FASTER

Qubit Bring-up, Characterisation & Testing at Incredible Speeds

QPU Monitoring

Automation Workflows

Data Visualisation

quantrolox.com

INTEGRATED WITH

QBLOX

QUANTUM MACHINES

Zurich Instruments

QuantrolOx (**quantrolox.com**) is the developer of Quantum Edge software for qubit, and quantum processor tune up automation. They envision a world where every quantum computer will be fully automated enabling quantum scientists to spend less time tuning qubits and more time on advancing quantum computing, thereby accelerating the path to practical quantum computers. Quantum Edge integrates with major quantum hardware providers by building on open-architecture principles enabling organisations to select the best components for their quantum systems.

kiutra (**kiutra.com**) supplies innovative cryogenic solutions, products, and services that provide ultra-low temperatures. We design and build turnkey cryostats for the development, characterization, and testing of quantum systems, as well as for their continuous operation. Our systems do not require liquid cooling media, such as the rare and expensive helium-3, making them fast, cost-effective, scalable, and sustainable – ideal for providing cooling along the entire quantum technology chain

Pasqal (**pasqal.io**), we build Programmable Quantum Simulators and Quantum Computers made of 2D and 3D Atomic Arrays. Neutral atoms trapped in optical tweezers and addressed with laser beams are ideal indistinguishable quantum systems to realize superposition and entanglement, at the heart of powerful Quantum Information Processing. It is a highly scalable platform, benefiting from tens of years of development which has brought some of contemporary physics' most spectacular achievements. We develop the lasers, the vacuum technology, the electronic controls and the full software stack to make the individual atoms accessible to quantum programmers worldwide.

Maybell is building the infrastructure for a quantum future. We engineer reliable, scalable and user-friendly quantum infrastructure hardware. We listen to our customers, understand their needs, and employ cutting-edge science and human-centered engineering to deliver industry-leading performance and unrivaled user experience. If you would like to find our more about our innovative cryogenic solutions (dilution refrigerators and high-density cabling), please visit **www.maybellquantum.com**

kiutra

Easy-to-use and
sustainable cryogenics

Discover the L-Type Rapid

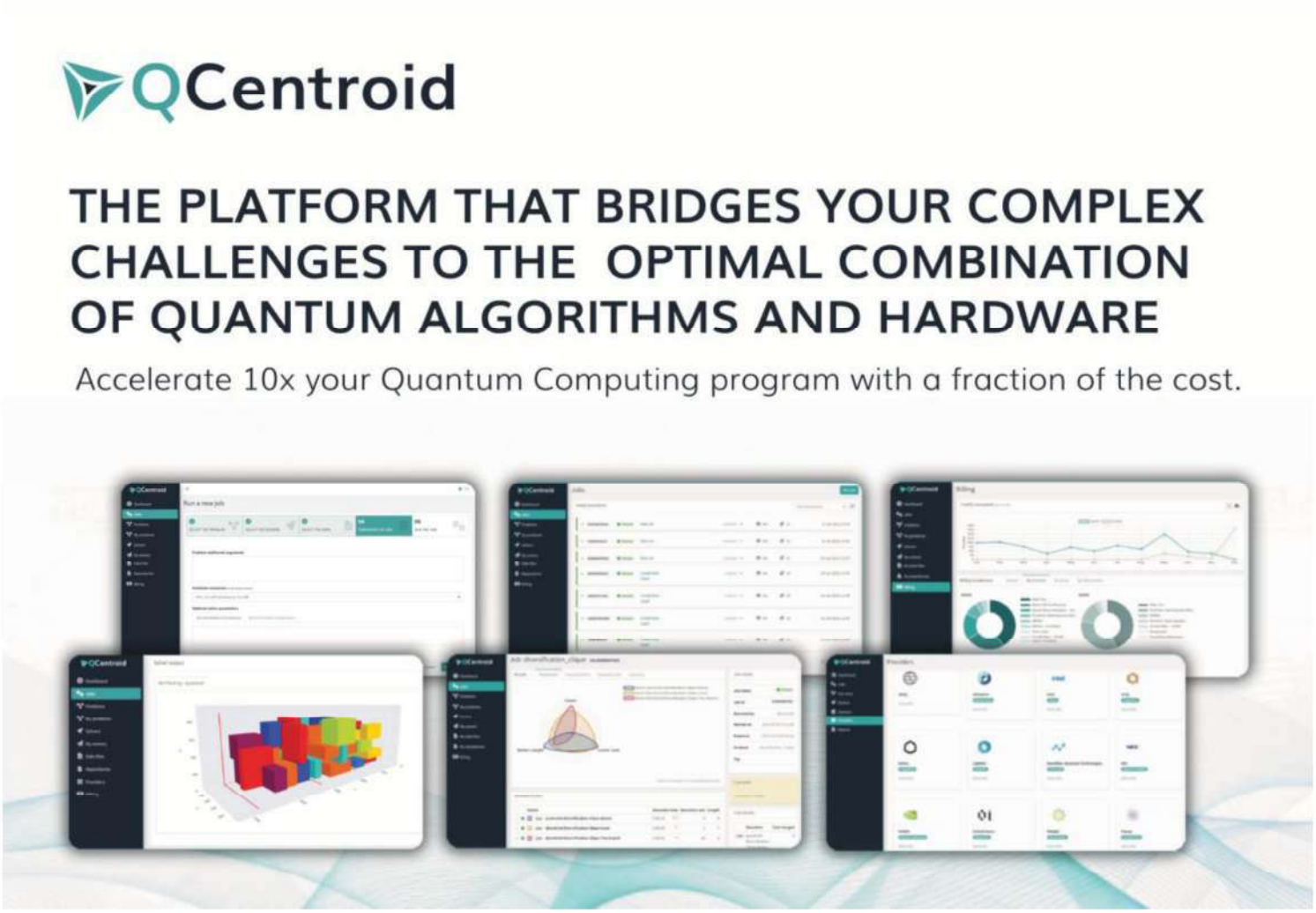
Super-fast automated
characterization cryostat
for sub-Kelvin and
Kelvin temperatures

Find out more

info@kiutra.com
kiutra.com

GOLD SPONSOR

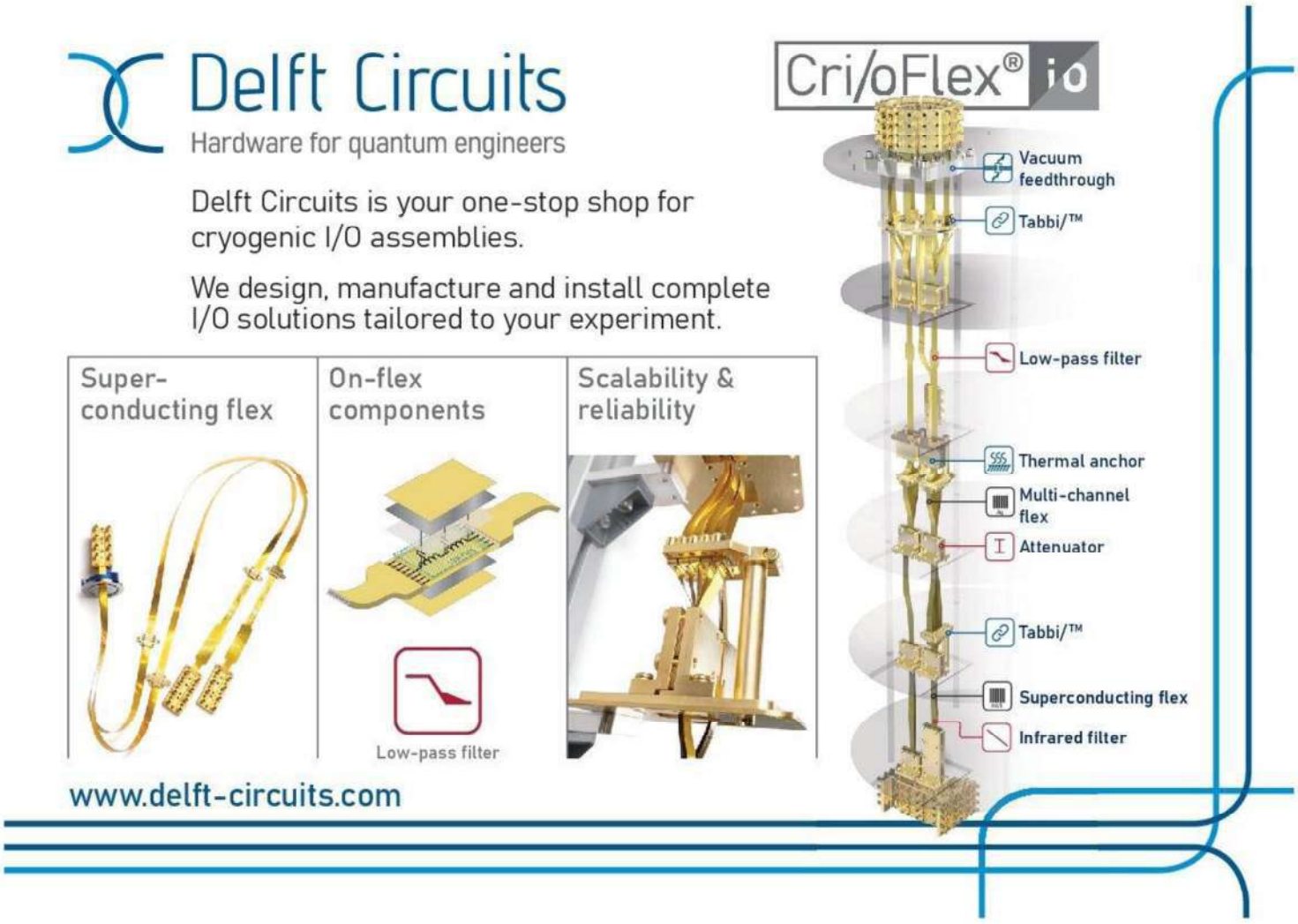
QCentroid (qcentroid.xyz) aim to democratize quantum computing, unlocking endless possibilities and addressing humanity's greatest challenges. QCentroid mission is to accelerate access to quantum computing for companies of all sizes that face complex problems. The focus is on those aiming for sustainable transformation, net-zero goals, and climate adaptation solutions. Our Quantum-as-a-Service and Quantum Ops Platform offers unified access and invaluable comparisons between diverse algorithms, connecting providers, creators, and consumers. QCentroid Suite is the platform that accelerates testing, comparison and deployment of the best quantum, inspired or hybrid computational solutions. Optimizing for business efficiency and net zero goals at the same time.



SILVER SPONSORS

Delft Circuits
Hardware for quantum engineers

Delft Circuits (**delft-circuits.com**) is a hardware company from the Netherlands. Delft Circuits designs develops, and manufactures i/o solutions (cabling) for the quantum industry. The Cri/oFlex® technology introduces an ultra-low thermal conductance and scalable cryogenic i/o solution, using conducting and superconducting circuits on flexible substrates. Designed specifically for cryogenic setups, it provides excellent microwave performance, low thermal load, integrated signal conditioning, flexibility, ease of installation and reliability.



attocube systems is the technology leader for ultra precise nanopositioning and measurement solutions, compatible with extreme environmental conditions such as ultra-high vacuum, magnetic field, as well as cryogenic to elevated operating temperatures (**www.attocube.com**)

IBM **Quantum** IBM Quantum (**quantum.ibm.com**) is bringing useful quantum computing to the world and making the world quantum-safe. IBM Quantum builds the hardware, software, and services users will need to solve useful problems with quantum computers, while securing enterprises for the quantum future

BRONZE SPONSORS

PARTNERS

CSIC Consejo Superior de Investigaciones Científicas | QTEP

BIST Barcelona Institute of Science and Technology

ICREA

España Puede | Financiado por la Unión Europea NextGenerationEU | Plan de Recuperación, Transformación y Resiliencia

TOCHA New Generation of Devices to Harness Topology

TalentQ Quantum SPAIN

EXHIBITORS


QUANTUM MACHINES


Zurich
Instruments


qruise


QBLOX


KEYSIGHT


MULTIVERSE
COMPUTING


QuantrolOx


kiutra


PASQAL


Maybell


QCentroid


Delft Circuits
Hardware for quantum engineers


attocube
WITTENSTEIN Group


IBM Quantum


SINGLE QUANTUM
Excellence in photon detection


ACTIVE
TECHNOLOGIES


SPECSGROUP


invest
in
bavaria


QUANTUM
MOTION


Onnes
Technologies


OXFORD
INSTRUMENTS


QUANTWARE


SCALINQ


gmv
INNOVATING SOLUTIONS


VASTA

Quantum Computing is a small world. We make it big.

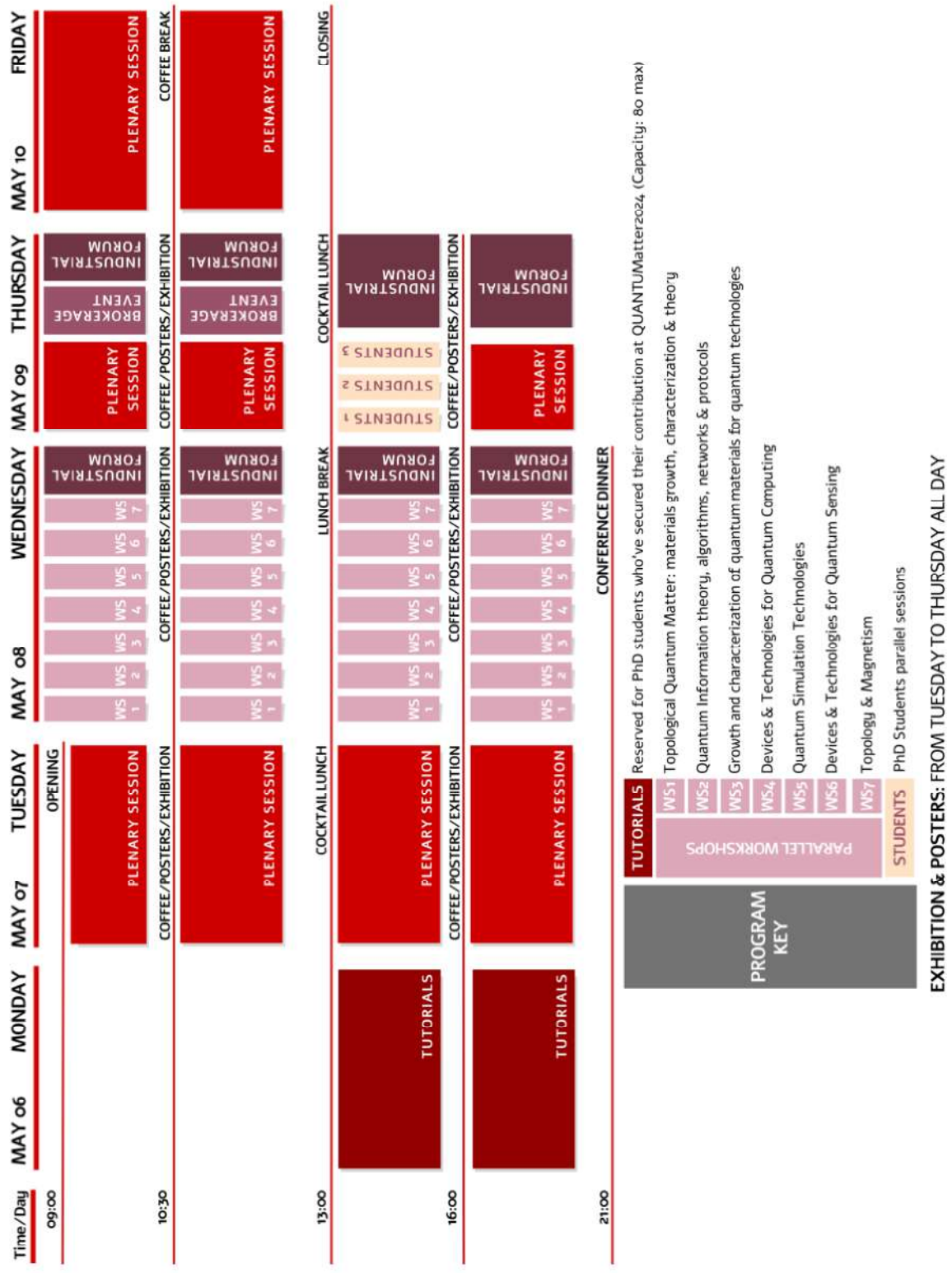
Quantum for your key applications.

Pasqal is a quantum scale-up that strives to bring practical quantum advantage to customers across the globe to address real-world problems touching almost all domains and verticals (such as financial industries, energy and utilities, pharmaceutical industry, logistics and mobility, etc.).

www.pasqal.com

Pasqal

PROGRAM AT A GLANCE



Maybell

THE QUANTUM INFRASTRUCTURE COMPANY

DENVER, COLORADO

COPENHAGEN, DENMARK

MayQ Labs

Expert-managed turnkey quantum hardware facilities to enhance research productivity

INFO@MAYBELLQUANTUM.COM TO LEARN MORE

PROGRAM

Program updated as of 24/04/2024;
For updates, please check the QUANTUMatter 2024 website ➡
P: Plenary / K: Keynote / I: Invited / O: Oral / T: Tutorial

MONDAY (06/05/2024)

	Topological Matter Tutorials	
13:30	**Athanasios Dimoulas** (NCSRD, Greece) MBE growth of 2D topological quantum materials	T
14:30	**Tomas Jungwirth** (Czech Academy of Sciences, Czech Republic) Altermagnets: An unconventional magnetic class	T
15:30	**Coffee Break**	
16:00	**Maia García Vergniory** (Max Planck for Chemical Physics of Solids, Germany & DIPC, Spain)	T
17:00	**Ramon Aguado** (ICMM-CSIC, Spain) From Majorana to Andreev and back	T

Scan the QR for QUANTUMatter 2024 Abstracts Book

Share with us your vision of the Conference.
Post your photos and comments
#Quantumatter2024

@QuantumConf

TUESDAY (07/05/2024)

08:45	**Welcome Ceremony**	
09:10	**Ignacio Cirac** (Max Planck Institute of Quantum Optics, Germany) Quantum Computing and Simulation in the NISQ era	P
09:50	**Susanne Yelin** (Harvard University, USA) Quantum Simulation of Molecules and Materials with present-day Reconfigurable Quantum Processors	I
10:20	**Coffee Break – Poster Session – Exhibition**	
11:00	**Amir Yacoby** (Harvard University, USA) Quantum Sensing of Quantum Matter	K
11:30	**Philippe Bouyer** (UvA /Quantum Delta NL, The Netherlands) From matter waves to quantum sensors	I
12:00	**Pascal Degiovanni** (CNRS - ENS Lyon, France) Single electron interferometric sensing of quantum electromagnetic noise	O
12:15	**María José Martínez-Pérez** (INMA, CSIC-Univ. of Zaragoza, Spain) Integration of Magnons into Superconducting Circuits for Sensing Applications	O
12:30	**Poster Session 1**	
13:00	**Cocktail Lunch offered by QUANTUMatter 2024** **Poster Session – Exhibition**	
14:00	**Michelle Simmons** (University of New South Wales, Australia) Atomic Electronics – building qubits in silicon with atomic precision	K
14:30	**Deung-Jang Choi** (CFM-CSIC, UPV/EHU, Spain) Quantum Control at the Atomic Scale: From Ångstrom-Scale Qubit Platforms to Topological Superconductivity	I
15:00	**Martin Hayhurst Appel** (University of Cambridge, UK) A Spin Qubit Coupled to a Collective Nuclear Quantum Register	O
15:15	**Benjamin Brock** (Yale University, USA) Controlling a High-Q Cavity with a Kerr-cat Qubit	O
15:30	**Soeren Wengerowsky** (ICFO, Spain) Cavity-Enhanced on-demand Spin-Wave Solid State Quantum Memory	O
15:45	**Alessandro Crippa** (NEST, CNR-Nano and SNS, Italy) A gate tunable transmon qubit in planar Ge	O
16:00	**Coffee Break – Poster Session – Exhibition**	
17:00	**Leo Kouwenhoven** (Delft University of Technology, The Netherlands) Andreev and Majorana bound states in nanoscale devices	K
17:30	**Ilan Rosen** (MIT, USA) Generating highly entangled states and synthetic gauge fields on a superconducting processor	O

WEDNESDAY (08/05/2024)

WORKSHOP 01 Topological Quantum Matter: materials growth, characterization & theory		
09:00	**Carmen Rubio Verdú** (ICFO, Spain) Universal moiré nematic phase in twisted graphene	I
09:30	**Paritosh Karnatak** (University of Basel, Switzerland) Large tunable kinetic inductance in a twisted graphene superconductor	O
09:45	**Marc Vila** (LBNL and University of California, Berkeley, USA) Giant Resistance Switch in Twisted Transition Metal Dichalcogenide Tunnel Junctions	O
10:00	**Dmitri Efetov** (LMU, Germany) Thermodynamic measurements of the correlated states in Magic Angle Twisted Bilayer Graphene	I
10:30	**Coffee Break – Poster Session – Exhibition**	
11:30	**Raquel Pinheiro de Almeida Queiroz** (Columbia University, USA) Quantum geometry and material properties	I
12:00	**Sophie Gueron** (Université Paris Saclay – LPS, France) Evidence of helical states in bismuth	I
12:30	**Tanweer Ahmed** (CIC Nanogune, Spain) Role of Lifshitz transitions and Berry curvature dipole on nonlinear Hall effect in low symmetry Bilayer graphene	O
12:45	**Borislav Polovnikov** (LMU, Germany) Implementation of the Bilayer Hubbard Model in a Moiré Heterostructure	O
13:00	**Enrique Diez** (Universidad de Salamanca, Spain) Hydrodynamic electron flow in graphene	O
13:30	**Lunch Break**	
15:00	**Pascal Gehring** (UCLouvain, Belgium) Large Anomalous Ettingshausen effect in a micron-sized magnetic Weyl semimetal on-chip cooler	O
15:15	**Giovanni Vignale** (National University of Singapore, Singapore) Theory of non-conserved density accumulations in the anomalous Hall effects	O
15:30	**Luis Canonico** (ICN2, Spain) Orbital origin of hidden spin textures in centrosymmetric $PtSe_2$ monolayer and their proximity applications	O
15:45	**Pierre Capiod** (JUNIA-ISEN, France) Artificial quantum systems based on semi-conducting quantum dots chains: towards quantum simulations in a SSH chain.	O
16:00	**Nicetu Tibau Vidal** (University of Hong Kong, Hong Kong SAR) Annihilation operators for 2D non-abelian anyons	O
16:15	**Coffee Break – Posters Session – Exhibition**	
17:00	**Adolfo G. Grushin** (Institut Néel / CNRS, France) Amorphous topological metals	I
17:30	**Johan Christensen** (IMDEA Materials, Spain) Topological sonic defects	O
17:45	**Giacomo Rebora** (École Normale Supérieure de Lyon, France) Tunable Edge Magnetoplasmon Resonator	O

WEDNESDAY (08/05/2024)

WORKSHOP 02 Quantum information theory, algorithms, networks & protocols		
09:00	**Antonio Acin** (ICFO, Spain) Security proof of discrete-modulated continuous-variable quantum key distribution	I
09:30	**Maryam Afsary** (University of Warsaw, Poland) Secure key rate improvement methods in DI-QKD protocols	O
09:45	**Piotr Grochowski** (University of Innsbruck & IQOQI Innsbruck, Austria) Quantum control of continuous systems via nonharmonic potential modulation	O
10:00	**Manuel Gessner** (Universidad de Valencia, Spain) Hierarchies of quantum metrology bounds beyond Cramér-Rao	O
10:15	**Esperanza Lopez** (Instituto de Fisica Teorica, Spain) Comparative study of quantum error correction strategies for the heavy-hexagonal lattice	O
10:30	**Coffee Break – Poster Session – Exhibition**	
11:15	**Mikel Sanz** (NQUIRE Center - UPV/EHU, Spain) Training embedding quantum kernels with quantum neural networks	I
11:45	**Vanio Markov** (Wells Fargo, USA) Quantum Time Series Similarity Measures and Quantum Temporal Kernels	O
12:00	**Germán Rodrigo** (IFIC UV-CSIC, Spain) Quantum algorithms in collider particle physics	O
12:15	**Raphael Seidel** (Fraunhofer FOKU, Germany) Quantum Backtracking in Qrisp applied to Sudoku Problems	O
12:30	**Alessandro Tosini** (University of Pavia, Italy) Causal influence versus signalling for interacting quantum channels	O
12:45	**Geza Toth** (University of the Basque Country UPV/EHU, Spain) Quantum Wasserstein distance based on an optimization over separable states	O
13:00	**Matteo Ippoliti** (The University of Texas at Austin, USA) Phases of quantum information on a noisy quantum processor	I
13:30	**Lunch Break**	
15:00	**Julia Mathe** (TU Wien, Austria) Estimation of entanglement monotones in spin systems	O
15:15	**Teemu Ojanen** (Tampere University, Finland) Avoiding exponential bottlenecks in measurement-induced entanglement phase transitions	O
15:30	**Yariv Yanay** (University of Maryland, USA) Detecting Measurement-Induced Entanglement Transitions With Unitary Mirror Circuits	O
15:45	**Javier Osca** (University of the Balearic Islands, Spain) Stochastic Optical Quantum Circuit Simulator: model, design and implementation	O
16:00	**German Sierra** (Instituto de Física Teórica UAM-CSIC, Spain) Photonic Implementation of the Quantum Morra Game	O
16:15	**Coffee Break – Posters Session – Exhibition**	

WEDNESDAY (08/05/2024)

17:00	**Barbara Kraus** (Technical University of Munich, Germany) Testing and verifying quantum computations and simulations	I
17:30	**Daniel Bultrini** (University of Heidelberg, Germany) Mixed quantum-classical dynamics for near term quantum computers	O
17:45	**Baptiste Anselme Martin** (Eviden (Quantum Lab), France) Combining Matrix Product States and Noisy Quantum Computers for Quantum Simulation	O
18:00	**Gergeley Zarand** (Budapest Univ. Technology and Economics, Hungary) Quantum information jet in the infinite temperature Hubbard model	O

WEDNESDAY (08/05/2024)

WORKSHOP 03 Growth and characterization of quantum materials for quantum technologies		
09:00	**Nicola Poccia** (IFW Dresden, Germany & UNINA, Italy) Cuprate Twistronics for a New Generation of Macroscopic Quantum Hardwares	I
09:30	**Diana Serrano** (CNRS - Institut de Recherche de Chimie Paris, France) Long optical coherence in $Eu_xLa_{1-x}PO_4$ crystals, a new synthetic material for quantum technologies	O
09:45	**Philippe Goldner** (Chimie ParisTech PSL, France) Rare Earth-Diamond Hybrid Structures for Optical Quantum Technologies	O
10:00	**Robert Chapman** (ETH Zurich, Switzerland) Lithium niobate-on-insulator integrated photonics for linear optical quantum computing	O
10:15	**Davide Costa** (QuTech, The Netherlands) Record carrier mobility in group IV semiconductor materials	O
10:30	**Coffee Break - Poster Session - Exhibition**	
11:15	**Jordi Arbiol** (ICREA / ICN2, Spain) Quantum nanostructures at atomic scale: From vertical hybrid nanowires to planar nanowire networks and 2DEG/2DHG systems	I
11:45	**Malcolm Connolly** (Imperial College London, UK) Nanomagnet-induced Synthetic Spin-Orbit Coupling in a Superconductor-Semiconductor Nanowire	O
12:00	**Nilanthy Balakrishnan** (Keele University, UK) Growth of Iron selenide layers via salt-assisted chemical vapour deposition	O
12:15	**Taylor Stock** (University College London, UK) Single-Atom Control of Arsenic Incorporation in Silicon for Quantum Materials Fabrication	O
12:30	**Iván Martínez Ibarburu** (UAM, Spain) Unveiling the interlayer interaction in a 1H/1T TaS_2 van der Waals heterostructure	O

WEDNESDAY (08/05/2024)

12:45	**Senthil Kumar Karuppannan** (IMRE A*STAR, Singapore) Role of interface in quantum device	O
13:00	**Nitin Samarth** (Penn State University, USA) Epitaxially engineered quantum materials for quantum technologies: interfacing topology, magnetism, and superconductivity	I
13:15	**Lunch Break**	
15:00	**Rosa Diaz** (Purdue University, USA) Understanding Inherent Structural Defects and Chemical Distribution at Topological Superconductor-Semiconductor Interfaces and Heterostructures Using Advance Electron Microscopy	O
15:15	**Ivan Pinto Huguet** (ICN2, Spain) Automatic detection of vacancies in WS_2 for Quantum Materials studies using HAADF-STEM Imaging	O
15:30	**Ernst Jan Vesseur** (Thermo Fischer Scientific, The Netherlands) Advancements in High-Resolution Microscopy Techniques for Quantum Device Characterization	O
15:45	**Deep Lall** (National Physical Laboratory, UK) Characterising frequency fluctuations in superconducting qubits	O
16:00	**Giovanni Oakes** (Quantum Motion, UK) High-fidelity dispersive spin readout in a scalable unit cell of silicon quantum dots	O
16:15	**Tobias Schulli** (The European Synchrotron ESRF, France) Strain control, imaging and tuning developed for SiGe qubit devices	O
16:30	**Coffee Break – Posters Session – Exhibition**	
17:00	**Javad Shabani** (New York University, USA) Understanding of disorder for enhancement of superconducting topological gap	I
17:30	**Andreas K. Hüttel** (University of Regensburg, Germany) Adiós flatland – Quantum transport in MoS_2 nanotube and nanoribbon quantum dots	O
17:45	**Artem Denisov** (ETH Zurich, Switzerland) Ultra-long relaxation of a Kramers qubit formed in a bilayer graphene quantum dot	O
18:00	**Hongguang Wang** (MPI-FKF, Germany) Quantum nanostructures of correlated metal oxides	O

WEDNESDAY (08/05/2024)

	WORKSHOP 04 Devices & Technologies for Quantum Computing	
09:00	**Silvia Zorzetti** (Fermilab, USA) Unlocking the Quantum Internet: Advancements in High-Efficiency Microwave-Optical Transduction	I
09:30	**Chien-An Wang** (QuTech, TU Delft, The Netherlands) Operating semiconductor quantum processors with hopping spins	O
09:45	**Maxim De Smet** (QuTech, TU Delft, The Netherlands) High-fidelity spin shuttling in silicon quantum dots	O
10:00	**Robert Starek** (Palacky University, Czech Republic) Storage and retrieval of quantum operations – an experimental test	O
10:15	**Mykhailo Moskalets** (IFISC (CSIC-UIB), Spain) Single-particle emission from the Andreev's level	O
10:30	**Coffee Break - Poster Session - Exhibition**	
11:15	**Tahereh Niknejad** (Qblox BV, The Netherlands) Qblox Quantum Control Stacks: Accelerating Experiments, Reducing Error, and Enabling Large-Scale Quantum Computing	O
11:30	**Aamir Mohammed Ali** (Chalmers University of Technology, Sweden) Thermally driven quantum refrigerator autonomously resets superconducting qubit	O
11:45	**Ramon Szmuk** (Quantum Machines, Israel) A scalable local addressing system for optically addressable qubits using integrated photonics	O
12:00	**Larysa Tryputen** (QuTech and Netherlands Organisation for Applied Scientific Research (TNO), The Netherlands) Interconnect Properties of Spin Qubit Devices	O
12:15	**Brendan Rhyno** (University of Illinois at Urbana-Champaign, USA) Exploring noisy quantum Kibble-Zurek physics with superconducting transmon qubits	O
12:30	**Anastasiia Nikolaeva** (International Center for Quantum Optics & Quantum Technologies LLC, Russia) Quantum computing with qubits embedded in trapped-ion qudits	O
12:45	**Victor Champain** (CEA, France) Parametric longitudinal coupling between a semiconductor charge qubit and a RF resonator	O
13:00	**Pino Caballero-Gil** (University of La Laguna, Spain) Oblivious Transfer and Bit Commitment Based on Quantum Communication	O
13:15	**Lunch Break**	
15:00	**Audrey Bienfait** (ENS Lyon, France) Implementing a quantum memory with a frequency and bandwidth-tuneable superconducting resonator	I
15:30	**Daniel Margineda** (CIC nanoGUNE, Spain) Gate-controlled metallic superconductors and superconducting diodes	O

WEDNESDAY (08/05/2024)

15:45	**Jorge Huamani Correa** (AGH University of Krakow, Poland) Theory of Superconducting Diode effect in Multiterminal Josephson junctions	O
16:00	**Samuel D. Escribano** (Weizmann Institute of Science, Israel) Poor's man Majorana with superconducting phase control	O
16:15	**Coffee Break – Posters Session – Exhibition**	
17:00	**Visa Vesterinen** (VTT, Finland) Enabling technologies for large-scale cryogenic quantum computers: parametric amplifiers	I
17:30	**Yannic Rath** (National Physical Laboratory, UK) Integrating tensor networks with quantum computing for simulations of strongly correlated materials	O
17:45	**Benedikt Fauseweh** (TU Dortmund University, Germany) Digital Quantum Simulation of Quantum Many-Body Dynamics on NISQ Devices	O

WEDNESDAY (08/05/2024)

	WORKSHOP 05 Quantum Simulation Technologies	
09:00	**Magdalena Stobinska** (Warsaw University, Poland) Enhancing free space DI QKD via employing NPA hierarchy method	I
09:30	**Oles Shtanko** (IBM Quantum, USA) Experimental Reconstruction of Local Integrals of Motion for Quantum Many-Body Dynamics	O
09:45	**Ayaka Usui** (Universitat Autònoma de Barcelona, Spain) Simplifying the simulation of local Hamiltonian dynamics	O
10:00	**Matthias Werner** (Qilimanjaro Quantum Tech / UB, Spain) Quantum simulation of 1D-fermionic systems with Ising Hamiltonians	O
10:15	**Dong-Ling Deng** (Tsinghua University, China) Digital simulation of non-Abelian anyons with superconducting qubits	O
10:30	**Coffee Break – Poster Session – Exhibition**	
11:15	**Karl Jansen** (Deutsches Elektronen-Synchrotron DESY, Germany) The Center for Quantum Technology and Applications: activities and use cases	I
11:45	**Sofia Vallecorsa** (CERN, Switzerland) Quantum Technolgy Initiative at CERN	I
12:15	**Rebekka Garreis** (Silicon Quantum Computing, UNSW, Australia) A quantum materials simulator based on Coulomb-confined quantum dots	O
12:30	**Tobias Grass** (DIPC, Spain) Cold atoms with flat bands – from synthetic bilayers to flat band Bose-Einstein condensates	O
12:45	**Manfred Mark** (Uni Innsbruck - Institut für Experimentalphysik, Austria) Observation of vortices in dipolar quantum gases	O
13:00	**Zhi-Yuan Wei** (Max Planck Institute for Quantum Optics, Germany) Kondo Impurity in an attractive Hubbard Bath	O

WEDNESDAY (08/05/2024)

13:15	**Lunch Break**	
15:00	**Joris Kattemölle** (University of Konstanz, Germany) Optimal quantum circuits for the quantum simulation of quantum matter	O
15:15	**Tzu-Kan Hsiao** (National Tsing Hua University, Taiwan) Towards quantum simulation of spin wave modes in quantum dot arrays	O
15:30	**David Zueco** (CSIC, Spain) Neural Network simulations of quantum long range models	O
15:45	**Nikodem Szpak** (University of Duisburg-Essen, Germany) Quantum simulation of strong field phenomena and curved spaces in deformed optical lattices	O
16:00	**Yijia Zhou** (Shanghai Qi Zhi Institute, China) Neutral Atoms with Rydberg Interactions for Many-Body Physics and Quantum Simulations	O
16:15	**Coffee Break – Posters Session – Exhibition**	
17:00	**Matti Silveri** (University of Oulu, Finland) Dynamics beyond two-level approximation in transmon arrays	I
17:30	**Jesús Cobos Jiménez** (Basque Country University, Spain) Noise-aware variational eigensolvers: A dissipative approach for lattice gauge theories	O
17:45	**Javier del Pino** (University of Konstanz, Germany) Dynamical Gauge Fields with Bosonic Codes in Nonlinear Resonators	O
18:00	**Simone Gasparinetti** (Chalmers University of Technology, Sweden) Universal control of a bosonic mode via drive-activated native cubic interaction	O

WEDNESDAY (08/05/2024)

	WORKSHOP 06 **Devices & Technologies for Quantum Sensing**	
09:00	**Joseph Dufouleur** (IFW Dresden, Germany) Non-Hermitian topology in multi-terminal devices: from fundamental to applications	I
09:30	**Matteo Wauters** (University of Trento, Italy) Weak-measurement protection in quantum simulations of lattice gauge theories	O
09:45	**Sona Najafi** (IBM, USA) Measuring central charge from local measurements	O
10:00	**Viktor Könye** (University of Amsterdam, The Netherlands) Non-Hermitian physics without gain or loss: the skin effect of reflected waves	O
10:15	**Coffee Break – Poster Session – Exhibition**	
11:15	**Jorge Casanova** (EHU/UPV, Spain) High-Field NMR with Solid-state Quantum Sensors	I
11:45	**Christian Degen** (ETH Zürich, Switzerland) Quantum Sensors in Diamond: Technology and Applications	I

WEDNESDAY (08/05/2024)

12:15	**Debarghya Dutta** (University of Basel, Switzerland) Investigating Phase Transitions in Van Der Waals Magnets using a Quantum Sensor	O
12:30	**Stephanie Matern** (Pitaevskii BEC Center, CNR-INO and UniTrento, Italy) Quantum coherence-assisted sensing with parallel quantum dots	O
12:45	**Kalid Ulas** (University of Cambridge, UK) Charge sensing using a single-electron double-box in a silicon quantum dot array	O
13:00	**Viktor Ivády** (Eötvös Loránd University, Hungary) Electronic structure and decoherence of the VB center in hexagonal boron nitride for sensing in low dimensions	O
13:15	**Lunch Break**	
15:00	**Yelko del Castillo Hernández** ((INL, Portugal) Probing spin fractionalization with ESR-STM absolute magnetometry	O
15:15	**Simone Eizagirre Barker** (University of Cambridge, UK) Optically detected electronic spin resonance of single emitters in hexagonal boron nitride under an angle-resolved magnetic field at room temperature	O
15:30	**Vincent Jouanny** (EPFL, Switzerland) High-kinetic inductance coupled cavity arrays for analog quantum simulation	O
15:45	**Kilian Seibold** (University of Konstanz, Germany) Quantum dynamics of Dissipative Kerr solitons	O
16:00	**Coffee Break – Posters Session – Exhibition**	
17:00	**Francesco Hoch** (Sapienza University of Rome, Italy) Teleportation of a genuine single-rail vacuum/one-photon qubit generated via a quantum dot source	O
17:15	**Adrian Juan-Delgado** (CFM (CSIC-UPV/EHU), Spain) Engineering Photon Sources with Interacting Quantum Emitters	O
17:30	**Nicolas Fabre** (Telecom Paris, France) Time-frequency quantum metrology	O

WEDNESDAY (08/05/2024)

	WORKSHOP 07 Topological Magnetism	
09:00	**Jairo Sinova** (Johannes Gutenberg University Mainz, Germany) Unconventional spin transport and dynamics in altermagnets	I
09:30	**Amilcar Bedoya Pinto** (University of Valencia, Spain) Connecting Fermi-surface topology and spin-orbit torques in Weyl Semimetal/Ferromagnet Heterostructures	O
09:45	**Yu Liu** (Niels Bohr Institute, University of Copenhagen, Denmark) Ferromagnetic hybrid nanostructure and its zero-field application	O
10:00	**Ryuji Fujita** (University of Oxford, UK) Real-space evidence for 2D-XY ordering in a van der Waals ferromagnet	O
10:15	**Coffee Break – Poster Session – Exhibition**	
11:15	**Frédéric Bonell** (Spintec, France) Epitaxial van der Waals heterostructures for magnetism and spin-charge conversion	I
11:45	**Sergio Barquero** (University of Amsterdam, The Netherlands) Magnetism meets Topology: Electronic structure of the candidate FM-TI $Mn_{1+x}Sb_{2-x}Te_4$ by ARPES	O
12:00	**Sara Catalano** (Materials Physics Center, Spain) Tunnelling spectroscopy and Josephson coupling through EuS/Al interfaces	O
12:15	**Thorsten Hesjedal** (University of Oxford, UK) Exploration of Topological Magnetic Objects at Interfaces using Resonant Elastic X-Ray Scattering	O
12:30	**Olivier Boulle** (CEA, France) Manipulation of magnetic skyrmions for memory and logic applications	I
13:00	**Lunch Break**	
15:00	**Marie-Blandine Martin** (CNRS-Thales, France) Towards a topology-based compact neuromorphic component	I
15:30	**Mehmet Cengiz Onbasli** (Koc University, Turkey) Topologically protected spin chirality beyond room temperature	O
15:45	**Bo Peng** (University of Cambridge, UK) Photo-induced electronic and spin topological phase transitions in monolayer single-element ferroelectrics	O
16:00	**Coffee Break – Posters Session – Exhibition**	
17:00	**Wei Wu** (University College London, UK) Exploring the spin-bearing molecular network for quantum materials and quantum computing	O
17:15	**Carmen Gomez Carbonell** (ICN2, Spain) Magnetic properties of MBE-grown $MnSb_2Te$	O
17:30	**Pablo Cova Fariña** (QuTech, The Netherlands) Observation of magnon dynamics in a quantum dot ladder	O

WEDNESDAY (08/05/2024)

	INDUSTRIAL FORUM	
09:00	**Artur Ekert** (University of Oxford, UK) The Age of Computation is yet to Come	K
09:30	**Roman Orus** (Multiverse Computing & DIPC, Spain) Multiverse Computing: Quantum and Quantum-Inspired AI and Beyond	I
09:50	**Jelena Trbovic** (QuantrolOx, Finland) Accelerating the Development of Quantum Computers through Automation	I
10:10	**Felice Francesco Tafuri** (Keysight Technologies, USA) Accelerating the Quantum Workflow from Design to Experiments	I
10:30	**Coffee Break – Poster Session – Exhibition**	
11:00	**James S. Clarke** (Intel, USA) Spin Qubits produced with a 300mm fabrication line: An update on Intel Si/SiGe devices	K
11:30	**Gertjan Eenink** (QuTech & TNO, The Netherlands) Scaling spin qubit devices: vertical interconnects through Al_2O_3	O
11:45	**Nikolai Drobotun** (Delft Circuits B.V., The Netherlands) Flexible stripline I/O with embedded filtering: scalable signal delivery platform with proven qubit performance	O
12:00	**Alexia Salavrakos** (Quandela, France) SPOQC: a Spin-Optical Quantum Computing architecture	O
12:15	**Miguel Fernando Gonzalez-Zalba** (Quantum Motion, UK) Coherent control and large-scale characterisation of silicon quantum devices fabricated using 300-mm wafer processes	O
12:30	**Samira Nik** (European Innovation Council (EIC), Belgium) EIC Quantum Tech Portfolio and Activities	I
12:45	Round Table Tackling Investment in Quantum Technologies; European Innovation Council/Private Investment • **Samira Nik** (EIC, Belgium): moderator • **Enrique Lizaso** (Multiverse Computing, Spain) • **Olivier Tonneau** (Quantonation, France) • **Nikolay Dimov** (EIB, Luxembourg)	
13:30	**Lunch Break**	
15:00	**Fabio Absaloni** (Quantum Machines, Denmark) Hermetic packaging for cryogenic experiments	O
15:15	**Pau Jorba** (Kiutra, Germany) ADR based sub-Kelvin cryostats for applied quantum technologies	I
15:35	**Yemliha Bilal Kalyoncu** (Qblox BV, The Netherlands) Integrated and Scalable Quantum Control	I
15:55	**Yonatan Cohen** (Quantum Machines, Israel) Quantum advantage via Classical Control	I
16:15	**Coffee Break – Posters Session – Exhibition**	
17:00	**Claudius Riek** (Zurich Instruments, Switzerland) Title to be defined	I

WEDNESDAY (08/05/2024)

17:20	**Alexandre Dauphin** (PASQAL, France) Exploring quantum materials with a neutral atom processor	I
17:40	**Anurag Saha Roy** (Qruise, Germany) Improving flux-based gates in superconducting QPUs through model learning of qubit and control stack parameters	I
18:00	**Pasquale Cilibrizzi** (Heriot-Watt University, UK) Ultra-narrow inhomogeneous spectral distribution of telecom-wavelength vanadium centres in isotopically enriched silicon carbide	O
18:15	**Izaskun Oregui Bravo** (TECNALIA, Spain) Quantum for Logistics: solving real-world bin packing and package delivery routing problems using quantum annealers	O
18:30	**Hans Werner Schumacher** (PTB, Germany) Optimized semiconductor single electron pumps for metrology and quantum technology	O

20:00	**CONFERENCE DINNER** **Restaurant PETRITEGI SAGARDOTEGIA** Petritegi Bidea, 8 • Astigarraga, 20115, Gipuzkoa **Shuttle transfer info provide onsite**

THURSDAY (09/05/2024)

	PLENARY SESSION	
09:00	**Peter Lodahl** (University of Copenhagen, Denmark) Deterministic single-photon hardware for scalable quantum-information processing	I
09:30	**David Perconte** (Neel institute/ CNRS, France) Evidence for chiral supercurrent in quantum Hall Josephson junctions	O
09:45	**Luca Giacomelli** (Université Paris Cité, France) Emergence of the Schmid transition of a Josephson junction in a multimode environment	O
10:00	**Alfredo Levy Yeyati** (Universidad Autónoma de Madrid, Spain) Photonic heat transport and the Schmid transition in Josephson junctions	O
10:15	**Zeila Zanolli** (Utrecht University, The Netherlands) Quantum Materials optolelectronics	O
10:30	**Coffee Break – Poster Session – Exhibition**	
11:00	**Mete Atature** (University of Cambridge, UK) Shedding Light on Nuclear Spins: Through the looking-glass	I
11:30	**Gabriel Araneda** (University of Oxford, UK) A network of trapped-ion quantum computers	O
11:45	**Abhishek Banerjee** (Harvard University, USA) Superfluid stiffness of twisted graphene	O
12:00	**Mohammad Hafezi** (University of Maryland, USA) Strongly interacting bosonic physics in layered two-dimensional van der Waals materials	I
12:30	**Andreas Wallraff** (ETH Zurich, Switzerland) Title to be defined	I
13:00	**Cocktail Lunch offered by QUANTUMatter 2024** **Poster Session – Exhibition**	
14:00	**Poster Session 2**	
14:30	**Parallel sessions – PhD Students**	

THURSDAY (09/05/2024)

"QUANTUM MATTER" Parallel session – PhD Students		
14:30	**Timon Baltisberger** (University of Basel, Switzerland) Fast optical-manipulation of a coherent hole-spin in an open microcavity	O
14:40	**Jaime Saez-Mollejo** (ISTA, Austria) Microwave-driven two-hole spin qubits	O
14:50	**Marcos Rubín Osanz** (INMA - CSIC - Universidad de Zaragoza), Spain) Dispersive readout of molecular spin qubits	O
15:00	**Joaquin Medina Dueñas** (ICN2, Spain) Optimal Charge-to-Spin Conversion Tuned by Intraparticle Entanglement	O
15:10	**Josef Svetlik** (ICN2, Spain) Proximity Induced Magnetism and Spin-orbit Coupling in Graphene/VxW1-xSe2 Heterostructure	O
15:20	**Pablo Moles** (Universidad Complutense de Madrid, Spain) Impact of vacancies on the transport in twisted bilayer graphene quantum point contacts	O
15:30	**Marc Botifoll** (ICN2, Spain) End-to-end Autonomous Unveiling of Physical Knowledge of Quantum Devices through Electron Microscopy Data	O
15:40	**Andrés Bejarano** (DIPC, Spain) Statistical properties of light emission in current-driven single-molecule STM-junctions	O
15:50	**Martina Soldini** (University of Zurich, Switzerland) Charge-4e superconductivity in a Hubbard model	O
16:00	**Coffee Break – Poster Session – Exhibition**	

THURSDAY (09/05/2024)

"QUANTUM INFO & COMPUTING" Parallel session – PhD Students		
14:30	**Josefine Enkner** (ETH Zürich, Switzerland) In situ modification of the Quantum Hall effect with cavity vacuum fields	O
14:40	**Laurin Fischer** (IBM Quantum, Switzerland) Dual frame optimization for informationally complete quantum measurements	O
14:50	**Gian Gentinetta** (EPFL, Switzerland) Overhead-constrained circuit knitting for variational quantum dynamics	O
15:00	**Noah Goss** (University of California, Berkeley, USA) Empowering Qudit Quantum Computing by Traversing the Dual Bosonic Ladder	O
15:10	**Xanda Kolesnikow** (The University of Sydney, Australia) Gottesman-Kitaev-Preskill State Preparation Using Periodic Driving	O
15:20	**Frederik Pfeiffer** (Technical University of Munich & WMI, Germany) Efficient decoupling of a non-linear qubit mode from its environment	O
15:30	**Daniel Michel Pino González** (ICMM-CSIC, Spain) Minimal Kitaev-transmon qubit based on double quantum dots	O

THURSDAY (09/05/2024)

15:40	**Cristian Tabares López** (IFF-CSIC, Spain) A variational toolbox for analog quantum simulators	O
15:50	**Ian Yang** (Austrian Academy of Sciences, Austria) Hot Schrödinger Cat States	O
16:00	**Coffee Break – Poster Session – Exhibition**	

THURSDAY (09/05/2024)

"QUANTUM TECH" Parallel session – PhD Students		
14:30	**Marta Cagetti** (ICFO, Spain) Quantum simulator based on electromechanically coupled carbon nanotube	O
14:40	**Carolina del Río Bueno** (INMA (CSIC-UZ), Spain) Remote spin-spin interactions mediated by superconducting circuits for quantum applications	O
14:50	**Marta Irene Garcia Cid** (INDRA/UPM, Spain) Experimental Realization of a Quantum Zero-Knowledge Proof	O
15:00	**Jonas Grammel** (Karlsruhe Institute of Technology, Germany) Telecom O-band quantum dots in an open access fiber-based microcavity	O
15:10	**Stefanie Grotowski** (Walter Schottky Institute TUM, Germany) Superconducting MoSi Thin Films for Single-Photon Detection	O
15:20	**Valentin Guichard** (C2N – CNRS, France) Controlling the generation of large cluster states with residual visibility measurements	O
15:30	**Vidul Joshi** (Yale University, USA) Quantum Zeno effect: preventing a photon from exiting a cavity.	O
15:40	**Axel Leblanc** (CEA, France) Tunable charge-4e supercurrent in Ge-based JoFET	O
15:50	**David Rower** (MIT, USA) Circularly Polarized Driving and Commensurate Pulses for Fast Single-Qubit Gates with Fluxonium	O
16:00	**Noah Shofer** (University of Cambridge, UK) Tuning the coherent interaction of an electron qubit and a many-body register	O
16:10	**Coffee Break – Poster Session – Exhibition**	

THURSDAY (09/05/2024)

	INDUSTRIAL FORUM	
09:00	**Nadia Belabas** (CNRS - C2N, France) A frequency network through parallel processing of frequency-bin entangled photons from a 21 GHz SOI micro-resonator	O
09:15	**Alessandro Laneve** (Sapienza University of Rome, Italy) Polarization-wavevector correlation in entangled photons from cavity-embedded quantum dots	O
09:30	**Andreas Fyrillas** (Quandela, France) High-Fidelity Quantum Information with Machine Learning-Characterized SiN Photonic Circuits	O
09:45	**Alexandra Bernasconi** (QphoX, The Netherlands) An integrated microwave-to-optics interface for scalable quantum computing	O
10:00	**Arnau Riera** (Qilimanjaro Quantum Tech, Spain) Variational diabatic annealing schedules with Landau-Zener-Stückelberg interference	O
10:15	**Oscar Gargiulo** (Kiutra GmbH, Germany) Accelerating resonator spectroscopy using microwave pulses	O
10:30	**Coffee Break - Poster Session - Exhibition**	
11:00	**Jay M. Gambetta** (IBM, USA) Quantum Computing at the Utility Scale and Beyond	K
11:30	**Mathias Pont** (Quandela, France) A versatile single-photon-based quantum computing platform	O
11:45	**Carlos Kuchkovsky** (Qcentroid, Spain) Quantum Operations and Business Innovation: Leveraging Sustainability and Energy Efficiency for Accelerated Impact	O
12:00	**Thijs Stavenga** (Quantware, The Neteherlands) Look-up table based fast tune-up of superconducting quantum processors	O
12:15	**Gianni Casonato** (EUMETSAT, Germany) Pseudo-Qubit Modelling - Enabling Large Scale Application Simulations	O
12:30	**Sorin Bolos** (Transilvania Quantum, Romania) Vulnerabilities of the Reset Operation on Superconducting Qubits	O
13:00	**Cocktail Lunch offered by QUANTUMatter 2024** **Poster Session - Exhibition**	
14:00	**Poster Session 2**	O
	Industrial Forum (BasQ/IBM Session)	
14:30	**Nicolas Lorente** (Materials Physics Center, Spain) Localisation, Thermalisation and Time Crystals: Quantum Simulations of Disorder	O
14:45	**Sergiy Zhuk** (IBM Quantum, IBM Research Europe -Dublin, Ireland) Trotter error bounds and dynamic multi-product formulas for Hamiltonian simulation	O
15:00	**Eric Switzer** (Donostia International Physics Center, Spain) Quasi-2D Time Crystals on NISQ Hardware: Challenges & Opportunities	O

THURSDAY (09/05/2024)

15:15	**Niall Robertson** (IBM Quantum, Ireland) Approximate Quantum Compiling for Quantum Simulation: A Tensor network based approach	O
15:30	**Rubén Esteban Llorente** (Centro de Física de Materiales, Spain) Quantum computation of the dynamics of the Jaynes-Cummings Hamiltonian for nanophotonics	O
15:45	**Nathan Keenan** (IBM Dublin, Ireland) Evidence of Kardar-Parisi-Zhang scaling on a digital quantum simulator	O
16:00	**Coffee Break - Posters Session - Exhibition**	
16:30	**David Casanova** (DIPC, Spain) Physically motivated enhancements of variational quantum eigensolvers for quantum chemistry	O
16:45	**William Kirby** (IBM Quantum, USA) The Quantum Krylov Method	O
17:00	**Antonio Mezzacapo** (IBM, USA) Diagonalizing large many-body systems on a quantum processor using the quantum Krylov method	O
17:15	**Josu Etxezarreta Martinez** (Tecnun - University of Navarra, Spain) Projected Lindblad dynamics via Hamiltonian symmetries for Quantum Error Mitigation	O
17:30	**Juan Borge** (Mondragon University, Spain) Error estimation in current noisy quantum computers	O
17:45	**Elisa Bäumer** (IBM Research Zurich, Switzerland) Quantum Fourier Transform using Dynamic Circuits	O
18:00	**Francesco Di Marcantonio** (UPV/EHU, Spain) Quantum Many-Body phase diagram characterization using Fidelity-based Kernels	O
18:15	**Roman Orus** (Multiverse Computing & DIPC, Spain) News on Variational Quantum Machine Learning	O

Friday (10/05/2024)

PLENARY SESSION		
09:00	**Jens Eisert** (Freie Universität Berlin, Germany) Potential and limitations of near-term quantum computing	I
09:30	**Ting Rei Tan** (The University of Sydney, Australia) Analog quantum simulation of quantum chemical dynamics with a trapped-ion system	O
09:45	**Felix Hoffet** (ICFO - The Institute of Photonic Science, Spain) Ultra-high indistinguishability of two dissimilar and independent cold-atomic quantum nodes	O
10:00	**Angela Kou** (University of Illinois Urbana-Champaign, USA) Driving the fluxonium qubit	I
10:30	**Coffee Break**	
11:00	**Claudia Felser** (Max-Planck-Gesellschaft, Germany) Chirality and Topology	P
11:40	**Yulia Maximenko** (Colorado State Universtity, USA) Unconventional quantum phases and their visualization with atomic resolution	I
12:10	**Ana Asenjo-Garcia** (Columbia University in the city of New York, USA) Universal scaling laws for correlated decay of many-body quantum systems	I
12:40	**Francesca Ferlaino** (University of Innsbruck & IQOQI, Austria) Advancing Many-Body Quantum Physics with Dipolar Quantum Gases	I
13:10	**Closing & QUANTUMatter2025 announcement**	

QTEP Quantum Technologies Platform

CSIC

Developing quantum science and technology in Spain

QTEP is the quantum ecosystem created by CSIC to advance the field of quantum technologies, fostering training, research and innovation in a new generation of secure communication devices, computers and sensors based on quantum phenomena, such as entanglement or superposition.

Research

QTEP is a collaborative effort among CSIC groups and partnering academic and industrial institutions, pushing the boundaries of quantum communication, quantum computing and quantum sensing, and advancing the tools and devices to fabricate new quantum technologies.

>100
Researchers

35
Groups

9
Institutions

Contact

Instituto de Física Fundamental
C/ Serrano 113b, 28006 Madrid, Spain
Tlf: +34 9156 68 00 (ext 442461)

@qtep_csic

qtep@csic.es

qtep.csic.es

Financiado por la Unión Europea NextGenerationEU

Plan de Recuperación, Transformación y Resiliencia

SPEAKERS LIST

Baptiste Anselme Martin (Eviden (Quantum Lab), France) Combining Matrix Product States and Noisy Quantum Computers for Quantum Simulation	Oral Parallel Workshop 2	163
Tommaso Antonelli (ETHZ, Switzerland) Hybridisation of Andreev bound states in a hybrid four terminal Josephson junction	Poster	325
Martin Hayhurst Appel (University of Cambridge, UK) A Spin Qubit Coupled to a Collective Nuclear Quantum Register	Oral Plenary	136
Gabriel Araneda (University of Oxford, UK) A network of trapped-ion quantum computers	Oral Plenary	137
Isidora Araya Day (TU Delft, The Netherlands) Chiral adiabatic transmission protected by Fermi surface topology	Poster	326
Jordi Arbiol (ICREA / ICN2, Spain) Quantum nanostructures at atomic scale: From vertical hybrid nanowires to planar nanowire networks and 2DEG/2DHG systems	Invited Paralle Workshop	97
Ana Asenjo-Garcia (Columbia University in the city of New York, USA) Universal scaling laws for correlated decay of many-body quantum systems	Invited	86
Desislava Atanasova (Austrian Academy of Sciences, Austria) Novel 3D circuit QED architecture for quantum information processing	Poster	327
Mete Atature (University of Cambridge, UK) Shedding Light on Nuclear Spins: Through the looking-glass	Invited	87
Andrés Ayuela (CFM/DIPC, Spain) Interplay Between Topological and Defect States: Periodic One-Dimensional Patterns in Bilayer Graphene	Poster	328
Yujeong Bae (Empa, Switzerland) Atomic-scale quantum sensing of electric and magnetic fields in a scanning tunneling microscope	Poster	329
Nilanthy Balakrishnan (Keele University, UK) Growth of Iron selenide layers via salt-assisted chemical vapour deposition	Oral Parallel Workshop 3	179
Anthony Balchin (University of Surrey, UK) Passive Protection of Quantum Information in Mixed-Range Quantum Spin Chains	Poster	330
Timon Baltisberger (University of Basel, Switzerland) Fast optical-manipulation of a coherent hole-spin in an open microcavity	Oral Parallel Students	253
Pantelis Bampoulis (University of Twente, The Netherlands) Topological Phase Transition from 1D Edge States to 0D End States in Germanene Nanoribbons	Poster	332
Abhishek Banerjee (Harvard University, USA) Superfluid stiffness of twisted graphene	Oral Plenary	138

Sergio Barquero (University of Amsterdam, The Netherlands) Magnetism meets Topology: Electronic structure of the candidate FM-TI $Mn_{1+x}Sb_{2-x}Te_4$ by ARPES	Oral Parallel Workshop 7	243
Pablo Bastante (Universidad Autónoma de Madrid, Spain) Engineering Transport Orbitals in Single Molecule Junctions	Poster	333
Elisa Bäumer (IBM Research Zurich, Switzerland) Quantum Fourier Transform using Dynamic Circuits	Oral Session Basque IBM	301
Adam Bednorz (University of Warsaw, Poland) Testing dimension by a null witness	Poster	334
Amilcar Bedoya Pinto (University of Valencia, Spain) Connecting Fermi-surface topology and spin-orbit torques in Weyl Semimetal/Ferromagnet Heterostructures	Oral Parallel Workshop 7	244
Max Beer (RWTH Aachen University, Germany) Si/SiGe based quantum dot devices for memory and micron-scale connectivity with more than 200 gate electrodes	Poster	335
Andrés Bejarano (DIPC, Spain) Statistical properties of light emission in current-driven single-molecule STM-junctions	Oral Parallel Students	254
Nadia Belabas (CNRS - C2N, France) A frequency network through parallel processing of frequency-bin entangled photons from a 21 GHz SOI micro-resonator	Oral IF	281
Maria Benito (IMB-CNM, Spain) Towards reduced dielectric losses in superconducting quantum circuits	Poster	336
Alexandra Bernasconi (QphoX, The Netherlands) An integrated microwave-to-optics interface for scalable quantum computing	Oral IF	282
Audrey Bienfait (ENS Lyon, France) Implementing a quantum memory with a frequency and bandwidth-tuneable superconducting resonator	Invited Paralle Workshop	99
Sourav Biswas (DIPC, Spain) A study on the effect of ring exchange interaction in a two-leg Bose-Hubbard ladder	Poster	337
Ainitze Biteri (EHU, Spain) Amplified Nanoscale Detection of Labelled Molecules via Surface Electrons on Diamond	Poster	338
Ivan A. Bocanegra-Garay (Universidad de Valladolid, Spain) Control of a qubit by means of a Classical field: The driven Jaynes-Cummings model	Poster	339
Sorin Bolos (Transilvania Quantum, Romania) Vulnerabilities of the Reset Operation on Superconducting Qubits	Oral IF	283
Frédéric Bonell (Spintec, France) Epitaxial van der Waals heterostructures for magnetism and spin-charge conversion	Invited Paralle Workshop	100

Juan Borge (Mondragon University, Spain) Error estimation in current noisy quantum computers	Oral Session Basque IBM	302
Marc Botifoll (ICN2, Spain) Generalisation of a novel routine for band gap mapping at sub-nanometric resolution	Oral Parallel Students	510
Olivier Boulle (CEA, France) Manipulation of magnetic skyrmions for memory and logic applications	Invited Paralle Workshop	101
Philippe Bouyer (University of Amsterdam/Quantum Delta NL, The Netherlands) From matter waves to quantum sensors	Invited	88
A. Mert Bozkurt (TU Delft, The Netherlands) Tailoring arbitrary energy-phase relationships using Josephson tunnel junctions	Poster	340
Benjamin Brock (Yale University, USA) Controlling a High-Q Cavity with a Kerr-cat Qubit	Oral Plenary	139
Vittorio Buccheri (Chalmers University of Technology, Sweden) Towards Andreev molecules in semiconducting nanowires	Poster	341
Daniel Bultrini (University of Heidelberg, Germany) Mixed quantum-classical dynamics for near term quantum computers	Oral Parallel Workshop 2	164
Pino Caballero-Gil (University of La Laguna, Spain) Oblivious Transfer and Bit Commitment Based on Quantum Communication	Oral Parallel Workshop 4	195
Marta Cagetti (ICFO, Spain) Quantum simulator based on electromechanically coupled carbon nanotube	Oral Parallel Students	256
David Caldevilla-Asenjo (Materials Physics Center, Spain) Growth of AlOx tunnelling barriers via oxidation of Al in thermalized atomic oxygen atmosphere	Poster	342
John Campbell (Maynooth University, Ireland) Polarization Characterization of BBO and ppKTP SPDC-based Entanglement Light Sources	Poster	343
Luis Canonico (ICN2, Spain) Orbital origin of hidden spin textures in centrosymmetric PtSe2 monolayer and their proximity applications	Oral Parallel Workshop 1	151
Pierre Capiod (JUNIA-ISEN, France) Artificial quantum systems based on semi-conducting quantum dots chains: towards quantum simulations in a SSH chain.	Oral Parallel Workshop 1	152
Giacomo Cappiello (Università di Firenze, Italy) Quantum AI for Alzheimer's disease early screening	Poster	344
Mariano Caruso (Fidesol | UGR, Spain) Classical and Quantum devices to train Learning Models	Poster	345
David Casanova (DIPC, Spain) Physically motivated enhancements of variational quantum eigensolvers for quantum chemistry	Oral Session Basque IBM	303

Jorge Casanova (EHU/UPV, Spain) High-Field NMR with Solid-state Quantum Sensors	Invited Paralle Workshop	102
Gianni Casonato (EUMETSAT, Germany) Pseudo-Qubit Modelling - Enabling Large Scale Application Simulations	Oral IF	284
Sara Catalano (Materials Physics Center, Spain) Tunnelling spectroscopy and Josephson coupling through EuS/Al interfaces.	Oral Parallel Workshop 7	245
Robert Cernansky (Ulm University, Institute for Quantum Optics, Germany) Quantum sensing of RF fields with 10 Hz spectral resolution using NV centers in Silicon Carbide	Poster	346
Victor Champain (CEA, France) Parametric longitudinal coupling between a semiconductor charge qubit and a RF resonator	Oral Parallel Workshop 4	196
Adam Chaou (Freie Universität Berlin, Germany) Disordered topological crystalline phases	Poster	347
Robert Chapman (ETH Zurich, Switzerland) Lithium niobate-on-insulator integrated photonics for linear optical quantum computing	Oral Parallel Workshop 3	180
Yuanbo Chen (The University of Tokyo, Japan) Exploring indefinite causal order in the development of quantum batteries	Poster	348
Deung-Jang Choi (CFM-CSIC, UPV/EHU, Spain) Quantum Control at the Atomic Scale: From Ångstrom-Scale Qubit Platforms to Topological Superconductivity	Invited	89
Johan Christensen (IMDEA Materials, Spain) Topological sonic defects	Oral Parallel Workshop	–
Carlo Ciaccia (University of Basel, Switzerland) Cos(2phi) Josephson Junction and Gate Controlled Josephson Diode in Proximitized InAs Supercurrent Interferometers*	Poster	349
Pasquale Cilibrizzi (Heriot-Watt University, UK) Ultra-narrow inhomogeneous spectral distribution of telecom-wavelength vanadium centres in isotopically enriched silicon carbide	Oral IF	285
Ignacio Cirac (Max Planck Institute of Quantum Optics, Germany) Quantum Computing and Simulation in the NISQ era	Plenary	77
James S. Clarke (Intel, USA) Spin Qubits produced with a 300mm fabrication line: An update on Intel Si/SiGe devices	Keynote IF	82
Jesús Cobos Jiménez (Basque Country University, Spain) Noise-aware variational eigensolvers: A dissipative approach for lattice gauge theories	Oral Parallel Workshop 5	212
Yonatan Cohen (Quantum Machines, Israel) Quantum advantage via Classical Control	Invited IF	124

Malcolm Connolly (Imperial College London, UK) Nanomagnet-induced Synthetic Spin-Orbit Coupling in a Superconductor-Semiconductor Nanowire	Oral Parallel Workshop 3	181
Ivo Cools (Chalmers, Sweden) Coplanar stripline resonators for superconductor-semiconductor hybrid devices	Poster	350
Davide Costa (QuTech, The Netherlands) Record carrier mobility in group IV semiconductor materials	Oral Parallel Workshop 3	182
Pablo Cova Fariña (QuTech, The Netherlands) Observation of magnon dynamics in a quantum dot ladder	Oral Parallel Workshop 7	246
Alessandro Crippa (NEST, CNR-Istituto Nanoscienze and Scuola Normale Superiore, Italy) A gate tunable transmon qubit in planar Ge	Oral Plenary	140
Davide Cugini (Università degli studi di Pavia, Italy) Exponential optimization of quantum state preparation via adiabatic thermalization	Poster	351
Aron W. Cummings (ICN2, Spain) Hot electron dynamics in graphene – a linear-scaling atomistic approach	Poster	352
Samuel D. Escribano (Weizmann Institute of Science, Israel) Poor's man Majorana with superconducting phase control	Oral Parallel Workshop 4	197
Jacopo D'Alberto (University of Milan, Italy) Simulating the Dynamics of Open Quantum Systems with Quantum Monte Carlo Methods	Poster	353
Onur Danaci (Leiden University, The Netherlands) Curriculum reinforcement learning for quantum architecture search	Poster	354
Julian Daser (Austrian Academy of Sciences, Austria) Control of Collective Dark States in Waveguide QED	Poster	355
Reza Dastbasteh (Tecnun, University of Navarra, Spain) Additive twisted codes: new distance bounds and infinite families of quantum codes	Poster	356
Alexandre Dauphin (PASQAL, France) Exploring quantum materials with a neutral atom processor	Invited IF	125
Antonio de Marti i Olius (Tecnun - University of Navarra, Spain) The closed-branch decoder for quantum LDPC codes	Poster	357
Maxim De Smet (QuTech, TU Delft, The Netherlands) High-fidelity spin shuttling in silicon quantum dots	Oral Parallel Workshop 4	198
Christian Degen (ETH Zürich, Switzerland) Quantum Sensors in Diamond: Technology and Applications	Invited Paralle Workshop	103
Pascal Degiovanni (CNRS - ENS Lyon, France) Single electron interferometric sensing of quantum electromagnetic noise	Oral Plenary	141

Xavier del Arco Fargas (INMA, Spain) Theoretical study of GdW10 and GdW30 molecules energy transitions and experimental fitting.	Poster	358
Yelko del Castillo Hernández (International Iberian Nanotechnology Laboratory (INL), Portugal) Probing spin fractionalization with ESR-STM absolute magnetometry	Oral Parallel Workshop 6	229
Javier del Pino (University of Konstanz, Germany) Dynamical Gauge Fields with Bosonic Codes in Nonlinear Resonators	Oral Parallel Workshop 5	213
Carolina del Río Bueno (INMA (CSIC-UZ), Spain) Remote spin-spin interactions mediated by superconducting circuits for quantum applications.	Oral Parallel Students	256
Dong-Ling Deng (Tsinghua University, China) Digital simulation of non-Abelian anyons with superconducting qubits	Oral Parallel Workshop 5	214
Artem Denisov (ETH Zurich, Switzerland) Ultra-long relaxation of a Kramers qubit formed in a bilayer graphene quantum dot	Oral Parallel Workshop 3	183
Nassim Derriche (The University of British Columbia, Canada) Non-uniform and anisotropic polarizability resulting in pronounced local repulsion minima in high-Tc superconductors	Poster	359
Elena Desdentado (Universidad de Castilla-La Mancha, Spain) Studying the relationship of the quantum software and the energy consumption and success ratio	Poster	360
Aprameyan Desikan (Indian Institute of Science Education and Research, Mohali, India) Using Entangled Generalized Coherent States for Photonic Quantum Metrology	Poster	361
Francesco Di Marcantonio (University of the Basque Country UPV/EHU, Spain) Quantum Many-Body phase diagram characterization using Fidelity-based Kernels	Oral Session Basque IBM	304
Rosa Diaz (Purdue University, USA) Understanding Inherent Structural Defects and Chemical Distribution at Topological Superconductor-Semiconductor Interfaces and Heterostructures Using Advance Electron Microscopy	Oral Parallel Workshop 3	184
Enrique Diez (Universidad de Salamanca, Spain) Hydrodynamic electron flow in graphene	Oral Parallel Workshop 1	154
Athanasios Dimoulas (NCSRD, Greece) MBE growth of 2D topological quantum materials	Tutorial	133
Olesia Dmytruk (CPHT, CNRS, Ecole polytechnique, Institut Polytechnique de Paris, France) Hybrid light-matter states in topological superconductors coupled to cavity photons	Poster	362

Nikolai Drobotun (Delft Circuits B.V., The Netherlands) Flexible stripline I/O with embedded filtering: scalable signal delivery platform with proven qubit performance	Oral IF	286
Gábor Drótos (HUN-REN Institute for Nuclear Research, Hungary) Certifying a complex qubit Hilbert space in a prepare-and-measure scenario: how self-testing helps	Poster	363
Joseph Dufouleur (IFW Dresden, Germany) Non-Hermitian topology in multi-terminal devices: from fundamental to applications	Invited Paralle Workshop	104
Debarghya Dutta (University of Basel, Switzerland) Investigating Phase Transitions in Van Der Waals Magnets using a Quantum Sensor	Oral Parallel Workshop 6	230
Dzhavid Dzhavadzade (University of Stuttgart, Germany) Nuclear spin - photon entanglement on NV center for Quantum Repeater applications	Poster	364
Shayan Edalatmanesh (DIPC, Spain) Exotic electronic states in borylated graphene nanoribbons on a metallic substrate	Poster	365
Leonard Edens (nanoGUNE, Spain) Spin and charge control of topological end states in exchange biased chiral graphene nanoribbons	Poster	366
Gertjan Eenink (QuTech and Netherlands Organisation for Applied Scientific Research (TNO), The Netherlands) Scaling spin qubit devices: vertical interconnects through Al_2O_3	Oral IF	287
Dmitri Efetov (LMU, Germany) Thermodynamic measurements of the correlated states in Magic Angle Twisted Bilayer Graphene	Invited Paralle Workshop	–
Jens Eisert (Freie Universität Berlin, Germany) Potential and limitations of near-term quantum computing	Invited	90
Simone Eizagirre Barker (University of Cambridge, UK) Optically detected electronic spin resonance of single emitters in hexagonal boron nitride under an angle-resolved magnetic field at room temperature	Oral Parallel Workshop 6	231
Artur Ekert (University of Oxford/Centre for Quantum Technologies, NUS, UK/Singapore) The Age of Computation is yet to Come	Keynote IF	84
Josefine Enkner (ETH Zürich, Switzerland) In situ modification of the Quantum Hall effect with cavity vacuum fields	Oral Parallel Students	257
Daniel Escanez-Exposito (University of La Laguna, Spain) QuantumSolver AI: A Quantum Artificial Intelligence Module	Poster	367
Rubén Esteban Llorente (Centro de Física de Materiales, Spain) Quantum computation of the dynamics of the Jaynes-Cummings Hamiltonian for nanophotonics	Oral Session Basque IBM	305

Josu Etxezarreta Martinez (Tecnun - University of Navarra, Spain) Projected Lindblad dynamics via Hamiltonian symmetries for Quantum Error Mitigation	Oral Session Basque IBM	306
Nicolas Fabre (Telecom Paris, France) Time-frequency quantum metrology	Oral Parallel Workshop 6	232
Benedikt Fauseweh (TU Dortmund University, Germany) Digital Quantum Simulation of Quantum Many-Body Dynamics on NISQ Devices	Oral Parallel Workshop 4	199
Claudia Felser (Max Planck Institute for Chemical Physics of Solids, Germany) Chirality and Topology	Plenary	78
Francesca Ferlaino (University of Innsbruck & IQOQI, Austria) Beyond Proximity: Phenomena in Long-Range Interacting Quantum Gases	Invited	91
Sofia Ferreira Teixeira (CIC nanoGUNE, Spain) Unconventional charge transport nonreciprocity in the superconductor $ZrTe_3$	Poster	368
Julian Ferreiro-Velez (Tecnalia-UPV/EHU, Spain) Shortcuts for Adiabatic and Variational Algorithms in Molecular Simulation	Poster	369
Ulderico Filippozzi (Kavli Institute of Nanoscience, The Netherlands) Enhanced Superconducting Fluctuations in Two- Dimensional Oxide Superconductor	Poster	370
Laurin Fischer (IBM Quantum, Switzerland) Dual frame optimization for informationally complete quantum measurements	Oral Parallel Students	258
Thomas Frederiksen (DIPC, Spain) Crossed graphene nanoribbons for electron quantum optics and spintronics	Poster	371
Ryuji Fujita (University of Oxford, UK) Real-space evidence for 2D-XY ordering in a van der Waals ferromagnet	Oral Parallel Workshop 7	247
Andreas Fyrillas (Quandela, France) High-Fidelity Quantum Information with Machine Learning-Characterized SiN Photonic Circuits	Oral IF	288
Jay M. Gambetta (IBM, USA) Quantum Computing at the Utility Scale and Beyond	Keynote IF	85
Eider Garate (Fundación Tekniker, Spain) Variational Quantum Regression on NISQ Hardware with Error Mitigation	Poster	372
Irene García (UV, Spain) Generalized spin squeezing with limited measurements	Poster	374

Marta Irene Garcia Cid (INDRA/Universidad Politecnica de Madrid, Spain) Experimental Realization of a Quantum Zero-Knowledge Proof	Oral Parallel Students	259
Mikel Garcia de Andoin (Tecnalia-UPV/EHU, Spain) Extensions of Digital-Analog Quantum Computation	Poster	375
David García Pons (Instituto de Nanociencia y Materiales de Aragón (INMA), Spain) Experimental study of GdW10 and GdW30 molecular magnets	Poster	376
Maia García Vergniory (Max Planck for Chemical Physics of Solids - DIPC, Germany/Spain) Topological Quantum Chemistry	Tutorial	134
Oscar Gargiulo (Kiutra GmbH, Germany) Accelerating resonator spectroscopy using microwave pulses	Oral IF	290
Rebekka Garreis (Silicon Quantum Computing, UNSW, Australia) A quantum materials simulator based on Coulomb-confined quantum dots	Oral Parallel Workshop 5	215
Jaime Garrido Aldea (Institut Catala de Nanociencia i Nanotecnologia (ICN2), Spain) Development of an automated workflow for well converged DFT calculations using SIESTA and the AIIDA infrastructure satisfying FAIR data principles	Poster	377
Jakub Garwola (University of Toronto, Canada) Spin impurity in interaction with multiple baths via non-commuting coupling operators: An analytic approach	Poster	378
Simone Gasparinetti (Chalmers University of Technology, Sweden) Universal control of a bosonic mode via drive-activated native cubic interaction	Oral Parallel Workshop 5	216
Pascal Gehring (UCLouvain, Belgium) Large Anomalous Ettingshausen effect in a micron-sized magnetic Weyl semimetal on-chip cooler	Oral Parallel Workshop 1	155
Gian Gentinetta (École polytechnique fédérale de Lausanne, Switzerland) Overhead-constrained circuit knitting for variational quantum dynamics	Oral Parallel Students	260
Jemy Geordy (Macquarie University, Australia) Quantum Control of nano-diamond Nitrogen Vacancy spin ensembles	Poster	379
Manuel Gessner (Universidad de Valencia, Spain) Hierarchies of quantum metrology bounds beyond Cramér-Rao	Oral Parallel Workshop 2	165
Arnob Kumar Ghosh (Uppsala University, Sweden) Investigation of dissipative Rashba nanowire	Poster	380
Madhura Ghosh Dastidar (Indian Institute of Technology Madras, India) Random number generation using single photon emitters embedded in nanopillars	Poster	381

Philippe Goldner (Chimie ParisTech PSL, France) Rare Earth-Diamond Hybrid Structures for Optical Quantum Technologies	Oral Parallel Workshop 3	185
Carmen Gomez Carbonell (Catalan Institute of Nanoscience and Nanotechnology (ICN2), Spain) Magnetic properties of MBE-grown $MnSb_2Te$	Oral Parallel Workshop 7	248
Miguel Fernando Gonzalez-Zalba (Quantum Motion, UK) Coherent control and large-scale characterisation of silicon quantum devices fabricated using 300-mm wafer processes	Oral IF	291
Rosa Gonzalo (Universitat de les Illes Balears, Spain) Heat and charge transport in interacting nanoconductors driven by time-modulated temperatures	Poster	382
Noah Goss (University of California, Berkeley, USA) Empowering Qudit Quantum Computing by Traversing the Dual Bosonic Ladder	Oral Parallel Students	261
Jonas Grammel (Karlsruhe Institute of Technology, Germany) Telecom O-band quantum dots in an open access fiber-based microcavity	Oral Parallel Students	262
Tobias Grass (DIPC, Spain) Cold atoms with flat bands – from synthetic bilayers to flat band Bose-Einstein condensates	Oral Parallel Workshop 5	217
Piotr Grochowski (University of Innsbruck & IQOQI Innsbruck, Austria) Quantum control of continuous systems via nonharmonic potential modulation	Oral Parallel Workshop 2	166
Stefanie Grotowski (Walter Schottky Institute Technichal University of Munich, Germany) Superconducting MoSi Thin Films for Single-Photon Detection	Oral Parallel Students	263
Adolfo G. Grushin (Institut Néel / CNRS, France) Amorphous topological metals	Invited Paralle Workshop	105
Sophie Gueron (Université Paris Saclay - LPS, France) Evidence of helical states in bismuth	Invited Paralle Workshop	106
Valentin Guichard (C2N - CNRS, France) Controlling the generation of large cluster states with residual visibility measurements	Oral Parallel Students	264
Sabhyata Gupta (Institut für Theoretische Physik, Leibniz University, Germany) Simulation of a Rohksar-Kivelson ladder on a NISQ device	Poster	383
Mohammad Hafezi (University of Maryland, USA) Strongly interacting bosonic physics in layered two-dimensional van der Waals materials	Invited	92

Jabir Hakami (Jazan University, Saudi Arabia) Quantum Emitter-Mediated Robust Chirality in the Vicinity of Nanophotonic Waveguide	Poster	384
Christian Louis Hanotel Pinzón (MIEM HSE University, Russia) Toponomic Quantum Computation	Poster	385
Thorsten Hesjedal (University of Oxford, UK) Exploration of Topological Magnetic Objects at Interfaces using Resonant Elastic X-Ray Scattering	Oral Parallel Workshop 7	249
Francesco Hoch (Sapienza University of Rome, Italy) Teleportation of a genuine single-rail vacuum/one-photon qubit generated via a quantum dot source	Oral Parallel Workshop 6	224
Felix Hoffet (ICFO - The Institute of Photonic Science, Spain) Ultra-high indistinguishability of two dissimilar and independent cold-atomic quantum nodes	Oral Plenary	142
Panyu Hou (IIIS, Tsinghua University, China) Non-destructive measurement of trapped-ion mechanical oscillators	Poster	386
Tzu-Kan Hsiao (National Tsing Hua University, Taiwan) Towards quantum simulation of spin wave modes in quantum dot arrays	Oral Parallel Workshop 5	218
Mengyao Hu (Leiden University, The Netherlands) Optimizing Bell Inequalities via Tensor Network Contractions in Tropical Algebra	Poster	387
Jorge Huamani Correa (AGH University of Krakow, Poland) Theory of Superconducting Diode effect in Multiterminal Josephson junctions	Oral Parallel Workshop 4	200
José Hugo Garcia (ICN2, Spain) Exploring Quantum Property-Data Correlations in Metal Organic Frameworks using Unsupervised Learning	Poster	388
Andreas K. Hüttel (University of Regensburg, Germany) Adiós flatland - Quantum transport in MoS2 nanotube and nanoribbon quantum dots	Oral Parallel Workshop 3	186
Donika Imeri (Universität Hamburg, Germany) Photonically Connected Nuclear Spin Microprocessors	Poster	389
Matteo Ippoliti (The University of Texas at Austin, USA) Phases of quantum information on a noisy quantum processor	Invited Paralle Workshop	107
Viktor Ivády (Eötvös Loránd University, Hungary) Electronic structure and decoherence of the VB center in hexagonal boron nitride for sensing in low dimensions	Oral Parallel Workshop 6	234
Thies Jansen (University of Twente, The Netherlands) Induced supercurrent in the intrinsic magnetic topological insulator MnBi2Te4	Poster	390
Karl Jansen (Deutsches Elektronen-Synchrotron DESY, Germany) The Center for Quantum Technology and Applications: activities and use cases	Invited Paralle Workshop	108

Jayanth Jayakumar (University of Warsaw, Poland) Quantum-enhanced joint estimation of phase and phase diffusion	Poster	391
Sreehari Jayaram (3. Physikalisches Institut, Germany) Static and Dynamic Properties of a 2D Superconductor Investigated by NV Center SPM	Poster	392
Pau Jorba (Kiutra, Germany) ADR based sub-Kelvin cryostats for applied quantum technologies	Invited IF	126
Vidul Joshi (Yale University, USA) Quantum Zeno effect: preventing a photon from exiting a cavity.	Oral Parallel Students	265
Vincent Jouanny (EPFL, Switzerland) High-kinetic inductance coupled cavity arrays for analog quantum simulation	Oral Parallel Workshop 6	235
Adrian Juan-Delgado (Centro de Física de Materiales (CSIC-UPV/EHU), Spain) Engineering Photon Sources With Interacting Quantum Emitters	Oral Parallel Workshop 6	236
Tomas Jungwirth (Czech Academy of Sciences, Czech Republic) Altermagnets: An unconventional magnetic class	Tutorial	135
Valerii Kachin (University of Warsaw, Poland) Ultra-robust topologically protected edge states in quasi-1D systems	Poster	393
Yemliha Bilal Kalyoncu (Qblox BV, The Netherlands) Integrated and Scalable Quantum Control	Invited IF	127
Ioannis Karapatzakis (Karlsruhe Institute of Technology, Germany) Coherent control of Tin-Vacancy centers in diamond using superconducting waveguides at 50 mK	Poster	394
Paritosh Karnatak (University of Basel, Switzerland) Large tunable kinetic inductance in a twisted graphene superconductor	Oral Parallel Workshop 1	156
Senthil Kumar Karuppannan (Institute of Materials Research and Engineering, A-Star, Singapore) Role of interface in quantum device	Oral Parallel Workshop 3	187
Joris Kattemölle (University of Konstanz, Germany) Optimal quantum circuits for the quantum simulation of quantum matter	Oral Parallel Workshop 5	219
Máté Kedves (Budapest University of Technology and Economics, Hungary) Self-heating effects and switching dynamics in graphene multiterminal Josephson junctions	Poster	395
Nathan Keenan (IBM Dublin, Ireland) Evidence of Kardar-Parisi-Zhang scaling on a digital quantum simulator	Oral Session Basque IBM	307
Megan Kelly (University of Leeds, UK) Probing charge neutrality in InAs/GaSb coupled quantum wells	Poster	396
Sun-Woo Kim (University of Cambridge, UK) Two room-temperature superconductivity claims in 2023: Separating fact from fiction	Poster	397

William Kirby (IBM Quantum, USA) Diagonalizing large many-body systems on a quantum processor using quantum Krylov	Oral Session Basque IBM	308
Dennis Klaassen (University of Twente, The Netherlands) Quantum Spin Hall States and Topological Phase Transition in Germanene	Poster	398
Matyas Kocsis (Budapest University of Technology and Economics, Hungary) Nanosecond switching of gate controlled supercurrent in an Al/InAs nanowire	Poster	399
Xanda Kolesnikow (The University of Sydney, Australia) Gottesman-Kitaev-Preskill State Preparation Using Periodic Driving	Oral Parallel Students	266
Nikola David Komericki (Fraunhofer Institute for Applied Solid State Physics (IAF), Germany) 2K, 300mm Wafer Level Characterization of Josephson Junctions for Transmon Qubits	Poster	400
Artem Kononov (University of Basel, Switzerland) Coherent control of a few-channel hole type gatemon qubit	Poster	401
Viktor Könye (University of Amsterdam, The Netherlands) Non-Hermitian physics without gain or loss: the skin effect of reflected waves	Oral Parallel Workshop 6	237
Kerim Köster (Karlsruhe Institute of Technology, Germany) A cavity-enhanced spin-photon interface for color centers in diamond	Poster	402
Angela Kou (University of Illinois Urbana-Champaign, USA) Driving the fluxonium qubit	Invited	93
Leo Kouwenhoven (Delft University of Technology, The Netherlands) Andreev and Majorana bound states in nanoscale devices	Keynote	79
Barbara Kraus (Technical University of Munich, Germany) Testing and verifying quantum computations and simulations	Invited Paralle Workshop	110
Wenjun Kuang (National Innovation Institute of Defense Technology, China) Magnetization Signature of Topological Surface States in a Nonsymmorphic Superconductor	Poster	403
Carlos Kuchkovsky (qcentroid, Spain) Quantum Operations and Business Innovation: Leveraging Sustainability and Energy Efficiency for Accelerated Impact	Oral IF	292
Tobias Kuhn (University of Augsburg, Germany) Hybrid qubits in Kitaev chains	Poster	404
Dibyendu Kuiri (AGH University Krakow, Poland) Topological phase enhancement in planar Josephson junction in the long junction regime	Poster	405
Kuldeep Kuldeep (Aalto University, Finland) Quantum Phase transition in proximity induced superconducting Palladium/WTe2 junction	Poster	406

Susmit Kumar (Justervesenet, Norway) Quantum anomalous Hall effect materials and devices for metrology: An EPM project	Poster	407
Adesh Kushwaha (The University of Sydney, Australia) Demonstrating Quantum Enhancement in Light-Harvesting Systems	Poster	408
Adria Labay Mora (IFISC, Spain) Associative Memories in the Quantum Regime	Poster	409
Petros Laccotripes (University of Cambridge, UK) Spin-photon entanglement from a telecom wavelength quantum-dot	Poster	410
Mateusz Lacki (Jagiellonian University, Poland) Ground states of one-dimensional dipolar lattice bosons at unit filling	Poster	411
Deep Lall (National Physical Laboratory, UK) Characterising frequency fluctuations in superconducting qubits	Oral IF	293
Alessandro Laneve (Sapienza University of Rome, Italy) Polarization-wavevector correlation in entangled photons from cavity-embedded quantum dots	Oral IF	294
Axel Leblanc (CEA, France) Tunable charge-4e supercurrent in Ge-based JoFET	Oral Parallel Students	267
Sebastian Leontica (University College London, UK) Entanglement growth from squeezing on the matrix product state manifold	Poster	412
Nico Leumer (DIPC, Spain) Spatially-resolved dissipation in a quantum wire with a coherent scatterer	Poster	413
Alfredo Levy Yeyati (Universidad Autónoma de Madrid, Spain) Photonic heat transport and the Schmid transition in Josephson junctions	Oral Plenary	143
Dylan Lewis (University College London, UK) Geodesic Algorithm for Unitary Gate Design with Time-Independent Hamiltonians	Poster	414
Weikang Li (Center for Quantum Information, IIIS, Tsinghua University, China) Exploring Quantum Learning Models on Superconducting Devices	Poster	415
Yu Liu (Niels Bohr Institute, University of Copenhagen, Denmark) Ferromagnetic hybrid nanostructure and its zero-field application	Oral Parallel Workshop 7	250
Peter Lodahl (University of Copenhagen, Denmark) Deterministic single-photon hardware for scalable quantum-information processing	Invited	94
Esperanza Lopez (Instituto de Fisica Teorica, Spain) Comparative study of quantum error correction strategies for the heavy-hexagonal lattice	Oral Parallel Workshop 2	167
Nicolas Lorente (Materials Physics Center, Spain) Localisation, Thermalisation and Time Crystals: Quantum Simulations of Disorder	Oral Session Basque IBM	309

Yanan Lu (Tsinghua University, China) Observing Information Backflow from Controllable Non-Markovian Multi-channels in Diamond	Poster	416
Zhide Lu (Tsinghua University, China) Deep quantum neural networks equipped with the backpropagation algorithm	Poster	417
Fernando Luis (INMA, CSIC, Spain) Two-qubit [Dy2] molecules deposited into micro-SQUID susceptometers: in situ characterization of their spin response	Poster	418
Rouven Maier (Stuttgart University, Germany) ENDOR-Qdyne: A Nanoscale NMR Spectroscopy Protocol Applicable to High Magnetic Fields	Poster	419
Lucas Maisel Licerán (Utrecht University, The Netherlands) Wannier excitons in two-dimensional topological insulators with strong spin-orbit coupling	Poster	420
Shalini Maji (AGH University of Krakow, Poland) Detection of Majorana bound states by scanning gate microscopy	Poster	421
Daniel Margineda (CIC nanoGUNE, Spain) Gate-controlled metallic superconductors and superconducting diodes	Oral Parallel Workshop 4	201
Manfred Mark (Universität Innsbruck - Institut für Experimentalphysik, Austria) Observation of vortices in dipolar quantum gases	Oral Parallel Workshop 5	220
Vanio Markov (Wells Fargo, USA) Quantum Time Series Similarity Measures and Quantum Temporal Kernels	Oral Parallel Workshop 2	168
Marie-Blandine Martin (CNRS-Thales, France) Towards a topology-based compact neuromorphic component	Invited Paralle Workshop	111
Ana Martin Fernandez (UPV/EHU, Spain) Synchronised nuclear spin drive	Poster	422
Dunkan Martínez (Universidad Complutense de Madrid, Spain) Exposing Bound States in the Continuum in InSb nanowire networks	Poster	423
Iván Martínez Ibarburu (UAM, Spain) Unveiling the interlayer interaction in a 1H/1T TaS2 van der Waals heterostructure	Oral Parallel Workshop 3	188
Sergio Martínez-Losa del Rincón (Universidad de Zaragoza, Spain) Enhancing MUMAX3 software for Magnon-Cavity Interactions	Poster	424
Rodrigo Martínez-Peña (DIPC, Spain) Quantum reservoir computing in finite dimensions	Poster	425
María José Martínez-Pérez (Instituto de Nanociencia y Materiales de Aragón, INMA, CSIC-University of Zaragoza, Spain) Integration of Magnons into Superconducting Circuits for Sensing Applications	Oral Plenary	144

Jorge Martinez-Romeral (ICN2, Spain) Resilient Intraparticle Entanglement and its Manifestation in Spin Dynamics of Disordered Dirac Materials	Poster	426
Carolina Martinez Strasser (DIPC, Spain) Topological properties of a non- Hermitian quasi-1D chain with a flat band	Poster	427
Javier Mas Sole (Universidade de Santiago de Compostela, Spain) Hamiltonian Forging of a Thermofield Double	Poster	428
Stephanie Matern (Pitaevskii BEC Center, CNR-INO, Universitá di Trento, Italy) Quantum coherence-assisted sensing with parallel quantum dots	Oral Parallel Workshop 6	238
Julia Mathe (TU Wien, Austria) Estimation of entanglement monotones in spin systems	Oral Parallel Workshop 2	169
Francisco Jesús Matute-Cañadas (UAM, Spain) Quantum circuits with multiterminal Josephson-Andreev junctions	Poster	429
Yulia Maximenko (Colorado State Universtity, USA) Unconventional quantum phases and their visualization with atomic resolution	Invited	95
Adrià Medeiros Garay (C2N - Universitė Paris Saclay, France) Accessing the dynamics of a single spin with a polarization-dependent projective measurement	Poster	430
Joaquin Medina Dueñas (ICN2, Spain) Optimal Charge-to-Spin Conversion Tuned by Intraparticle Entanglement	Oral Parallel Students	268
Phillip Mercebach (Universidad Autónoma de Madrid, Spain) Thermoelectric signatures of Bogoliubov Fermi Surface in superconducting 3D Topological Insulator Heterostructures	Poster	431
Antonio Mezzacapo (IBM, USA) Chemistry Beyond the Reach of Exact Solutions of the Schroedinger Equation on a Quantum-centric Supercomputer	Oral Session Basque IBM	310
Aamir Mohammed Ali (Chalmers University of Technology, Sweden) Thermally driven quantum refrigerator autonomously resets superconducting qubit	Oral Parallel Workshop 4	202
Pablo Moles (Universidad Complutense de Madrid, Spain) Impact of vacancies on the transport in twisted bilayer graphene quantum point contacts	Oral Parallel Students	269
Morteza Moradi (University of Warsaw, Poland) Maximally Violation of Local Realism Using Optical Hybrid Entanglement	Poster	432
Gabriel Moraes Oliveira (Autonomous University of Madrid, Spain) Switching currents limited by the inverse proximity effect in a flux-tunable superconductor	Poster	433
Mykhailo Moskalets (Instituto de Física Interdisciplinar y Sistemas Complejos IFISC (CSIC-UIB), Spain) Single-particle emission from the Andreev's level	Oral Parallel Workshop 4	203

Enrique Munoz (Pontificia Universidad Catolica de Chile, Chile) Electromagnetic coupling and transport in a topological insulator–graphene heterostructure	Poster	435
David Munoz Ramo (Quantinuum PLC, UK) Experimental realization of the cumulant expansion of the Lanczos Method for the calculation of Green's functions	Poster	436
Mariamo Mussa Juane (CESGA, Spain) QAOA ansatz and differential evolution for quantum molecular comparison	Poster	437
Sona Najafi (IBM, USA) Measuring central charge from local measurments	Oral Parallel Workshop 6	239
Gabriele Natale (ETH Zürich, Switzerland) Bragg-spectroscopy of a dissipation-induced instability in an atom-cavity system	Poster	438
Samira Nik (European Innovation Council (EIC), Belgium) EIC Quantum Tech Portfolio and Activities	Invited IF	–
Tahereh Niknejad (Qblox BV, The Netherlands) Qblox Quantum Control Stacks: Accelerating Experiments, Reducing Error, and Enabling Large-Scale Quantum Computing	Oral Parallel Workshop 4	204
Anastasiia Nikolaeva (International Center for Quantum Optics & Quantum Technologies LLC, Russia) Quantum computing with qubits embedded in trapped-ion qudits	Oral Parallel Workshop 4	205
Leo Noirot (CEA Grenoble, France) Limiting mechanisms for the lifetime and coherence of a hole-spin qubit strongly coupled to a cavity	Poster	439
Giovanni Oakes (Quantum Motion, UK) High-fidelity dispersive spin readout in a scalable unit cell of silicon quantum dots	Oral Parallel Workshop 3	189
Teemu Ojanen (Tampere University, Finland) Avoiding exponential bottlenecks in measurement-induced entanglement phase transitions	Oral Parallel Workshop 2	170
Javier Oliva (UNAV, Spain) Modelling Leakage with Perturbation Theory in Singlet-Triplet Spin Qubits	Poster	440
Mehmet Cengiz Onbasli (Koc University, Turkey) Topologically protected spin chirality beyond room temperature	Oral Parallel Workshop 7	251
Izaskun Oregui Bravo (TECNALIA, Spain) Quantum for Logistics: solving real-world bin packing and package delivery routing problems using quantum annealers	Oral IF	295
Dmytro Oriekhov (Kavli Institute of Nanoscience, TU Delft, The Netherlands) Compressing neural networks by SVD in topological phase classification problem	Poster	441

Roman Orus (Multiverse Computing & DIPC, Spain) News on Variational Quantum Machine Learning	Oral Session Basque IBM	311
Roman Orus (Multiverse Computing & DIPC, Spain) Multiverse Computing: Quantum and Quantum-Inspired AI and Beyond	Invited IF	128
Javier Osca (University of the Balearic Islands, Spain) Stochastic Optical Quantum Circuit Simulator: model, design and implementation	Oral Parallel Workshop 2	171
Ana Palacios de Luis (Qilimanjaro Quantum Tech, Spain) Addressing the scalability of quantum annealing of classical problems	Poster	442
Siddhartha Patra (Donostia International Physics Center, Spain) Efficient tensor network simulation of IBM's largest quantum processors	Poster	443
Ruben Pellicer-Guridi (Materials Physics Center, Spain) Study of spectral spread in nitrogen vacancy centers in diamond for coherent spin control of electron and nitrogen nuclei ensembles	Poster	444
Bo Peng (University of Cambridge, UK) Photo-induced electronic and spin topological phase transitions in monolayer single-element ferroelectrics	Oral Parallel Workshop 7	252
David Perconte (Neel institute/ CNRS, France) Evidence for chiral supercurrent in quantum Hall Josephson junctions	Oral Plenary	145
Jorge Perez-Bailon (INMA, Spain) YBCO SQUIDs for High-Frequency Magnetic Particle Characterization	Poster	445
Jordi Pérez-Guijarro (Universitat Politécnica de Catalunya, Spain) On classical advice, sampling advise and complexity assumptions for learning separations	Poster	447
Simon Pettersson Fors (Chalmers University of Technology, Sweden) Control strategies for static ZZ coupling in flux-tunable transmon coupler systems	Poster	448
Fabio Pezzoli (University of Milano-Bicocca, Italy) Emergent quantum spin Hall phase in GeSn heterostructures on silicon	Poster	449
Frederik Pfeiffer (Technical University of Munich & Walther-Meißner-Institut, Germany) Efficient decoupling of a non-linear qubit mode from its environment	Oral Parallel Students	270
Daniel Michel Pino González (ICMM-CSIC, Spain) Minimal Kitaev-transmon qubit based on double quantum dots	Oral Parallel Students	271
Ivan Pinto Huguet (ICN2, Spain) Automatic detection of vacancies in WS2 for Quantum Materials studies using HAADF-STEM Imaging	Oral Parallel Workshop 3	190
Carlos Pobes Aranda (INMA, Spain) Mo/Au TESs for Quantum Technologies	Poster	450
Nicola Poccia (IFW Dresden & University of Naples Federico II, Germany/Italy) Cuprate Twistronics for a New Generation of Macroscopic Quantum Hardwares	Invited Paralle Workshop	113

Claudia Politi (ETH Zürich, Switzerland) Towards circular Rydberg qubits of calcium atoms	Poster	451
Borislav Polovnikov (LMU, Germany) Implementation of the Bilayer Hubbard Model in a Moiré Heterostructure	Oral Parallel Workshop 1	157
Mathias Pont (Quandela, France) A versatile single-photon-based quantum computing platform	Oral IF	296
Albert Pool (DLR, Germany) Nonlinear dynamics as a ground-state problem on a quantum computer	Poster	452
Sunny Pradhan (University of the Basque Country, Spain) Discrete Abelian lattice gauge theories on a ladder and their dualities with quantum clock models	Poster	453
Lucien Québaud (Austrian Academy of Sciences, Austria) A Superconducting Platform for Quantum Information Processing	Poster	454
Yannic Rath (National Physical Laboratory, UK) Integrating tensor networks with quantum computing for simulations of strongly correlated materials	Oral Parallel Workshop 4	206
Giacomo Rebora (École Normale Supérieure de Lyon, France) Tunable Edge Magnetoplasmon Resonator	Oral Parallel Workshop 1	158
Maximilian Reichert (University of the Basque Country, Spain) Heisenberg-Limited Quantum Lidar for Joint Range and Velocity Estimation	Poster	455
Hannu Reittu (VTT Technical Research Centre of Finland, Finland) Approximate quantum adiabatic Hamiltonian simulation on quantum computers	Poster	456
Jeremias Resch (Karlsruhe Institute of Technology, Germany) Magneto-optical properties of Fourier-limited Tin-Vacancy centers in diamond	Poster	457
Brendan Rhyno (University of Illinois at Urbana-Champaign, USA) Exploring noisy quantum Kibble-Zurek physics with superconducting transmon qubits	Oral Parallel Workshop 4	207
Hannes Riechert (Ecole Polytechnique, France) Coherent control of a carbon nanotube-based gatemon qubit	Poster	458
Claudius Riek (Zurich Instruments, Switzerland) Enabling Quantum Technology - from individual devices to 100s of qubits	Invited IF	–
Arnau Riera (Qilimanjaro Quantum Tech, Spain) Variational diabatic annealing schedules with Landau-Zener-Stückelberg interference	Oral IF	297
Antonio Lucas Rigotti Manesco (Delft University of Technology, The Netherlands) Fermionic quantum computation with Cooper pair splitters	Poster	459

Marina Ristol Roura (Instituto Ibermática de Innovación (i3B), Spain) Simulating battery properties using IBM quantum processors	Poster	460
Emil Rizvanov (Comenius University in Bratislava, Slovakia) Design and numerical simulation of Josephson traveling-wave parametric amplifier using new circuit simulator	Poster	461
Niall Robertson (IBM Quantum, Ireland) Approximate Quantum Compiling for Quantum Simulation: A Tensor network based approach	Oral Session Basque IBM	312
Germán Rodrigo (IFIC UV-CSIC, Spain) Quantum algorithms in collider particle physics	Oral Parallel Workshop 2	172
Constantino Rodríguez (CESGA, Spain) Algorithmic method to decompose unitary operators in local terms.	Poster	462
Ilan Rosen (MIT, USA) Generating highly entangled states and synthetic gauge fields on a superconducting processor	Oral Plenary	146
David Rower (MIT, USA) Circularly Polarized Driving and Commensurate Pulses for Fast Single-Qubit Gates with Fluxonium	Oral Parallel Students	272
Aron Rozgonyi (HUN-REN Wigner RCP, Hungary) Training iterated protocols for distillation of GHZ states with variational quantum algorithms	Poster	463
Marcos Rubín Osanz (Instituto de Nanociencia y Materiales de Aragón (CSIC - Universidad de Zaragoza), Spain) Dispersive readout of molecular spin qubits	Oral Parallel Students	263
Carmen Rubio Verdú (ICFO, Spain) Universal moiré nematic phase in twisted graphene	Invited Paralle Workshop	114
Roberto Ruiz (Instituto de Física Teórica, Spain) The Bethe Ansatz as a Quantum Circuit	Poster	464
Sungguen Ryu (IFISC, Spain) Unraveling Timing Noise-Induced Decoherence in Single-Electron Sources	Poster	465
Francesc Sabater (University of Barcelona, Spain) The Fermionic Tonks-Girardeau gas: composite boson formation and a novel formulation of the ground state wave function	Poster	466
Jaime Saez-Mollejo (ISTA, Austria) Microwave-driven two-hole spin qubits	Oral Parallel Students	274
Palash Saha (AGH University of Krakow, Poland) Mean Field Theory Investigation of Spin Magnetizations in $MoTe_2/WSe_2$ Systems	Poster	467
Anurag Saha Roy (Qruise, Germany) Improving flux-based gates in superconducting QPUs through model learning of qubit and control stack parameters	Invited IF	129
Alexia Salavrakos (Quandela, France) SPOQC: a Spin-Optical Quantum Computing architecture	Oral IF	298

Nitin Samarth (Penn State University, USA) Epitaxially engineered quantum materials for quantum technologies: interfacing topology, magnetism, and superconductivity	Invited Paralle Workshop	115
William Samuelson (Lund University, Sweden) Minimal quantum dot based Kitaev chain with only local superconducting proximity effect	Poster	468
Julio Sánchez-Cánovas (University of Valladolid, Spain) Electric Dipole Forces on a Binary System of Atoms	Poster	469
Olatz Sanz (UNAV, Spain) Integration of maximum likelihood estimation for reducing the variance of ZNE	Poster	470
Mikel Sanz (NQUIRE Center - UPV/EHU, Spain) Training embedding quantum kernels with quantum neural networks	Invited Paralle Workshop	116
Ignacio Sardinero (Autonomous University of Madrid, Spain) Current-Phase relation in Fibonacci Josephson Junctions	Poster	471
Jonas Schuff (University of Oxford, UK) Fully autonomous tuning of a spin qubit	Poster	472
Tobias Schulli (The European Synchrotron ESRF, France) Strain control, imaging and tuning developed for SiGe qubit devices	Oral Parallel Workshop 3	191
Hans Werner Schumacher (Physikalisch-Technische Bundesanstalt, Germany) Optimized semiconductor single electron pumps for metrology and quantum technology	Oral IF	299
Kilian Seibold (University of Konstanz, Germany) Quantum dynamics of Dissipative Kerr solitons	Oral Parallel Workshop 6	240
Raphael Seidel (Fraunhofer Institute For Open Communication Systems, Germany) Quantum Backtracking in Qrisp applied to Sudoku Problems	Oral Parallel Workshop 2	173
Rubén Seoane Souto (Spanish Research Council (CSIC), Spain) Fermion-parity qubit in a double quantum dot	Poster	473
Llorenç Serra (Universitat de les Illes Balears, Spain) Quantum-anomalous-Hall current patterns and interference in thin slabs of chiral topological superconductors	Poster	474
Marc Serra Peralta (TU Delft, The Netherlands) Neural network decoding of quantum error correction experiments using soft measurement information	Poster	475
Diana Serrano (CNRS - Institut de Recherche de Chimie Paris, France) Long optical coherence in EuxLa1-xPO4 crystals, a new synthetic material for quantum technologies	Oral Parallel Workshop 3	192
Sofia Sevitz (University of Potsdam, Germany) Study of non-linear dynamics of a nanomechanical resonator with single-electron tunnelling	Poster	476

Javad Shabani (New York University, USA) Understanding of disorder for enhancement of superconducting topological gap	Invited Paralle Workshop	117
Prachi Sharma (Saarland university, Germany) Quantum subspace expansion in the presence of hardware noise	Poster	477
Huanhuan Shi (Karlsruher Institut für Technologie, Germany) Preparation of Emerging 2D Materials and their Heterostructures by Electrochemistry	Poster	478
Noah Shofer (University of Cambridge, UK) Tuning the coherent interaction of an electron qubit and a many-body register	Oral Parallel Students	275
Oles Shtanko (IBM Quantum, USA) Experimental Reconstruction of Local Integrals of Motion for Quantum Many-Body Dynamics	Oral Parallel Workshop 5	221
Oleg Shvetsov (Chalmers University of Technology, Sweden) Ultrastrong coupling between Andreev bound states and a high impedance lumped-element resonator	Poster	479
Michal Siemaszko (University of Warsaw, Poland) Time series prediction with photonic quantum memristor	Poster	480
German Sierra (Instituto de Física Teórica UAM-CSIC, Spain) Photonic Implementation of the Quantum Morra Game	Oral Parallel Workshop 2	174
Orlando J Silveira (Aalto University, Finland) Strain-induced topological edge states in few layers of SnTe	Poster	481
Matti Silveri (University of Oulu, Finland) Dynamics beyond two-level approximation in transmon arrays	Invited Paralle Workshop	118
Michelle Simmons (University of New South Wales, Australia) Atomic Electronics – building qubits in silicon with atomic precision	Keynote	80
Jairo Sinova (Johannes Gutenberg University Mainz, Germany) Unconventional magnetism: the emergence of altermagnetism and its new variants	Invited Paralle Workshop	119
Martina Soldini (University of Zurich, Switzerland) Charge-4e superconductivity in a Hubbard model	Oral Parallel Students	276
Ariadna Soro (Chalmers University of Technology, Sweden) Avoiding decoherence with giant atoms in a 2D structured environment	Poster	482
Rodrigo Soto Garrido (Pontificia Universidad Catolica, Chile) Fragile dislocation modes	Poster	483
Robert Starek (Palacky University, Czech Republic) Storage and retrieval of quantum operations – an experimental test	Oral Parallel Workshop 4	208
Thijs Stavenga (Quantware, The Netherlands) Look-up table based fast tune-up of superconducting quantum processors	Oral IF	300

Jedrzej Stempin (Adam Mickiewicz University, Poland) Revisiting quantum superpositions: Insights from the Generalized Lorentz Transformation	Poster	484
Magdalena Stobinska (Warsaw University, Poland) Enhancing free space DI QKD via employing NPA hierarchy method	Invited Paralle Workshop	120
Taylor Stock (University College London, UK) Single-Atom Control of Arsenic Incorporation in Silicon for Quantum Materials Fabrication	Oral Parallel Workshop 3	193
Josef Svetlik (ICN2, Spain) Proximity Induced Magnetism and Spin-orbit Coupling in Graphene/VxW1-xSe2 Heterostructure	Oral Parallel Students	277
Eric Switzer (Donostia International Physics Center, Spain) Quasi-2D Time Crystals on NISQ Hardware: Challenges & Opportunities	Oral Session Basque IBM	313
Ramon Szmuk (Quantum Machines, Israel) A scalable local addressing system for optically addressable qubits using integrated photonics	Oral Parallel Workshop 4	209
Dominik Szombathy (Budapest Unviersity of Technology and Economics, Hungary) Spectral properties of Random Clifford Circuits	Poster	485
Nikodem Szpak (University of Duisburg-Essen, Germany) Quantum simulation of strong field phenomena and curved spaces in deformed optical lattices	Oral Parallel Workshop 5	222
Cristian Tabares López (Institute of Fundamental Physics (IFF-CSIC), Spain) A variational toolbox for analog quantum simulators	Oral Parallel Students	278
Felice Francesco Tafuri (Keysight Technologies, USA) Accelerating the Quantum Workflow from Design to Experiments	Invited IF	130
Ting Rei Tan (The University of Sydney, Australia) Analog quantum simulation of quantum chemical dynamics with a trapped-ion system	Oral Plenary	147
Bilal Tanatar (Bilkent University, Turkey) Thermal and electronic properties of twisted bilayer ZnO	Poster	486
Abdelmalek Taoutioui (HUN-REN Institute for Nuclear Research, Hungary) Certifying asymmetric configuration of three qubit states in the prepare-and-measure scenario	Poster	487
Nicetu Tibau Vidal (University of Hong Kong, Hong Kong SAR) Annihilation operators for 2D non-abelian anyons	Oral Parallel Workshop 1	159
Hanifa Tidjani (TU Delft, The Netherlands) The Qube: a lattice of vertically and laterally coupled quantum dots	Poster	488
Andrei Voicu Tomut (ICN2, Spain) LatMatcher - AI-Powered Tool for 2D Material Stacking and Property prediction.	Poster	489

Alessandro Tosini (University of Pavia, Italy) Causal influence versus signalling for interacting quantum channels	Oral Parallel Workshop 2	175
Geza Toth (University of the Basque Country UPV/EHU, Spain) Quantum Wasserstein distance based on an optimization over separable states	Oral Parallel Workshop 2	176
Jelena Trbovic (QuantrolOx, Finland) Accelerating the Development of Quantum Computers through Automation	Invited IF	131
Lorenzo Siro Trezzini (Universitá di Pavia, Italy) Coarse Graining of Quantum Cellular Automata	Poster	490
Nermin Trnjanin (Chalmers University of Technology, Sweden) Induced Superconductivity in Hybrid Nanowires: Hysteretic Magnetotransport and Intrinsic Magnetic Fields	Poster	491
Larysa Tryputen (QuTech and Netherlands Organisation for Applied Scientific Research (TNO), The Netherlands) Interconnect Properties of Spin Qubit Devices	Oral Parallel Workshop 4	210
Ivan Tsitsilin (Walther-Meissner-Institute, Germany) Superconducting qubits at elevated frequencies	Poster	492
Patrycja Tulewicz (Adam Mickiewicz University, Poland) Experimental quantification of measuring quantum entanglement and Bell's nonlocality of two-qubit states	Poster	493
Kalid Ulas (University of Cambridge, UK) Charge sensing using a single-electron double-box in a silicon quantum dot array	Oral Parallel Workshop 6	241
Vasilisa Usova (Austrian Academy of Sciences, Austria) Closed-loop optimisation of quantum states in a high Q bosonic mode	Poster	494
Ayaka Usui (Universitat Autònoma de Barcelona, Spain) Simplifying the simulation of local Hamiltonian dynamics	Oral Parallel Workshop 5	223
Sofia Vallecorsa (CERN, Switzerland) Quantum Technolgy Initiative at CERN	Invited Paralle Workshop	121
Angelo Valli (Budapest University of Technology and Economics, Hungary) Full counting statistics and cumulant evolution in infinite temperature quantum spin chains	Poster	495
Borja Varona Uriarte (UPV/EHU, Spain) Automatic Detection of Nuclear Spins at Arbitrary Magnetic Fields via Signal-to-Image AI Model	Poster	496
Evgenij Vasilenko (Karlsruhe Institute of Technology, Germany) Spectroscopy and cavity-enhanced emission of Europium-based molecular systems	Poster	497
Valeria Vento (École polytechnique fédérale de Lausanne (EPFL), Switzerland) Measurement-induced collective vibrational quantum coherence under spontaneous Raman scattering in a liquid	Poster	498

Luan Martins Veríssimo (Donostia International Physics Center, Spain) Dissipative Symmetry-protected topological order induced by Z2 x Z2 generators	Poster	499
Visa Vesterinen (VTT, Finland) Enabling technologies for large-scale cryogenic quantum computers: parametric amplifiers	Invited Paralle Workshop	122
Giovanni Vignale (National University of Singapore, Singapore) Theory of non-conserved density accumulations in the anomalous Hall effects	Oral Parallel Workshop 1	160
Marc Vila (LBNL and University of California, Berkeley, USA) Giant Resistance Switch in Twisted Transition Metal Dichalcogenide Tunnel Junctions	Oral Parallel Workshop 1	161
Florinda Viñas Boström (Lund University, Sweden) Magnon-mediated topological superconductivity in a quantum wire	Poster	500
Giuseppe Vitagliano (TU Wien, Austria) Quantifying entanglement with global variances	Poster	501
Hongguang Wang (Max Planck Institute for Solid State Research, Germany) Quantum nanostructures of correlated metal oxides	Oral Parallel Workshop 3	194
Chien-An Wang (QuTech, Delft University of Technology, The Netherlands) Operating semiconductor quantum processors with hopping spins	Oral Parallel Workshop 4	211
Matteo Wauters (University of Trento, Italy) Weak-measurement protection in quantum simulations of lattice gauge theories	Oral Parallel Workshop 6	242
Zhi-Yuan Wei (Max Planck Institute for Quantum Optics, Germany) Kondo Impurity in an attractive Hubbard Bath	Oral Parallel Workshop 5	224
Soeren Wengerowsky (ICFO, Spain) Cavity-Enhanced on-demand Spin-Wave Solid State Quantum Memory	Oral Plenary	148
Matthias Werner (Qilimanjaro Quantum Tech / University of Barcelona, Spain) Quantum simulation of 1D-fermionic systems with Ising Hamiltonians	Oral Parallel Workshop 5	225
Odysseas Williams (ETH Zurich, Switzerland) Probing Integer and Fractional Quantum Hall States in GaAs with Microcavity Polaritons	Poster	502
Femke Witmans (University of Twente, The Netherlands) Normal state transport and induced superconductivity in SnTe nanowires	Poster	503
Izabella Wojciechowska (Adam Mickiewicz University in Poznan, Poland) Tuneable spin-to-charge interconversion and valley effects in ex-so-tic and twisted graphene-based VdW heterostructures	Poster	504

Jan Wojcik (Adam Mickiewicz University, Poland) Topological invariants of quantum walks	Poster	505
Zhen Wu (University of Twente, The Netherlands) Andreev bound states in Ge-Si core-shell nanowires	Poster	506
Wei Wu (University College London, UK) Exploring the spin-bearing molecular network for quantum materials and quantum computing	Oral Parallel Workshop 7	–
Fufang Xu (National Innovation Institute of Defense Technology, China) Analysis and compensation of the fringe contrast loss in an atomic gravimeter caused by carrier motion	Poster	507
Amir Yacoby (Harvard University, USA) Quantum Sensing of Quantum Matter	Keynote	81
Yariv Yanay (University of Maryland, USA) Detecting Measurement-Induced Entanglement Transitions With Unitary Mirror Circuits	Oral Parallel Workshop 2	177
Ian Yang (Austrian Academy of Sciences, Austria) Hot Schrödinger Cat States	Oral Parallel Students	279
Susanne Yelin (Harvard University, USA) Quantum Simulation of Molecules and Materials with present-day Reconfigurable Quantum Processors	Invited	96
Zeila Zanolli (Utrecht University, The Netherlands) Quantum Materials optolelectronics	Oral Plenary	149
Gergely Zarand (Budapest University Technology and Economics, Hungary) Quantum information jet in the infinite temperature Hubbard model	Oral Parallel Workshop 2	178
Zeki Zeybek (Universität Hamburg, Germany) Simulating Strongly Correlated Phases in One-Dimensional Rydberg Systems	Poster	508
Yijia Zhou (Shanghai Qi Zhi Institute, China) Neutral Atoms with Rydberg Interactions for Many-Body Physics and Quantum Simulations	Oral Parallel Workshop 5	226
Sergiy Zhuk (IBM Quantum, IBM Research Europe -Dublin, Ireland) Trotter error bounds and dynamic multi-product formulas for Hamiltonian simulation	Oral Session Basque IBM	314
Silvia Zorzetti (Fermilab, USA) Unlocking the Quantum Internet: Advancements in High-Efficiency Microwave-Optical Transduction	Invited Paralle Workshop	123
Eduárd Zsurka (University of Luxembourg, Luxembourg) Towards realistic modeling of proximitized magnetic topological insulator nanoribbons	Poster	509
David Zueco (CSIC, Spain) Neural Network simulations of quantum long range models	Oral Parallel Workshop 5	227

info@ai4am.net

https://ai4am.net

July 02-04 • Barcelona (Spain)

AI4AM 2024

ARTIFICIAL INTELLIGENCE FOR ADVANCED MATERIALS

ORGA-NISERS MAIN

PHANTOMS foundation

ICN2 Institut Català de Nanociència i Nanotecnologia

DIPC Donostia International Physics Center

NUS National University of Singapore — Institute for Functional Intelligent Materials

CONSTRUCTOR

Quantum Computing and Simulation in the NISQ era

J. Ignacio Cirac

Max-Planck Institute of Quantum Optics, Hans Kopfermannstr 1, D-85748 Garching, Germany

Ignacio.cirac@mpq.mpg.de

Abstract

Advancements in quantum computing have enabled the development of small-scale quantum computers and simulators that adhere to the principles of quantum physics. Despite its rapid progress, those devices are not yet flawless and errors accumulate, posing serious challenges to their application to interesting problems. In this talk I will first address how those errors affect the results of both quantum computations and the simulation of quantum many-body systems. In particular, I will present several quantum simulation algorithms, and discuss the potentiality of displaying quantum advantage in the presence of imperfections. Finally, I will describe some new ingredients of such algorithms, like the preparation of highly entangled states, and discuss how they can be sped up with the help of measurements.

Chirality and Topology

Prof. Dr. Claudia Felser

Max Planck Institute for Chemical Physics of Solids
Noethnitzer Strasse 40, 01187 Dresden

Chirality is a very active field of research in organic chemistry, closely linked to the concept of symmetry. Topology, a well-established concept in mathematics, has nowadays become essential to describe condensed matter [1,2]. At its core are chiral electron states on the bulk, surfaces and edges of the condensed matter systems, in which spin and momentum of the electrons are locked parallel or anti-parallel to each other. Magnetic and non-magnetic Weyl semimetals, for example, exhibit chiral bulk states that have enabled the realization of predictions from high energy and astrophysics involving the chiral quantum number, such as the chiral anomaly, the mixed axial-gravitational anomaly and axions [3-5]. Chiral topological crystals exhibit excellent chiral surface states [6,7] and different orbital angular momentum for the enantiomers, which can be advantageous in catalysis. The potential for connecting chirality as a quantum number to other chiral phenomena across different areas of science, including the asymmetry of matter and antimatter and the homochirality of life, brings topological materials to the fore [8].

References

[1] M. G. Vergniory, B. J. Wieder, L. Elcoro, S. S. P. Parkin, C. Felser, B. A. Bernevig, N. Regnault, Science 2022, 376, 6595.
[2] P. Narang, C. A. C. Gracia and C. Felser, Nat. Mater. 2021, 20, 293.
[3] J. Gooth et al., Nature 2017, 547, 324.
[4] J. Gooth et al., Nature 2019, 575, 315.
[5] D. M. Nenno, et al., Nat Rev Phys 2022, 2, 682.
[6] B. Bradlyn, J. Cano, Z. Wang, M. G. Vergniory, C. Felser, R. J. Cava and B. A. Bernevig, Science 2016, 353, aaf5037.
[7] N. B. M Schröter, et al., Science 2020, 369, 179.
[8] C. Felser, J. Gooth, preprint arXiv:2205.05809

Andreev and Majorana bound states in nanoscale devices

Leo Kouwenhoven

Delft University of Technology, The Netherlands

L.P.Kouwenhoven@tudelft.nl

Over the past decade we have studied Majorana bound states in hybrid devices of superconducting and semiconducting materials. Due to finite-size effects, unavoidable residual disorder and inhomogeneities in our devices, Majorana bound states with topological protection have not been observed. Instead of these studies in long hybrid nanowires, we have adopted a new bottom-up approach by building a Kitaev chain starting from a minimal cell. The minimal cell consists of two spin-polarized quantum dots coupled via a short, grounded superconductor. This coupling provides both single-electron tunneling between the quantum dots as well as a Cooperpair coupling via crossed Andreev reflection. We discuss how sweet spots can be found where Majorana states arise on the dots. This minimal cell is too short to develop a topological gap such that these Majorana states are only partially protection, hence these states have been dubbed 'poor man's Majorana's'. Ongoing work is on longer chains that are predicted to have more and more protection against local noise..

References

[1] Relevant reference: Dvir, Wang..., Kouwenhoven, Realization of a minimal Kitaev chain in coupled quantum dots. Nature 614(7948), 445–450 (2023)

Atomic Electronics – building qubits in silicon with atomic precision

Michelle Y. Simmons

Silicon Quantum Computing, Sydney, Australia

michelle.simmons@unsw.edu.au

The realisation of a large-scale error corrected quantum computer relies on our ability to reproducibly manufacture qubits that are fast, highly coherent, controllable and stable. The promise of achieving this requires a highly manufacturable platform, such as silicon and a deep understanding of the materials issues at the atomic scale that impact device operation. In this talk I will describe our progress to engineer every aspect of device behaviour in atomic qubits in silicon. This will cover the use of atomic precision lithography to achieve fast, controllable exchange coupling [1], fast, high fidelity qubit initialisation and read-out [2]; low noise all epitaxial gates allowing for highly stable qubits [3]; and qubit control [4] that provide a deep understanding of the impact of the solid-state environment [5] on qubit designs and operation. I will also discuss our latest results in analogue quantum simulation [6].

References

[1] Y. He, S.K. Gorman, D. Keith, L. Kranz, J.G. Keizer, and M.Y. Simmons, "A fast (…ns) two-qubit gate between phosphorus donor electrons in silicon", Nature 571, 371 (2019)

[2] D. Keith, M. G. House, M. B. Donnelly, T. F. Watson, B. Weber, M. Y. Simmons, "Microsecond Spin Qubit Readout with a Strong-Response Single Electron Transistor", Physical Review X 9, 041003 (2019); D. Keith, S. K. Gorman, L. Kranz, Y. He, J. G. Keizer, M. A. Broome, M. Y. Simmons, "Benchmarking high fidelity single-shot readout of semiconductor qubits", New Journal of Physics 21, 063011 (2019).

[3] L. Kranz S. K. Gorman B. Thorgrimsson Y. He D. Keith J. G. Keizer M. Y. Simmons, "Exploiting a Single-Crystal Environment to Minimize the Charge Noise on Qubits in Silicon", Advanced Materials 32, 2003361 (2020).

[4] L. Fricke, S.J. Hile, L. Kranz, Y. Chung, Y. He, P. Pakkiam, J.G. Keizer, M.G. House and M.Y. Simmons, "Coherent spin control of a precision placed donor bound electron qubit in silicon", Nature Communications 12, 3323 (2021).

[5] M. Koch, J.G. Keizer, P. Pakkiam, D. Keith, M.G. House, E. Peretz, and M.Y. Simmons, "Spin read-out in atomic qubits in an all-epitaxial three-dimensional transistor", Nature Nanotechnology 14, 137 (2019 – with cover article).

[6] M. Kiczynski, S.K. Gorman, H. Geng, M.B. Donnelly, Y. Chung, F. N. Krauth, M. T. Jones, J.G. Keizer, Y. He and M.Y. Simmons, "Experimental realisation of the single particle Su-Schrieffer-Heeger model in phosphorus doped silicon quantum dots", Nature 606, 694 (2022).

Quantum Sensing of Quantum Matter

Amir Yacoby

Harvard University, Cambridge MA

yacoby@g.harvard.edu

Abstract

Major scientific discoveries are often enabled by new measurement capabilities that provide novel perspectives into complex physical problems. Recent advances and discoveries made on quantum materials have challenged experimentalists to come up with new ways to probe their intrinsic properties. In this talk I will review some of the recent work we have done to develop a variety of local quantum sensing techniques and discuss how they can assist us in exploring quantum matter.

Spin Qubits produced with a 300mm fabrication line: An update on Intel Si/SiGe devices

James S. Clarke

Intel Corporation, 2501 NE 229th Ave, Hillsboro, OR 97124

James.s.clarke@intel.com

Abstract
Quantum computing holds the possibility of de-livering exponentially more computing power for some applications than today's largest supercom-puters. While many different qubit technologies exist, only spin qubits map to a fab transistor process. In this presentation, we present an update on the progress of Si/SiGe Qubits fabricated using the standard tools of Intel's latest technology node.

Introduction

The qubit is the fundamental device of a quantum computer. It is the equivalent to the transistor in CMOS logic devices. And while it took the semicon-ductor industry 42 years from the first transistor to the first 1M transistor microprocessor, the quantum commu-nity hopes to reach this milestone much faster. But there are no less than 10 qubit types and most require new materials and new inventions to realize even a few qubits. Of these qubit types, only spin qubits in silicon are similar to transistors and are compatible with the infrastructure of advanced CMOS fabrication. By leveraging all of the work in transistor fabrication, we can perhaps shorten accelerate the time. - The future of quantum computing starts with a grain of sand.

Spin Qubits

Spin qubits are similar in geometry to a conventional, planar transistor but are operated in the single electron regime and under a magnetic field. The two level system or 0 and 1 of the spin qubit is determined by the spin state (up/down) of a single electron and enables the one qubit gates of a quantum computer. Two qubit gates are achieved by controlled overlap of electron wavefunctions between adjacent qubits (transistors).

At Intel, we fabricate silicon-based quantum compu-ting devices in the same advanced 300mm fab where our next generation process technology is developed. In-tel's quantum hardware group has released a new silicon spin qubit test chip, Tunnel Falls, a 12-quantum-dot line-ar array fabricated using Intel's D1high-volume manu-facturing line. Tunnel Falls incorporates standard micro-electronics design, materials, and fabrication techniques including EUV li-thography for the patterning of tight pitch device features. (See Figures 1,2)
In this talk we will share a general overview of spin qubit devices and Intel's test chip.
We will then present qubit performance benchmarking of multiple qubit encodings on these Si/SiGe spin qubit devices. Finally, we will discuss how results from this work are being used to vali-date design features, device physics, and fabrication pro-cesses that are being tested in extensible arrays for future technologies.

Figures

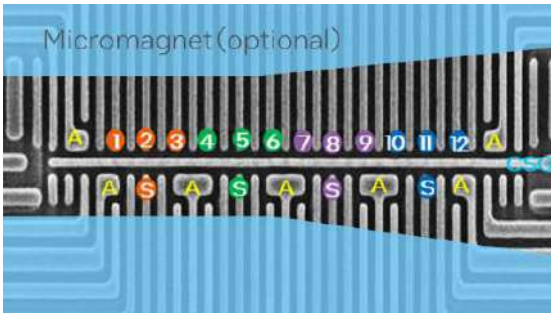


Figure 1: Top-Down SEM of a 12 "dot" linear array. Individual Gate wires (top) act as plungers and barriers to accumu-late single electrons under adjacent gates while "sensor dots" (bottom) can detect the spin of the electron in the qubit.

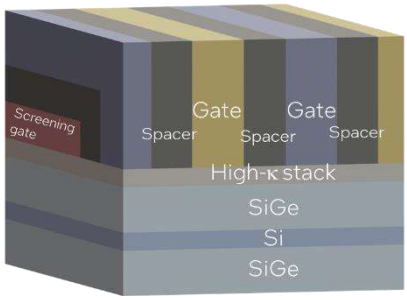


Figure 2: Cross section schematic of a spin qubit gate array fabri-cated through industry standard processes.

The Age of Computation is yet to Come

Artur Ekert

University of Oxford, UK

artur.ekert@maths.ox.ac.uk

The theory of classical universal computation was laid down in 1936, it was implemented within a decade, became commercial within another decade, and dominated the world's economy half a century later. The unavoidable step to the quantum level promises entirely new modes of computation that do not have classical analogues. At present it is not clear when, how and even whether fully-fledged quantum computers will eventually be built; but notwithstanding this, the quantum theory of computation already plays a much more fundamental role in shaping our world-view than its classical predecessor ever did. But what if the theory is eventually refuted—if some deeper limitation foils the attempt to build a scalable quantum computer? I would be thrilled to see that happen. Such an outcome is by far the most desired one. Not only would it lead to a revision of our fundamental knowledge about physics, we would expect it to provide even more fascinating types of computation. For if something stops quantum mechanics, we shall expect to have an exciting new whatever-stops-quantum-mechanics theory, followed by exciting new whatever-stops-quantum-computers computers. From this perspective it appears as though the age of computation has not yet even begun!

Quantum Computing at the Utility Scale and Beyond

Jay M. Gambetta

IBM T. J. Watson Laboratory, 1101 Kitchawan Rd., Yorktown Heights, NY 10598 USA

jay.gambetta@us.ibm.com

With a multitude of quantum demonstrations on 100+ qubits, quantum computing is now firmly in the era of utility where quantum computers can serve as a scientific tool to explore a new scale of problems that classical methods may not be able to solve. This scale, combined with advances in algorithms, is fundamental to enabling quantum advantage; the point where quantum computers can faithfully run one of more tasks providing business or scientific value with more accuracy, efficiently, or cost-effectiveness than with classical computation alone.

In this talk, we will highlight the progress in both quantum hardware and software that allow for computing observables on ~100 qubits within a reasonable time-budget on present-day devices. We then turn to the IBM Quantum roadmap, and how the technological improvements therein open up new opportunities not only for large-scale applications utilizing error-mitigation, but also pave the way toward future error corrected systems within the next decade.

References

[1] T. Ichikawa, H. et. al., "A comprehensive survey on quantum computer usage: How many qubits are employed for what purposes?" *arXiv:2307.16130*, 2023.

[2] E. Bäumer, V. Tripathi, D. S. Wang, P. Rall, E. H. Chen, S. Majumdar, A. Seif, and Z. K. Minev, "Efficient Long-Range Entanglement using Dynamic Circuits," *arXiv:2308.13065*, 2023.

[3] E. H. Chen, G.-Y. Zhu, R. Verresen, A. Seif, E. Bäumer, D. Layden, N. Tantivasadakarn, G. Zhu, S. Sheldon, A. Vishwanath, S. Trebst, and A. Kandala, "Realizing the Nishimori transition across the error threshold for constant-depth quantum circuits," *arXiv:2309.02863*, 2023.

[4] R. C. Farrell, M. Illa, A. N. Ciavarella, and M. J. Savage, "Scalable Circuits for Preparing Ground States on Digital Quantum Computers: The Schwinger Model Vacuum on 100 Qubits," *arXiv:2308.04481*, 2023.

[5] "Quantum Simulations of Hadron Dynamics in the Schwinger Model using 112 Qubits," *arXiv:2401.08044*, 2024.

[6] O. Shtanko, D. S. Wang, H. Zhang, N. Harle, A. Seif, R. Movassagh, and Z. Minev, "Uncovering Local Integrability in Quantum Many-Body Dynamics," *arXiv:2307.07552*, 2023.

[7] T. Yasuda, Y. Suzuki, T. Kubota, K. Nakajima, Q. Gao, W. Zhang, S. Shimono, H. I. Nurdin, and N. Yamamoto, "Quantum reservoir computing with repeated measurements on superconducting devices," *arXiv:2023.06706*, 2023.

[8] H. Yu, Y. Zhao, and T.-C. Wei, "Simulating large-size quantum spin chains on cloud-based superconducting quantum computers," *Phys. Rev. Res.*, vol. 5, p. 013183, Mar 2023

Figures

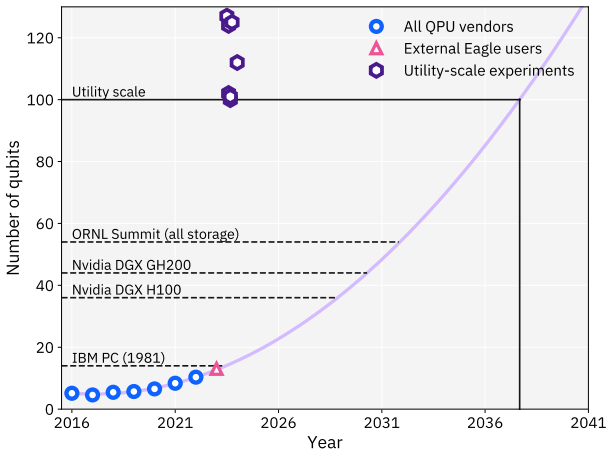


Figure 1: Estimated mean number of qubits used on all cloud-accessible modalities of quantum processing units (QPU) as a function of year (circles) [1], along with IBM Quantum data for its external users using 127-qubit Eagle processors in 2023 (triangle). The shaded region is an extrapolation from a quadratic fit to the data for all QPU vendors Dashed lines indicate the number of qubits that can be brute-force simulated using the indicated classical simulation hardware. Solid-line highlights the 100-qubit boundary for quantum utility that comes in 2038 at the current rate of progress. Utility scale experiments (hexagons) [2], [3], [4], [5], [6], [7], [8], utilizing 100+ qubits overlaid on top of the present-day trend.

Universal scaling laws for correlated decay of many-body quantum systems

Ana Asenjo-Garcia

Department of Physics, Columbia University, New York, New York 10027, USA

ana.asenjo@columbia.edu

A key challenge in scaling up quantum systems is the potential for correlated decay, which can significantly reduce the lifetime of states of interest. This talk answers the following question: what is the maximal decay rate of a quantum system, and how does it scale with system size? Addressing this question, especially for systems comprising a large number of particles, is challenging due to the exponential increase in complexity of the Hilbert space. I will present a method that circumvents this difficulty by reformulating the problem into finding the ground state energy of a generic spin Hamiltonian. By establishing strict upper and lower bounds on this energy, we discover universal scaling laws that depend solely on the system's size, dimensionality, and interaction range. These laws serve as upper limits on how fast any quantum state can decay, and offer valuable insights for research in quantum optics, metrology and sensing.

Shedding Light on Nuclear Spins: Through the looking-glass

Mete Atatüre

Cavendish Laboratory, University of Cambridge, JJ Thomson Ave., Cambridge CB30HE, UK

ma424@cam.ac.uk

Optically active spins in solids are strong candidates for scalable devices towards quantum networks. Semiconductor quantum dots set the state-of-the-art on optical properties as near-ideal single photon sources for the criteria of tuneability, brightness, and indistinguishability. The spin side of semiconductor quantum dots is complicated via the presence of nuclear spins of the hosting material. Their inherently mesoscopic nature leads to a unique realisation of a tripartite interface between light as information carrier, an electron spin as a proxy qubit, and an isolated nuclear spin ensemble. The ability to control these constituents and their mutual interactions create opportunities to realize an optically controllable ensemble of ~50,000 spins. In this talk, I will present a journey from treating the quantum dot nuclei as an uncontrolled noise source limiting spin coherence to the observation of their collective magnon modes and eventually to their capacity as quantum registers, all witnessed via a single electron spin driven by light.

From matter waves to quantum sensors

Philippe BOUYER

Univ. of Amsterdam and Technical Univ. Eindhoven
Quantum Delta NL

p.bouyer@uva.nl

Inertial sensors based on cold atoms and light-pulse interferometry exhibit state-of-the-art sensitivity and ultra-low measurement bias that could revolutionize a variety of fields including geophysics and seismology, gravitational wave detection and fundamental tests of gravity, and inertial navigation [1].

In the latter case, cold-atom interferometers are widely considered as breakthrough technology for future autonomous navigation. Nowadays, absolute quantum inertial sensors are available as commercial [2] and field-deployable devices [3].

New concepts of matter-wave interferometry can also be used to study the low frequency variations of the strain tensor of space-time and gravitation. They can be used for the most precise monitoring of gravity or for precise tests of the weak equivalence principle (WEP) [4].

For instance, the MIGA instrument, which is currently built in the underground laboratory in Rustrel, France will allow the monitoring of the evolution of the gravitational field at unprecedented sensitivity, which will be exploited both for geophysical studies and for Gravitational Waves (GWs) observations [5].

I present here some of the most recent advances in these fields.

References

[1] B. Barrett et al, "Mobile and remote inertial sensing with atom interferometers", in *Proc. of the International School of Physics "Enrico Fermi"*, 188, 493-555 (2014).

[2] V. Ménoret et al, "Gravity measurements below 10^{-9} *g* with a transportable absolute quantum gravimeter", *Sci. Rep. 8*, 12300 (2018).

[3] Y. Bidel et al., "Absolute airborne gravimetry with a cold atom sensor", *Journal of Geodesy* volume 94, Article number: 20 (2020)

[4] B. Barret et al, "Testing the Universality of Free Fall using correlated 39K -- 87Rb interferometers", AVS Quantum Sci. 4, 014401 (2022)

[5] A. Bertoldi et al, "Quantum sensors with matter waves for GW observation", Handbook of Gravitational Wave Astronomy (Eds. C. Bambi, S. Katsanevas and K. Kokkotas; Springer Singapore, 2021)

Figure

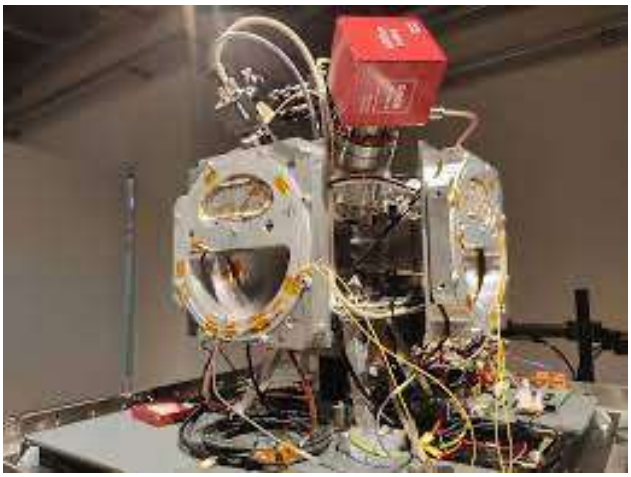


Figure 1: Prototype of a full 3D quantum corrected accelerometer for navigation [CNRS/IOGS/EXAIL]

Quantum Control at the Atomic Scale: From Ångstrom-Scale Qubit Platforms to Topological Superconductivity

Deung-Jang, Choi[1,2,3]

[1]*Centro de Fisica de Materiales, CFM/MPC (CSIC-UPV/EHU), Paseo Manuel de Lardizabal 5, 20018 Donostia-San Sebastian*
[2]*Donostia International Physics Center (DIPC), Paseo Manuel de Lardizabal 4, 20018 Donostia-San Sebastian*
[3]*Ikerbasque, Basque Foundation for Science, 48013 Bilbao, Spain*

djchoi@dipc.org

In the context of quantum science and technology, our study achieves harnessing individual electron spins within solid materials with precise atomic-level connections. Scanning Tunneling Microscope (STM) emerges as a mature technique for studying magnetic impurities on different substrates, serving as quantum sensors and building blocks for quantum information [1]. We successfully build, manipulate, and observe linked electron-spin qubits on an atom-by-atom basis [2]. Coherent control of these "remote" qubits is empowered through the introduction of localized magnetic field gradients generated by nearby single-atom magnets. Our readout methodology utilizes a sensor qubit within the tunnel junction, featuring pulsed double electron spin resonance. This enables swift single-, dual-, and triple-qubit operations, entirely through electrical means. The resulting Ångstrom-scale qubit platform opens the door to harnessing quantum capabilities, utilizing arrays of electron spins meticulously assembled atom by atom upon a surface.

In the second part of my talk, the experimental focus shifts to utilizing single magnetic atoms to assemble a 1-D spin chain on a superconducting surface, leading to diverse spin orderings, closing the superconducting gap, and approaching a topological quantum phase transition [3]. Calculations employing Bogoliubov-de Gennes theory anticipate the appearance of clear Majorana bound states for relatively small chains in specific arrangements [4], showcasing the potential for exploring topological quantum phenomena in a controlled manner.

References

[1] Colloquium: Atomic spin chains on surfaces. Review of Modern Physics 91, 041001 (2019)
[2] An atomic-scale multi-qubit platform, Science 382 (6666), 87-92 (2023)
[3] Atomic Manipulation of In-gap States on the β-Bi2Pd Superconductors, Physical Review B 104 (4), 045406 (2021).
[4] Calculations of in-gap states of ferromagnetic spin chains on s-wave wide-band superconductors, Physical Review B 104 (24), 245415 (2021).

Figures

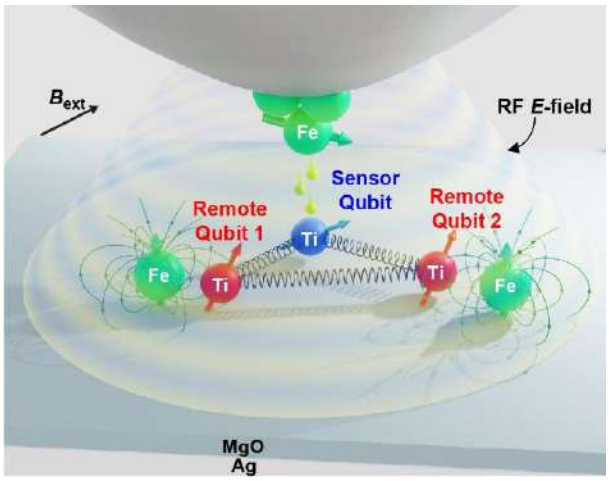


Figure 1: Three-Dimensional Model of a Single-Atom Electron Spin Qubit.

Potential and limitations of near-term quantum computing

Jens Eisert
FU Berlin, Arnimallee 14, 14195 Berlin

jense@zedat.fu-berlin. de

Quantum computers promise the efficient solution of some computational problems that are classically intractable. For many years, they have been primarily objects of theoretical study, as only in recent years, protagonists have set out to actually build intermediate-scale quantum computers. This creates an interesting state of affairs, but also begs for an answer to the question what such devices are possibly good for.

In this talk, we will present both encouraging as well as discouraging insights into near-term quantum computing, alongside a number of results offering substantial progress. We will discuss rigorous quantum advantages in paradigmatic problems [1,2], and will explore the use of quantum computers in machine learning [3,4] and optimization [5].

At the same time, we will find strong limitations, by providing efficient classical algorithms for instances of quantum algorithms, hence "de-quantizing" them [6,7], and by identifying limitations to quantum error mitigation [8]. Interestingly, it may depend on fine print of the non-unital quantum noise to what extent quantum computing with no error correction may be feasible [9]. The talk will end on the note that quantum simulation remains one of the most promising applications of near-term quantum devices [10,11].

References

1. Rev. Mod. Phys. 95, 035001 (2023).
2. arXiv:2307.14424 (2023).
3. Nature Comm. 15, 434 (2024).
4. arXiv:2306.13461, Nature Comm. (2024).
5. arXiv:2212.08678, Science Adv. (2024).
6. arXiv:2309.11647 (2023).
7. Phys. Rev. Lett. 131, 100803 (2023).
8. arXiv:2210.11505, Nature Phys. (2024).
9. In preparation (2024).
10. Nature Comm. 14, 3895 (2023).
11. Nature Phys. 17, 559 (2021).

Figures

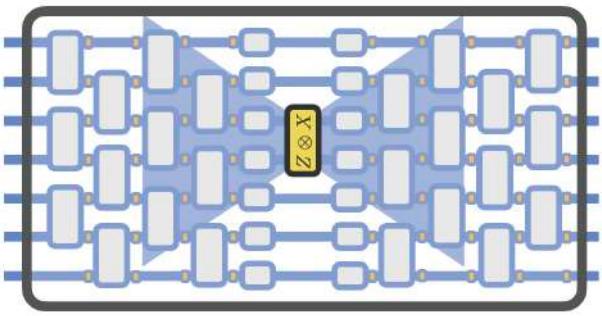


Figure 1: Efficient classical simulation for quantum circuits undergoing non-unital noise.

Advancing Many-Body Quantum Physics with Dipolar Quantum Gases

Francesca Ferlaino

Institute for Experimental Physics, Universität Innsbruck, Austria
&
Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Science

Silvia.Bonazza@uibk.ac.at

Dipolar quantum gases represent a fascinating and rapidly evolving field at the forefront of many-body quantum physics and quantum simulation. These gases, composed of ultracold atoms with strong magnetic, exhibit unique and tunable long-range interactions, distinct from the short-range interactions in traditional atomic gases. This talk provides an overview of recent developments and key insights in the study of dipolar quantum gases and their implications in various experimental setups, such as optical lattices and bulk systems. Moreover, we highlight recent experimental and theoretical advancements in understanding quantum phases, dynamics, and collective phenomena in dipolar gases, ranging from the discover of a supersolid state of matter to the realization of 'extended' quantum simulators. Overall, the study of dipolar quantum gases continues to inspire innovative research directions and offers promising avenues for exploring new frontiers in quantum science and technology.

Strongly interacting bosonic physics in layered two-dimensional van der Waals materials

Mohammad Hafezi

Joint Quantum Institute, University of Maryland, College Park, MD 20742

hafezi@umd.edu

Abstract

Having a controllable system with many strongly interacting particles lies at the core of quantum simulation. For many years, excitons, bound electron-hole pairs in semi-conductors, remained weakly interacting casting doubt on their potential as a suitable quantum simulation platform. In this talk, I introduce moiré lattices in layered transition metal dichalcogenides as a promising platform for strongly interacting excitons, offering relatively large flexibility in tuning parameters. Specifically, I report on the experimental observation of Mott insulating states of excitons, and corresponding transport properties[1]. Moreover, I discuss various interesting features of such systems, including the non-bosonic nature of such excitons[2], spin-polaron magnetic properties[3], collective radiative phenomena (akin to atomic arrays), and various non-interacting[4] and interacting topological states.

Figures

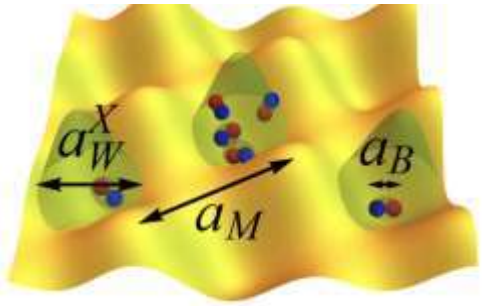


Figure 1: Illustration of moiré excitons in a superlattice potential. Different regimes of exciton Bohr radius (a_B), moiré lattice spacing (a_M), and Wannier orbital size (a_W^X) can be achieved by choosing different materials and twist angels[2].

References

[1] B. Gao, D. Suarez-Forero, S. Sarkar, Nat. Com. 15:2305 (2024)
[2] T.-S. Huang, P. Lunts, M. Hafezi arXiv:2310.19931 (2023)
[3] T.-S. Huang et al. PHYSICAL REVIEW B 107, 195151 (2023)
[4] Ming Xie, M. Hafezi, S. Das Sarma arXiv:2403.00052 (2024)

Driving the fluxonium qubit

Angela Kou
Aayam Bista, Matthew Thibodeau, Ke Nie, Kaicheung Chow, Wolfgang Pfaff, Bryan K. Clark

University of Illinois at Urbana-Champaign, Urbana, IL, USA 61802

akou@illinois.edu

The fluxonium qubit has garnered significant interest recently due to its high gate fidelities and strongly anharmonic spectrum. These valuable features have resulted in the fluxonium being proposed as the basis for a quantum processor, for use in transducing between microwave and optical signals, and as a nonlinear element for manipulating long-lifetime linear cavities. The capabilities of the fluxonium qubit for such schemes can be significantly improved under the application of a microwave drive. Here we discuss our recent experimental efforts demonstrating the benefits of applying a microwave drive for initializing and reading out a fluxonium qubit. We will conclude by discussing prospects for improving multiple-fluxonium devices through the application of a microwave drive [1].

Figures

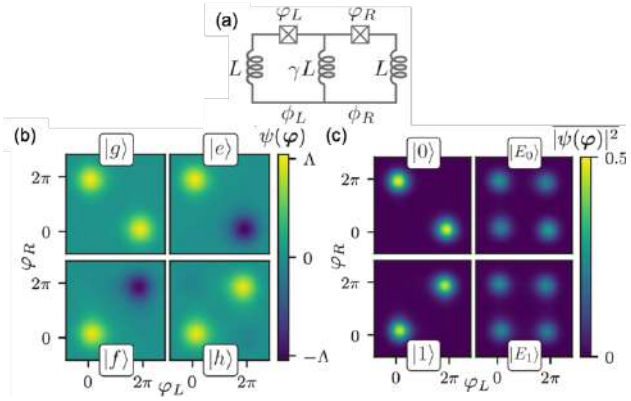


Figure 1: (a) Circuit diagram for a fluxonium molecule [2]. The energy eigenstates of the fluxonium molecule in the static (b) and driven (b) cases. The application of a microwave flux drive creates qubit states that are completely disjoint in phase for both the left and right fluxonium.

References

[1] Matthew Thibodeau, Angela Kou, Bryan K. Clark, arxiv: 2401.08762 (2024)
[2] A. Kou, W. C. Smith, U. Vool, R. T. Brierley, H. Meier, L. Frunzio, S. M. Girvin, L. I. Glazman, M. H. Devoret, Phys. Rev. X 7, 031037 (2017)

Deterministic single-photon hardware for scalable quantum-information processing

P. Lodahl

Center for Hybrid Quantum Networks (Hy-Q), Niels Bohr Institute, University of Copenhagen, Denmark

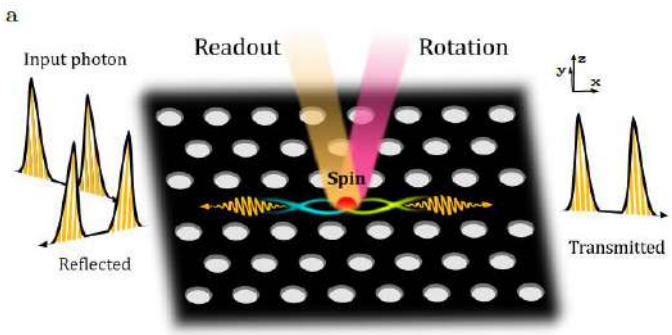
lodahl@nbi.ku.dk

Semiconductor quantum dots embedded in photonic nanostructures offer a highly efficient and coherent deterministic photon-emitter interface enabling on-demand single-photon sources and multi-photon entanglement sources [1,2]. We discuss the fundamental operational principles of these devices and introduce a protocol of deterministic entanglement generation by controlling a single spin in the quantum dot [3]. We will present the experimental state-of-the-art of multi-photon entanglement generation [4,5] including the realization of photon fusion [6], which is a primitive for fusion-based quantum computing. Finally, we discuss potential applications of this novel hardware for quantum communication and photonic quantum computing [7].

References

[1] Lodahl et al., Rev. Mod. Phys. 87, 347 (2015).
[2] Lodahl, Ludwig and Warburton, Phys. Today 75, 3-44 (2022).
[3] Tiurev et al., Phys. Rev. A L030601 (2022).
[4] Appel et al., Phys. Rev. Lett. 128, 233602 (2022).
[5] Meng et al., arXiv: 2310.12038
[6] Meng et al., arXiv: 2312.09070
[7] Uppu et al., Nature Nano. 16, 1308 (2021).

Figures



Unconventional quantum phases and their visualization with atomic resolution

Yulia Maximenko
Marlou Slot, Paul Haney, Sungmin Kim, Daniel Walkup, Nikolai Zhitenev, Fereshte Ghahari Kemari, Joseph Stroscio

Colorado State University, Department of Physics, 400 Isotope Dr, Fort Collins, CO 80521 USA
NIST, 100 Bureau Dr, Gaithersburg, MD 20899, USA

y.maximenko@colostate.edu

Newly discovered properties of magic angle graphene and other systems from the same family propelled the field of twistronics and motivated new research into tunable unconventional quantum phases. The research is driven in part by the search for robust quantum anomalous Hall insulators, topological superconductivity, correlated electronic states, and fractional statistics, and by the prospect of quantum simulation in solid state. In this lecture, I will showcase the exciting recent developments in the field of tunable 2D platforms highlighting the role played by scanning tunneling microscopy (STM) (Fig. 1). Through high-resolution magnetic-field scanning tunneling spectroscopy, surprising insights into quantum geometry and strongly correlated physics can be gained (Fig. 2). Specifically, I will report on the detection of the orbital magnetic moment and the emergent, anomalously large orbital magnetic susceptibility in twisted double bilayer graphene (TDBG)[1]. I will also discuss the potential in the field of quantum materials, combining STM, atomic manipulation, epitaxial growth, and stacked 2D devices.

References

[1] Y. Maximenko, M. R. Slot, P. M. Haney, et al, and J. A. Stroscio s, Science, 6666 (2023) 81-87

Figures

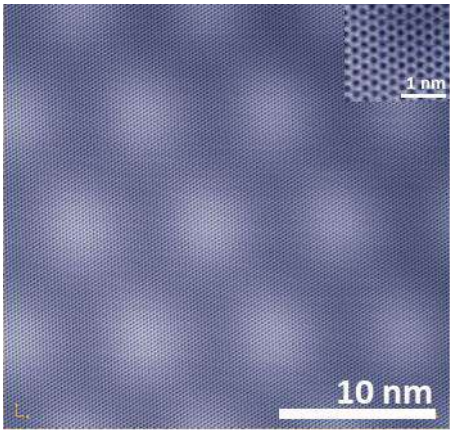


Figure 1: Topographical STM image of TDBG [1].

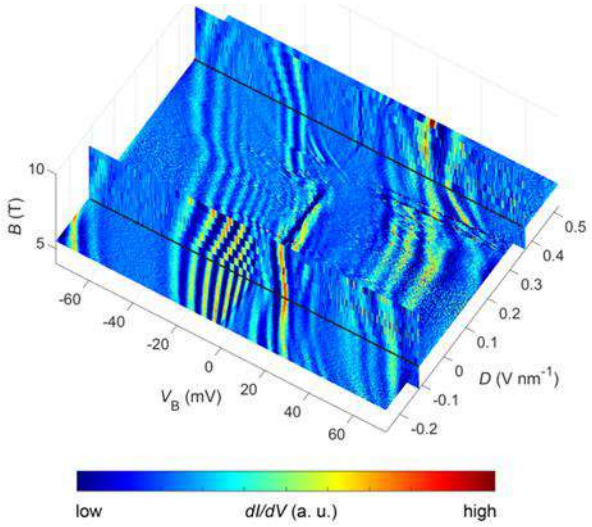


Figure 2: Slices of a 3D local density of states map in TDBG showing Landau levels, where x,y, and z axes are respectively displacement field, sample bias, and magnetic field [1].

Quantum Simulation of Molecules and Materials with present-day Reconfigurable Quantum Processors

Susanne F. Yelin
N. Maskara, S. Ostermann, J. Shee, M. Kalinowski, A. McClain Gomez, R. Araiza Bravo, D. S. Wang, A. I., Krylov, N. Y. Yao, M. Head-Gordon, M. D. Lukin

Harvard University, Dept. of Physics, Cambridge, MA 02138, USA

syelin@g.harvard.edu

Abstract

Simulations of quantum chemistry and quantum materials are believed to be among the most important potential applications of quantum information processors, but realizing practical quantum advantage for such problems is challenging. We introduce a simulation framework for strongly correlated quantum systems that can be represented by model spin Hamiltonians. Our approach [1] leverages reconfigurable qubit architectures to programmably simulate real-time dynamics and introduces an algorithm for extracting chemically relevant spectral properties via classical co-processing of quantum measurement results. We develop a digital-analog simulation toolbox for efficient Hamiltonian time evolution utilizing digital Floquet engineering and hardware-optimized multi-qubit operations to accurately realize complex spin-spin interactions, and as an example present an implementation proposal based on Rydberg atom arrays. Then, we show how detailed spectral and other relevant chemical information can be extracted from these dynamics through snapshot measurements and single-ancilla control, enabling the evaluation of excitation energies and finite-temperature susceptibilities from a single-dataset. To illustrate the approach, we show how this method can be used to compute key properties of a polynuclear transition-metal catalyst and 2D magnetic materials.

References

[1] Maskara N, Ostermann S, Shee J, Kalinowski M, Gomez AM, Bravo RA, Wang DS, Krylov AI, Yao NY, Head-Gordon M, Lukin MD. Programmable Simulations of Molecules and Materials with Reconfigurable Quantum Processors. arXiv:2312.02265.

Figures

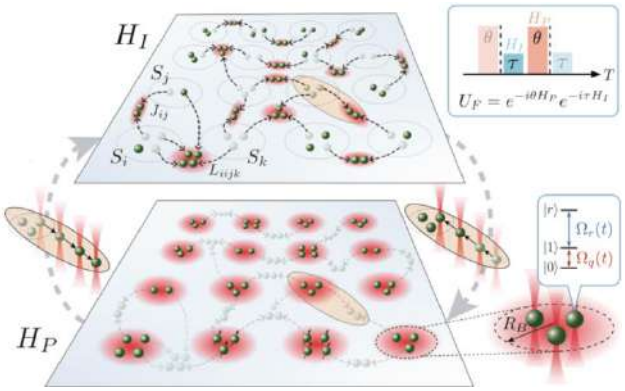


Figure 1: Hardware-efficient protocol for programmable simulation of generic spin Hamiltonian is based on applying sequences of interactions between non-overlapping few-qubit groups, moving atoms in between. This implementation of a complex spin model is using a dynamical projection approach where spin-S variables are encoded in the collective spin of a cluster of 2S qubits: interactions between spins are generated by evolving pairs of qubits from each cluster under an interaction Hamiltonian and then dynamically projected into the symmetric encoding space. This protocol can be realized in any reconfigurable quantum processor.

Quantum nanostructures at atomic scale: From vertical hybrid nanowires to planar nanowire networks and 2DEG/2DHG systems

Jordi Arbiol
M. Botifoll, S. Martí-Sánchez

ICREA & Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Campus UAB, Bellaterra, 08193 Barcelona, Catalonia, Spain

Contact@E-mail arbiol@icrea.cat

Abstract

Hybrid superconductor/semiconductor-based quantum devices (e.g.: for quantum computing applications) are mainly based on 3 different technologies: vapour-liquid-solid (VLS) grown vertical nanowires, selected area growth (SAG) nanowire networks and 2-dimensional electron gases (2DEG). By using AC STEM and 3D modelling, we will study the influence of polarity on the development and properties of these complex NW-like hybrid heterostructures vertically grown by VLS.[1-6] In a second part, we will show the natural evolution of this vertical technology to the flat SAG growth of NW networks on III-V substrates. In these complex core@shell or confined multilayer nanostructure configurations, strain relaxation mechanisms during the epitaxial growth play a key role in determining their final morphology, crystal structure and physical properties. To analyze these mechanisms, atomic-scale AC STEM studies are performed on horizontal arrays of nanowires. Monochromated Valence Electron Energy Loss Spectroscopy will be employed to spatially map the heterostructure's bandgap with sub-nanometer resolution and certify the influence of the high mismatch induced strain on the topological electronic properties at the interface of the core-shell region.[7-12] Finally, we will address the newly developed 2DEG heterostructures based on SiGe, fully compatible with CMOS technology, were the strain and composition at the Ge quantum wells will determine their final quantum properties [13].

References

[1] M. de la Mata, Nano Lett. 12, 2579 (2012)
[2] M. de la Mata, Nano Lett. 14, 6614 (2014)
[3] M. de la Mata, Nano Lett. 16, 825 (2016)
[4] M. de la Mata, Nano Lett. 19, 3396 (2019)
[5] M. Zamani, Adv. Mater. 32, 2001030 (2020)
[6] M. Valentini, Nature 612, 442 (2022)
[7] E. Oksenberg, ACS Nano 11, 6155 (2017)
[8] F. Krizek, Phys. Rev. Mater. 2, 093401 (2018)
[9] S. Vaitiekėnas, Phys. Rev. Lett. 121, 147701(2018)
[10] M. Friedl, Nano Lett. 18, 2666 (2018)
[11] P. Aseev, Nano Letters 19, 218 (2019)
[12] S. Martí-Sánchez, M. Botifoll, et al., Nature Commun. 13, 4089 (2022)
[13] D. Jirovec, Nature Mater. 20, 1106 (2021)

Figures

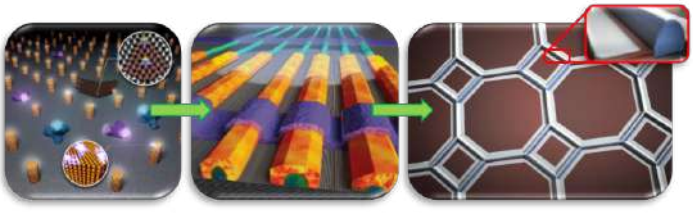


Figure 1: Semiconductor nanowires (r)evolution: from vapour liquid solid to guided growth and selected area growth quantum networks.

Security proof of discrete-modulated continuous-variable quantum key distribution

Antonio Acín

ICFO-The Institute of Photonic Sciences, 08860 Castelldefels (Barcelona), Spain

antonio.acin@icfo.eu

Continuous variable quantum key distribution with discrete modulation has the potential to provide information-theoretic security using widely available optical elements and existing telecom infrastructure. While their implementation is significantly simpler than that for protocols based on Gaussian modulation, proving their finite-size security against coherent attacks poses a challenge. We consider protocols in which, contrary to previous approaches, all the information is discretized. This allows using standard techniques developed in the discrete-variable scenario to prove the security of these protocols, with no significant loss in the key rate. We discuss several variants of these protocols and their security, the theoretical and implementation challenges and how the use of post-selection may open promising avenues to address them.

References

[1] S. Bäuml, C. Pascual García, V. Wright, O. Fawzi, A. Acín, arXiv:2303.09255.

Figures

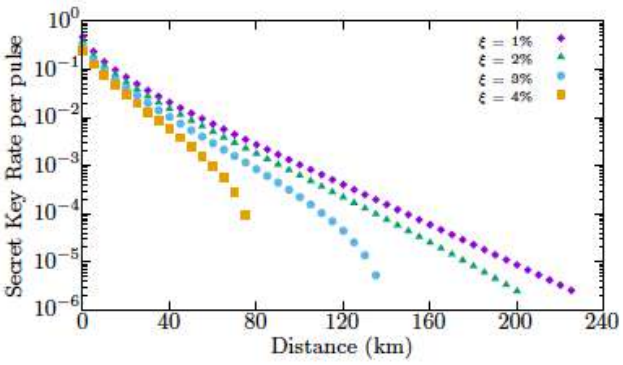


Figure 1: Asymptotic secret key generation rate in terms of distances D and excess noise.

Implementing a quantum memory with a frequency and bandwidth-tuneable superconducting resonator

Audrey Bienfait
Y. Wen, T. Lorriaux, V. Ranjan, D. Vion, B. Huard, E. Flurin, P. Bertet
Ecole Normale Supérieure de Lyon, CNRS, Laboratoire de Physique, F-69342 Lyon, France
audrey.bienfait@ens-lyon.fr

Among platforms for storing quantum states in the microwave domain, solid state spin ensembles addressed via superconducting circuits stand out for their multimodal storage capability and the second-long coherence time when operated at clock transitions [1].

Successful implementation of a practical memory scheme requires several keys features, such as the ability to tune on-demand the frequency and the bandwidth of the resonator [2]. In this talk, we will present a superconducting circuit architecture accomplishing both, allowing strong coupling to an ensemble of bismuth dopants in silicon. We devise a parametric process to dynamically control the virtual bandwidth of the superconducting circuit by exploiting its kinetic inductance nonlinearity, demonstrating coupling rate tuning range over a factor of 15.

The strong coupling of the spins to the resonator also set radiation loss as the main spin relaxation channel. Combined with nuclear and electronic drives, this Purcell effect enables to polarize the spins dynamically predominantly into a single ground state, allowing us to reach a cooperativity between the resonator and the spin ensemble near unity.

References

[1] Wolfowicz, G. et al. Nature nanotechnology 8, 561–564 (2013).
[2] Julsgaard, B. et al. Phys. Rev. Lett. 110, 250503 (2013).

Epitaxial van der Waals heterostructures for magnetism and spin-charge conversion

F. Bonell[1]
V. Polewczyk[1], Q. Guillet[1], K. Abdukayumov[1], J. Courtin[1], T. Guillet[2], F. Ibrahim[1], D. Dosenovic[3], C. Vergnaud[1], I. de Moraes[1], M. Chshiev[1], S.O. Valenzuela[2], H. Okuno[3], A. Marty[1], M. Jamet[1]

[1] *University Grenoble Alpes, CNRS, CEA, SPINTEC, 38000 Grenoble, France*
[2] *Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and the Barcelona Institute of Science and Technology (BIST), Bellaterra, Barcelona, Spain*
[3] *University Grenoble Alpes, CEA, IRIG-MEM, 38000 Grenoble, France*

frederic.bonell@cnrs.fr

Layered materials are a class of quantum materials with electronic properties of exceptional interest for several domains of solid-state physics. Their crystal structure with van der Waals bonding between unit layers makes it feasible to stabilize single 2D layers and to form a wide range of heterostructures without the constraint of lattice matching. In this family of materials, transition metal dichalcogenides and topological insulators hold great promise for spintronics owing to their large spin-orbit coupling and the locking between the electron spin and momentum [1]. The recent discovery of van der Waals 2D magnets has also opened exciting opportunities to explore low dimensionality magnetism, proximity phenomena in heterostructures and all-van der Waals spin devices [1]. While most research on these materials is currently performed with nanoflakes mechanically exfoliated from bulk crystals, molecular beam epitaxy is emerging as a powerful method to grow large-area 2D materials with fine tuning of the composition, control of the thickness down to the 2D limit and ability to fabricate heterostructures with sharp and clean interfaces. I will discuss the specificities and challenges of van der Waals epitaxy and review recent progress in the fabrication of van der Waals materials by this technique, including topological insulators [2], transition metal dichalcogenides [3,4] and 2D magnets [5-7]. I will then illustrate the potential of these materials for spintronics with examples of heterostructures in which spin-charge interconversion is implemented, leading to large spin-orbit torques and current-driven magnetization switching [8,9].

References

[1] R. Galceran et al., APL Mater. 9, 100901 (2021)
[2] Bonell et al., Cryst. Grow. Des. 17, 4655 (2017)
[3] Bonell et al., 2D Mater. 9, 015015 (2021)
[4] R. Salazar et al., Nano Lett. 22, 9260 (2022)
[5] E. Velez et al., ACS Appl. Elec. Mater. 4, 259 (2022)
[6] M. Ribeiro et al., npj 2D Mater. Appl. 6, 10 (2022)
[7] Q. Guillet et al., Phys. Rev. Mater. 7, 054005 (2023)
[8] Bonell et al., Nano Lett. 20, 5893 (2020)
[9] T. Guillet et al., Nano Lett. 24, 822 (2024)

Manipulation of magnetic skyrmions for memory and logic applications

O. Boulle

Spintec, Grenoble, France

Contact@E-mail (Century Gothic 10)

Skyrmions are topological spin textures which hold great promise as nanoscale bits of information in memory and logic devices [1]. The recent demonstration of room temperature skyrmions [2,3] as well as their current induced motion in industry compatible sputtered thin films have lifted important roadblocks toward the realization of skyrmion based devices. However, their development is impeded by a too low current induced velocity (about 100 m/s) [4] as well as the skyrmion Hall effect, namely a motion transverse to the current direction due to their topological charge which can lead to their annihilation in tracks. Antiferromagnetic (AF) skyrmions allow these limitations to be lifted owing to their vanishing magnetization and net zero topological charge, promising fast dynamics without skyrmion Hall effect. In this presentation, I will address the stabilization and current induced manipulation of skyrmion in compensated synthetic antiferromagnetic (SAF). I will first show that skyrmions can be stabilized at room temperature in Pt/Co/Ru based compensated SAFs and nucleated using local current injection or ultrafast laser pulses [5]. I will then show that SAF skyrmions can be moved by current at velocities over 900 m/s without skyrmion Hall effect. Micromagnetic simulations and analytical models using experimental parameters show that this enhanced skyrmion velocity can be explained by the compensation of the topological charges as well as an enhanced spin orbit torque in the synthetic antiferromagnet. I will conclude the talk with recent results on the electrical nucleation and detection of a skyrmion in magnetic tunnel junctions, which is another important milestone for skyrmion based devices [6]. Our results open important paths toward the realization of logic and memory devices based on the fast manipulation of skyrmions.

References

[1] A. Fert, V. Cros, and J. Sampaio, Nat. Nanotechnol. 8, 152 (2013).
[2] O. Boulle, Nature Nano., 11, 449 (2016)
[3] A. Fert, N. Reyren and V. Cros, Nat Rev Mater 2, 17031 (2017).
[4] R. Juge et al., Phys. Rev. Appl. 12, 044007 (2019)
[5] R. Juge et al., Nature Communication, 13, 4807 (2022)
[6] J. Urrestarazu Larranaga et al., arXiv:2308.00445 (2023)

High-Field NMR with Solid-state Quantum Sensors

Dr. Jorge Casanova

Department of Physical Chemistry, University of the Basque Country, UPV/EHU, Bilbao, Spain.

jcasanovamar@gmail.com

Solid-state quantum sensors based on nitrogen vacancy centres have successfully achieved NMR detection of chemicals located in the diamond surface. Transitioning to high magnetic field scenarios would facilitate the detection of quantities encoding structural information such as chemical shifts and J-couplings.

In this presentation, I will delve into the challenges and opportunities related to high-field NMR at the microscale and examine recently proposed techniques, namely AERIS [1] and J-INSECT [2], designed to achieve high-resolution NMR detection of distinct energy shifts at elevated magnetic fields.

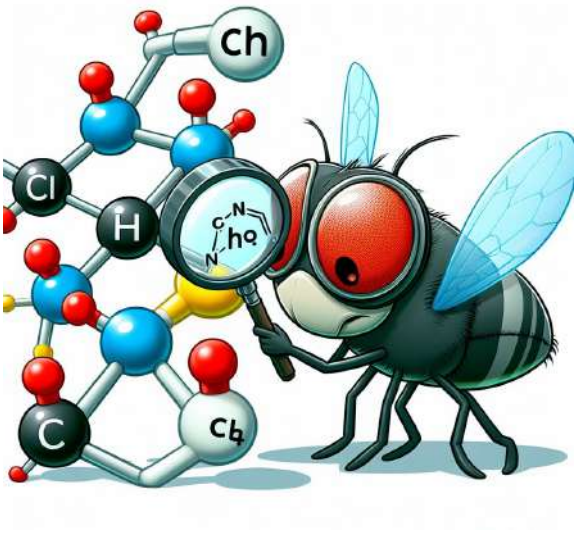


Figure 1: J-INSECT "agent" investigating a molecular compound.

References

[1] C. Munuera-Javaloy, A. Tobalina, and J. Casanova. *High-Resolution NMR Spectroscopy at Large Fields with Nitrogen Vacancy Centers,* Phys. Rev. Lett. 130, 133603 (2023).

[2] P. Alsina-Bolívar, A. Biteri-Uribarren, C. Munuera-Javaloy, and J. Casanova. J-coupling NMR Spectroscopy with Nitrogen Vacancy Centers at High Fields. arXiv: 2311.11880.

Quantum Sensors in Diamond: Technology and Applications

Prof. Christian Degen
Co-Authors (Century Gothic 10)

Department of Physics and Quantum Center, ETH Zurich, Zurich, Switzerland (Century Gothic 10)

degenc@ethz.ch (Century Gothic 10)

Abstract (Century Gothic 11)

Diamond has emerged as a unique material for a variety of applications, both because it is very robust and because it has defects with interesting properties. One of these defects, the nitrogen-vacancy (NV) center, shows quantum behavior up to above room temperature. Our group is exploring diamond as a platform for realizing nanoscale sensors with exquisite sensitivities and new capabilities.

In this talk, I will introduce the concept of diamond-based quantum sensors [1]. I will discuss the fabrication of diamond probes and their integration into plug-and-play sensor chips. I will also discuss current challenges in scanning probe microscopy (SPM) system integration [2]. The talk will conclude with illustrative examples of applications in metrology of magnetism and currents at the nanometer scale.

Figures

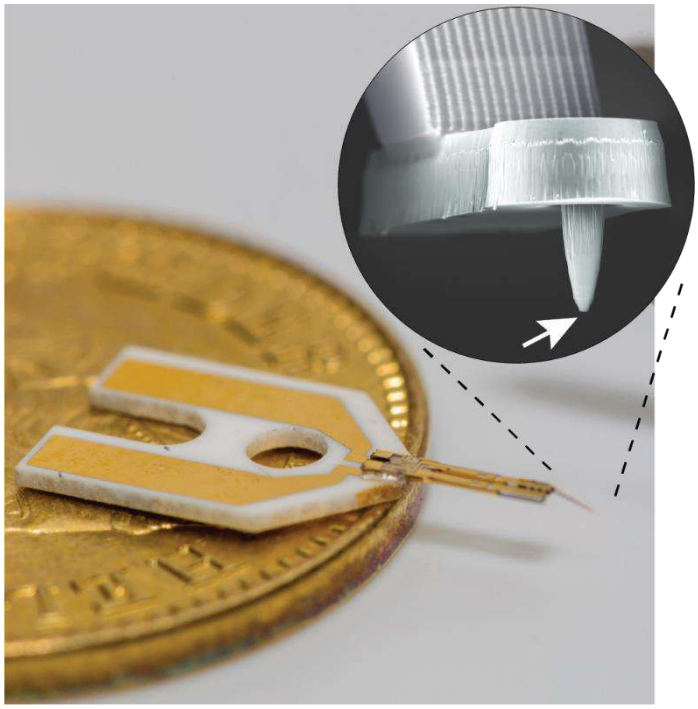


Figure 1: Commercial quantum scanning probe. Inset shows monolithic diamond tip with a single NV emitter at the tip apex (arrow).

References

[1] C. Degen, F. Reinhard, and P. Cappellaro, Quantum sensing, Rev. Mod. Phys. 89, 035002 (2017); doi:10.1103/RevModPhys.89.035002

[2] QZabre Ltd, Regina-Kägi-Strasse 11, 8050 Zurich, Switzerland; https://qzabre.com

Non-Hermitian topology in multi-terminal devices: from fundamental to applications

J. Dufouleur[1]
K. Ochkan,[1] V. Könye,[1] R. Chaturvedi,[1] A. Chyzhykova,[1] L. Veyrat,[1] R. Giraud,[1,2] D. Mailly,[3] A. Cavanna,[3] U. Gennser,[3] E. M. Hankiewicz,[4] B. Büchner,[1,5] J. van den Brink,[1,5] J. Budich,[5] I. C. Fulga[1]

[1] *IFW Leibniz Institute (Dresden, Germany)*
[2] *INAC-Spintec (Grenoble, France)*
[3] *C2N CNRS, Paris-Saclay university (Palaiseau, France)*
[4] *Institute for Theoretical Physics and Astrophysics, JMU (Würzburg, Germany)*
[5] *Technical University Dresden (Germany)*

j.dufouleur@ifw-dresden.de

Quantum devices characterized by non-Hermitian topology are predicted to show very robust and potentially useful properties, but realizing them has remained a daunting experimental task. This is because non-Hermiticity is often associated with gain and loss, which would require precise tailoring to produce the signatures of nontrivial topology.
Instead of gain/loss, we use the nonreciprocity of quantum Hall edge states to directly observe the non-Hermitian topology of a multi-terminal ring [1]. Our transport measurements evidence a robust, non-Hermitian skin effect: currents and voltages show an exponential profile, which persists also across Hall plateau transitions away from the regime of maximum non-reciprocity. Our observation of non-Hermitian topology in a quantum device introduces a scalable experimental approach to construct and investigate generic non-Hermitian systems.
As an example, we transpose the concepts introduced for the QHE device to classical electronic systems where the non-Hermitian topology allow us to build a non-Hermitian ohmmeter [2].

References

[1] Ochkan, K. *et al.*, Nat. Phys. (2024). https://doi.org/10.1038/s41567-023-02337-4
[2] V. Könye *et al.*, arXiv:2308.11367

Figures

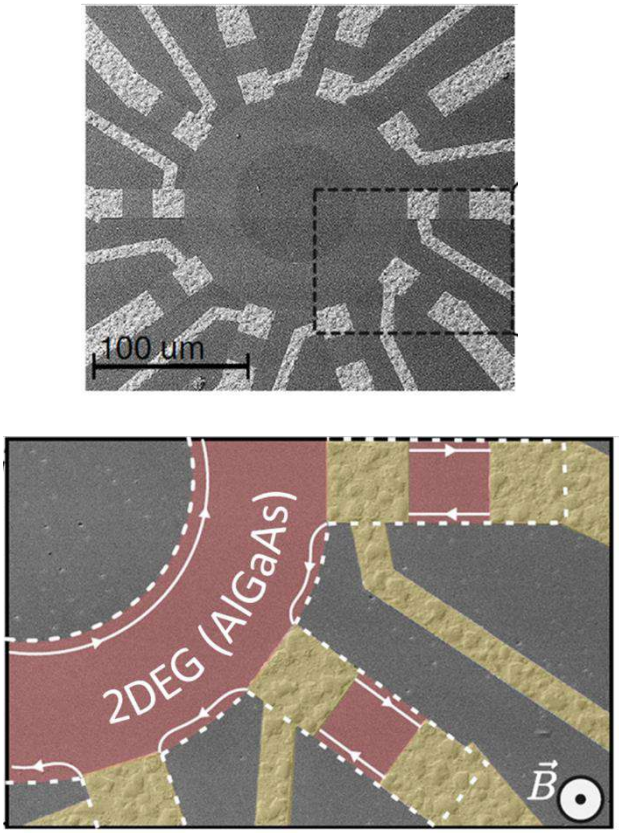


Figure 1: Scanning electron microscopy (SEM) image of the AlGaAs 2DEG device with a zoomed-in false-colour SEM image. The white lines indicate the edge quantum Hall states occurring in the presence of a perpendicular magnetic field at filling factor v = 1, whereas the white arrows indicate the direction of propagation of electrons. The 2DEG and ohmic contacts are highlighted in red and yellow, respectively. The white dashed lines show the boundaries of the 2DEG.

Amorphous topological metals

Speaker: Adolfo G. Grushin
Co-authors: Justin Schirmann, Selma Franca, Benjamin Wieder

Néel institute, CNRS, Grenoble, France
adolfo.grushin@neel.cnrs.fr

Abstract: Topological metals display physical phenomena different to conventional metals. These include Fermi-arc surface states, approximately quantised photoconductivity and negative magnetoresistance. However, all known topological metallic solids are crystalline. What is a meaningful definition of topological metals in non-crystalline solids? Do their Weyl nodes come in pairs? Can we enforce topology in non-crystalline metals? In this talk I will discuss these questions by proposing tools to define topological metals without translational symmetry. I will discuss some possible material realisations and physical principles to enforce them.

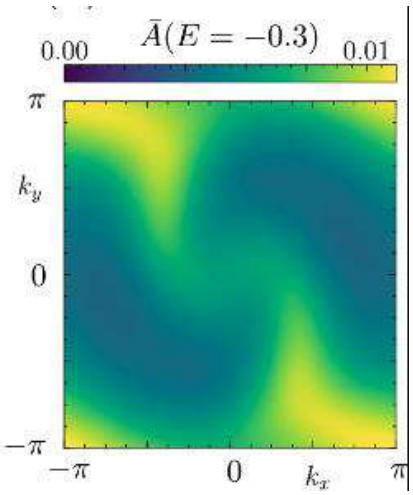


Figure 1: Spectral function of an amorphous topological metal

References

[1] S. Franca and A. G. Grushin **2304.01983**
[2] S. Franca and A. G. Grushin **2306.17117 Phys. Rev. Matt. (in press 2024)**
[3] J. Schirmann, S. Franca, B. Wieder, A. G. Grushin (in preparation 2024)
[4] J. Schirmann, S. Franca, F. Flicker, A. G. Grushin Phys. Rev. Lett. (in press 2024) **arXiv:2307.11054**

Figures

Evidence of helical states in bismuth

S. Guéron,
A. Bernard, M. Bard, Y. Peng, A. Kasumov, R. Deblock, M. Ferrier, F. Fortuna, V. T. Volkov, Yu. A. Kasumov, Y. Oreg, F. von Oppen, H. Bouchiat, S. Guéron

Université Paris Saclay and CNRS, Laboratoire de Physique des Solides, 91405 Orsay

Sophie.gueron@universite-paris-saclay.fr

Bismuth is possibly the first discovered Second-Order Topological Insulator, a relatively new state of matter characterized by topologically protected helical states, i.e counter-propagating 1D states whose spin orientation is locked to the propagation direction. Such states open many possibilities, from dissipationless charge and spin transport to new avenues for quantum computing. Connecting bismuth nanowires to superconducting contacts has revealed the ballistic character of the Andreev Bound States, suggesting topological protection [1,2]. We have also found the tell-tale high frequency signature of protected Andreev level crossings, a peaked absorption at phase pi [3]. More recently, through the statistical distribution of the switching current of a bismuth nanoring Josephson junction, we have determined that pairs relax relatively slowly compared to quasiparticles, an indication that helical states with opposite helicity are physically separated, a key feature of Second-Order Topological Insulators [4]. Finally, I will address the role played by helical states in generating non-reciprocal effects in bismuth, in the form of bilinear magnetoresistance in the normal state and Josephson diode in the superconducting state [5].

References

[1] A. Murani et al, Nature Communications 8, 15941 (2017).
[2] F. Schindler et al, Nature Physics 14, 918–924 (2018).
[3] A. Murani et al, Phys. Rev. Lett. 122, 076802 (2019).
[4] A. Bernard, Y. Peng et al, Nature Physics 19, 358 (2023).
[5] M. Bard, H. Bouchiat et al, in preparation.

Phases of quantum information on a noisy quantum processor

Matteo Ippoliti
J. C. Hoke, V. Khemani *et al* [Google Quantum AI]

Department of Physics, UT Austin
2515 Speedway, Austin, TX 78712, USA

ippoliti@utexas.edu

Measurement plays a peculiar role in quantum mechanics: beyond revealing properties of a system, it can also affect its state in nontrivial ways and give rise to striking new phenomena. Among such phenomena are novel phases defined by the structure of quantum correlations (such as entanglement) in many-body systems away from equilibrium. I will discuss the experimental realization of these measurement-induced phases of quantum information on Google Quantum AI's superconducting processor [1]. By using a hybrid quantum-classical order parameter that correlates experimental data with classical simulation, we obtain signatures of distinct entanglement phases on up to 70 qubits; one of these phases exhibits emergent quantum teleportation, where the non-locality of measurements enables correlations beyond the standard causal "light cone" of unitary dynamics. Furthermore, we show that noise, an inevitable limitation of near-term quantum hardware, can in fact be used to our advantage as an independent probe of the phases.

References

[1] J. C. Hoke, M. Ippoliti, V. Khemani, and Google Quantum AI, Nature 622 (2023), 481-486

Figures

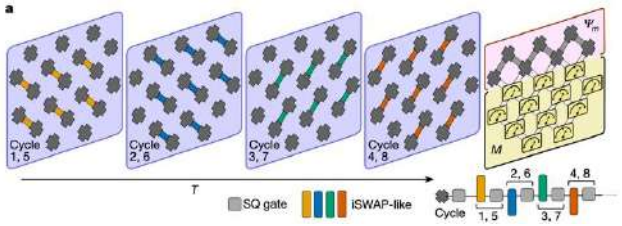


Figure 1: Quantum circuit implemented on Google Quantum AI's superconducting processor.

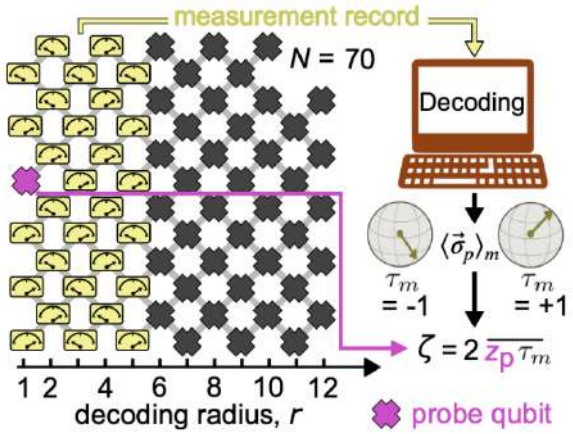


Figure 2: Quantum-classical order parameter to detect measurement-induced entanglement on a 70-qubit array.

The Center for Quantum Technology and Applications: activities and use cases

Karl Jansen

DESY, Platanenallee 6, 15738 Zeuthen, Germany

Contact: karl.jansen@desy.de

Abstract

The Center for Quantum Technology and Applications (CQTA) in Zeuthen is a science-led center, which will enable researchers from universities, industry, and other research institutions to develop new applications for complex quantum systems, or to develop optimization algorithms for current and future quantum computers. In the presentation the activities of the center in the areas of theoretical and experimental physics [1], classical optimization problems as well as quantum art will be discussed.

References

[1] Alberto Di Meglio, Karl Jansen, Ivano Tavernelli et.al., Quantum Computing for High Energy Physics: State of the Art and Challenges. Summary of the QC4HEP Working Group, arxiv:2307:03236.

Figures

Figure 1: Quantum computing offers the fascinating opportunity to solve problems which are extremely hard or even impossible to address on conventional computers. It opens up unimagined possibilities and may speed up research and development in many other fields.

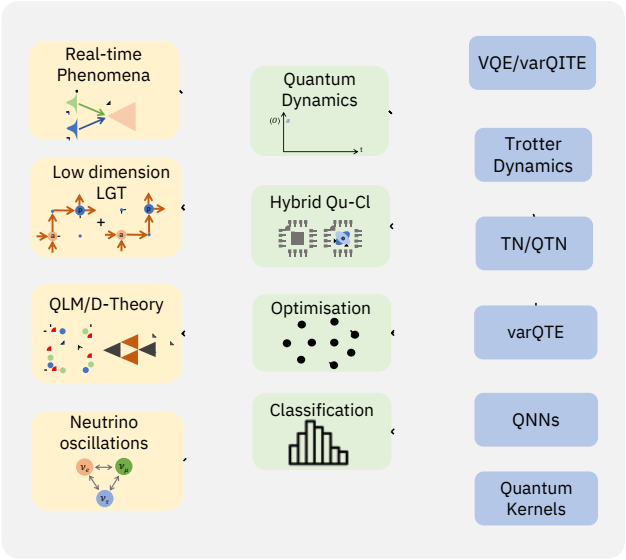


Figure 2: Proposed theoretical physical model systems (orange) with corresponding approaches (green) and quantum algorithms (blue), taken from [1].

Testing and verifying quantum computations and simulations

Barbara Kraus

Technical University of Munich, Germany

Barbara.Kraus@ph.tum.de

I will discuss here several protocols designed for the verification and the characterization of quantum devices. They range from protocols which were designed to verify the output of a quantum cloud computer using only classical means to practical testing and verification protocols of quantum devices utilized for quantum computation and simulation.

Towards a topology-based compact neuromorphic component

Marie-Blandine Martin[1]
Tristan da Câmara Santa Clara Gomes[1], Yanis Sassi[1], Sachin Krishnia[1], Dedalo Sanz-Hernandez[1], Tanvi Bhatnagar-Schöffmann[2], Dafiné Ravelosona[2], Damien Querlioz[2], Liza Herrera-Diez[2], Bruno Dlubak[1], Pierre Seneor[1], Vincent Cros[1], Julie Grollier[1], Nicolas Reyren[1]

[1]*Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay, 1 Avenue Augustin Fresnel, 91120 Palaiseau, France*
[2]*Centre de Nanosciences et de Nanotechnologies, CNRS, Université Paris-Saclay, 91120 Palaiseau, France*

Marie-blandine.martin@cnrs-thales.fr

Thanks to their original properties, magnetic skyrmions have many promising applications, from sensors through data storage to non-conventional computing [1-3]. Among the main advantages of magnetic skyrmions are their sub-micronic size, their particle-like behavior, their stability and non-volatility at room temperature and the low energy requirement for their motion. It has been shown, most often separately, that magnetic skyrmions can be experimentally nucleated [4-7], moved [4,7], annihilated [6] and detected electrically using Anomalous Hall effect [8] in metallic multilayers.
In this talk, we will propose a neuromorphic device design using full-electrical manipulation and detection of skyrmions to perform basic operations required for neuromorphic computing [9]. Indeed, the operating principle of an artificial neuromorphic component is to work by performing a simple operation: it multiplies various input signals with corresponding synaptic weights and sums them up [10]. Mathematically, this can be represented as $y = \Sigma(w_i x_i)$, where x_i are the inputs and w_i are the synaptic weights. All the building blocks necessary to achieve the demonstration of a weighted sum of skyrmions will be presented, from the nucleation and motion of a controlled number of magnetic skyrmions in multilayer tracks using electrical current pulse parameters to the electrical detection of a sum of skyrmions through anomalous hall effect.
The demonstrated skyrmion-based neuromorphic device paves the way to skyrmionic low-energy devices contributing to a global reduction of the environmental impact of AI applications.

References

[1] Fert, A., Reyren, N. and Cros, V. Nat Rev Mater 2 (2017) 17031
[2] Bourianoff G. et al, AIP Adv. 8 (2018) 055602
[3] Fert, A., Reyren, N. and Cros, V. Nat Rev Mater 2 (2017) 17031,
[4] Bourianoff G. et al, AIP Adv. 8 (2018) 055602
[5] K.M. Song et al, Nature Electronics 3.3 (2020) 148
[6] Legrand, W. et al. Nano Lett. 17 (2017) 2703
[7] Hrabec, A. et al. Nat. Commun. 8 (2017) 15765
[8] Woo, S. et al., Nat. Electron. 1(2018) 288
[9] Da Camara Santa Clara Gomes, T et al arXiv preprint arXiv:2310.16909
[10] Grollier, J et al Nat. Electron. 3 (2020) 360

Quantum geometry and material properties

Raquel Queiroz

Department of Physics, Columbia University, New York, NY 10027, USA

Raquel.queiroz@columbia.edu

I will discuss what quantum geometry is and how it is the natural language to describe various material properties of insulators, such as their effective mass, orbital magnetic moment and dielectric constant. This considerations make it possible to find materials which are suited for various technologies.

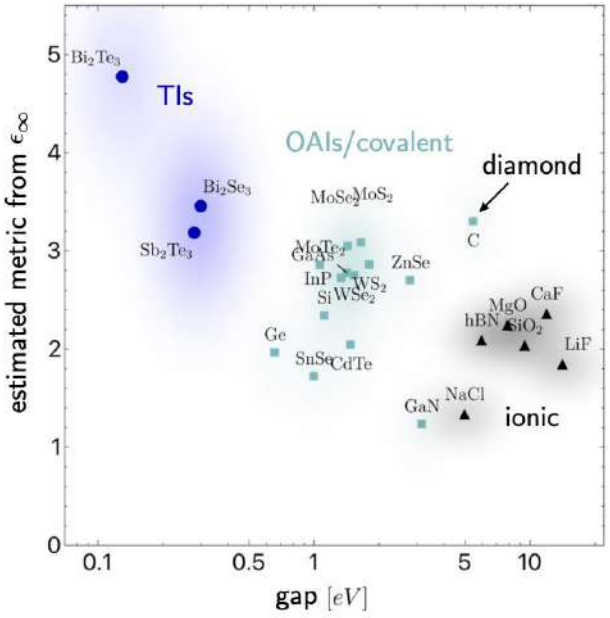


Figure 1: Adapted from Ref. [1]. Estimate of quantum metric (real part of quantum geometry) from the experimental and theoretical values of bulk dielectric constant.

References

[1] 1.Komissarov, I., Holder, T. & Queiroz, R. The quantum geometric origin of capacitance in insulators. *arXiv* (2023) doi:10.48550/arxiv.2306.08035.

[2] 1.Verma, N. & Queiroz, R. Instantaneous Response and Quantum Geometry of Insulators. *arXiv* (2024). doi: 10.48550/arxiv.2306.08035

Cuprate Twistronics for a New Generation of Macroscopic Quantum Hardwares

Nicola Poccia

Department of Physics, University of Naples Federico II and Leibniz Institute for Solid Materials Research Dresden.

n.poccia@ifw-dresden.de
nicola.poccia@unina.it

Recent technological advancements have enabled the preservation of near-perfect superconductivity and lattice structure in isolated, atomically thin $Bi_2Sr_2CuCa_2O_{8+\delta}$ (Bi-2212) crystals, facilitating the development of Bi-2212-based junctions [1,2]. These advancements focus on controlling the diffusion of oxygen interstitials, a key factor causing disorder in Bi-2212 cuprates. While intrinsic local lattice distortions in pristine cuprates [3] may contribute minimally without affecting the d-wave nature of the dominant order parameter, lattice distortions due to oxygen interstitials diffusion above 200 K [4,5] are detrimental. To counter this, a cryogenic stacking protocol has been developed, freezing oxygen interstitial motion at temperatures well below 200 K and rapidly establishing the interface in an ultra-low moisture environment [6-8]. This method has led to the creation of artificial intrinsic Josephson junctions, which show a strong dependence of Josephson energy on the twist angle, exhibiting unique properties at a 45° twist [6-8]. Notably, these junctions display fractional Shapiro steps and Fraunhofer patterns, indicating two degenerate Josephson ground states with time-reversal symmetry (TRS). The ability to control the junction current bias sequence to selectively break TRS allows the junction to enter either ground state. This discovery has prompted the proposal of a novel capacitively shunted qubit, termed 'flowermon,' characterized by its d-wave order parameter that offers inherent protection against charge-noise-induced relaxation and quasiparticle-induced dissipation [9]. The flowermon signifies a step towards high-coherence, hybrid superconducting quantum devices using unconventional superconductors. To fabricate complex circuits like those needed for the flowermon, a new technique involving cryogenic dry transfer of printable circuits embedded in a silicon nitride membrane has been developed [10]. This technique separates the circuit fabrication process, which involves chemical and physical stresses, from the creation of thin superconducting structures, thereby providing electrical contacts in a single step and protecting the superconducting surface from environmental damage.

References

[1] S. Y. F. Zhao, et al., Physical Review Letters 122, 247001 (2019).
[2] N. Poccia, et al., Physical Review Materials 4, 114007 (2020).
[3] N. Poccia, et al. Proceedings of the National Academy of Sciences 109, 15685-15690 (2012).
[4] N. Poccia, et al., Nature Materials 10, 733 (2011).
[5] M. Fratini, et al. Nature 466, 841 (2010).
[6] S. Y. F. Zhao, et al., Science 382, 1422 (2023).
[7] Y. Lee, et al., Advanced Materials 35, 2209135 (2023).
[8] M. Martini, et al., Materials Today 67, 106 (2023).
[9] V. Brosco, et al., Physical Review Letters 132, 017003 (2024).
[10] C. N. Saggau, et al., ACS Applied Materials & Interfaces 15, 51558-51564 (2023).

Universal moiré nematic phase in twisted graphene

Carmen Rubio Verdú
Simon Turkel[1], Yuan Song[1], Lennart Klebl[2], Rhine Samajdar[3], Mathias S. Scheurer[3,4], Jörn F. Venderbos[5,6], Kenji Watanabe[7], Takashi Taniguchi[8], Héctor Ochoa[1], Lede Xian[9,10], Dante M. Kennes[2,9], Rafael M. Fernandes[11], Ángel Rubio[9,12,13], Abhay N. Pasupathy[1]

[1]*Department of Physics, Columbia University, USA.* [2]*Institute for Theory of Statistical Physics, RWTH Aachen University, Germany.* [3]*Department of Physics, Harvard University, USA* [4]*Institute for Theoretical Physics, University of Innsbruck, Austria.* [5]*Department of Physics, Drexel University, USA.* [6]*Department of Materials Science and Engineering, Drexel University, USA.* [7]*Research Center for Functional Materials, National Institute for Materials Science, Japan.* [8]*International Center for Materials Nanoarchitectonics, Tsukuba, Japan.* [9]*Max Planck Institute for the Structure and Dynamics of Matter, Germany.* [10]*Songshan Lake Materials Laboratory, China.* [11]*School of Physics and Astronomy, University of Minnesota, USA.* [12]*Center for Computational Quantum Physics (CCQ), The Flatiron Institute, USA.* [13]*Nano-Bio Spectroscopy Group, Departamento de Física de Materiales, UPV/EHU, Spain*

Carmen.Rubio@icfo.eu

Graphene moiré superlattices display electronic flat bands. At integer fillings of these flat bands, insulating states due to strong electron–electron interactions are generally observed. However, the presence of other correlation-driven phases in twisted graphitic systems at non-integer fillings is unclear. We report [1] the existence of three-fold rotational (C3) symmetry breaking in twisted double bilayer graphene. Using spectroscopic imaging over large and uniform areas to characterize the direction and degree of C3 symmetry breaking, we find it to be prominent only at energies corresponding to the flat bands and nearly absent in the remote bands. We demonstrate that the magnitude of the rotational symmetry breaking does not depend on the degree of the heterostrain or the displacement field, being instead a manifestation of an interaction-driven electronic nematic phase. We show that the nematic phase is a primary order that arises from the normal metal state over a wide range of doping away from charge neutrality. Our modelling suggests that the nematic instability is not associated with the local scale of the graphene lattice, but is an emergent phenomenon at the scale of the moiré lattice. This suggest that nematic instabilities are common in moiré systems and may be universal elements of their phase diagrams.

References

[1] Rubio-Verdú et al., 'Moiré nematic phase in twisted double bilayer graphene', Nature Physics 18, 196 (2022)

Figures

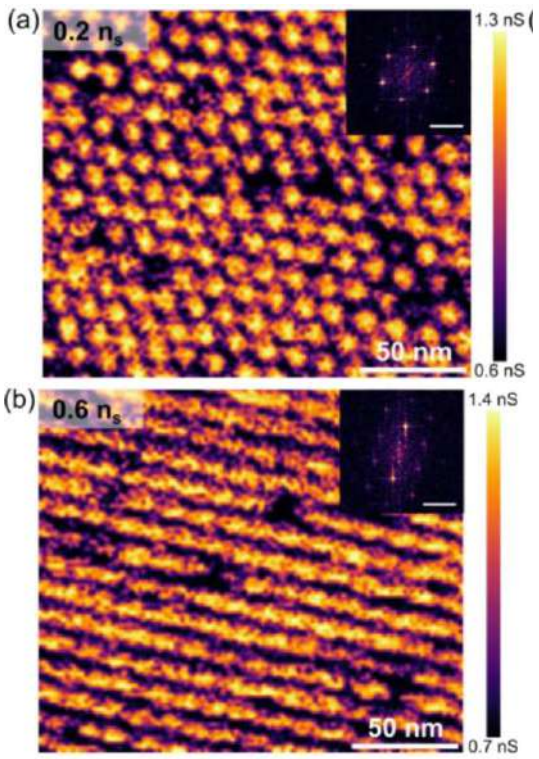


Figure 1: (a), (b), dI/dV maps at the energy of the VFB, close to charge neutrality (a) and around half-filling of the CFB (b). The insets show the fast Fourier transform of each LDOS map.

Epitaxially engineered quantum materials for quantum technologies: interfacing topology, magnetism, and superconductivity

Nitin Samarth

Dept. of Physics and Dept. of Materials Science & Engineering, Penn State University, University Park, PA 16802, USA

nsamarth@psu.edu

Quantum materials that interface magnetism, topology, and superconductivity are attractive for emerging quantum information technologies. We provide an overview of the opportunities presented by the epitaxial growth of diverse quantum materials using molecular beam epitaxy (MBE) and chemical vapor deposition (CVD). We discuss MBE-grown Dirac semimetal heterostructures [1-3] and ferromagnetic topological insulators interfaced with ferromagnetism [4], motivated by the effects of broken time-reversal symmetry on transport in topological states. We then show how epitaxially engineered heterostructures can lead to emergent superconductivity that coexists with topological order and ferromagnetism [5]. Finally, we investigate superconductivity in CVD-grown doped diamond films for potential applications in quantum technologies [6]. Supported by the Penn State 2DCC-MIP (NSF DMR-2039351), Penn State MRSEC (NSF DMR-2011839), and Q-NEXT, a DOE National Quantum Information Science Research Center.

References

[1] Y. Ou *et al.*, *Nat. Comm.* **13**, 2972 (2022).
[2] R. Xiao *et al.*, *Phys. Rev. Mater.* **6**, 024203 (2022).
[3] A. Mitra *et al.*, *Phys. Rev. Mater.* **7**, 094201 (2023).
[4] G. M. Ferguson *et al.*, *Nat. Mater.* **22**, 1100 (2023).
[5] H. Yi *et al.*, *Science* **383**, 634 (2024).
[6] J. Dwivedi *et al.*, in preparation (2024).

Figures

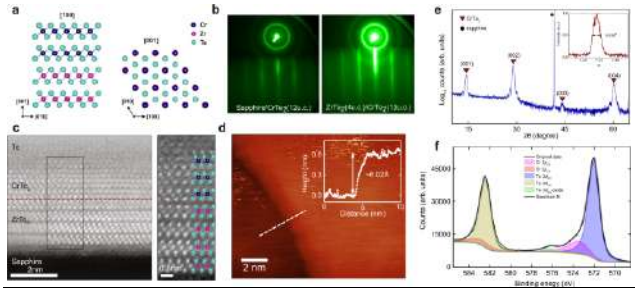


Figure 1: Example of the MBE growth and characterization of a hybrid Dirac semimetal ($ZrTe_2$)/2D ferromagnet ($CrTe_2$) heterostructure. The panels show (a) schematic crystal structure, (b) RHEED, (c) XRD, (d) TEM, (e) scanning tunnelling topography, and (f) x-ray photoelectron spectroscopy. Figure reprinted from Ref. [1].

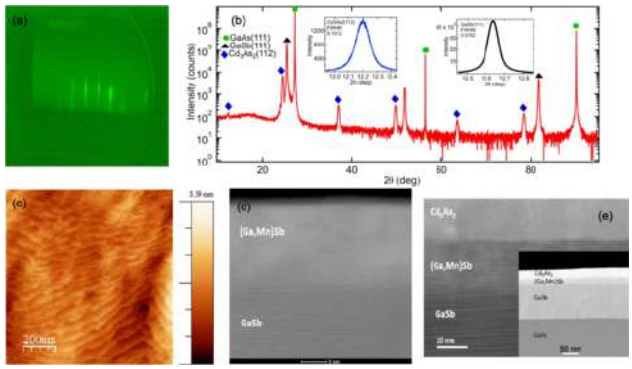


Figure 2: Example of the MBE growth and extensive characterization of a hybrid Dirac semimetal/ferromagnetic semiconductor heterostructure aimed at breaking time-reversal symmetry. The panels show (a) reflection high energy electron diffraction (RHEED), (b) x-ray diffraction (XRD), (c) atomic force microscopy (AFM), and (d), (e) transmission electron microscopy (TEM). Figure reprinted from Ref. [3].

Training embedding quantum kernels with quantum neural networks

Mikel Sanz
Pablo Rodríguez-Grasa

University of the Basque Country (UPV/EHU), B°Sarriena S/N, Leioa, Spain

mikel.sanz@ehu.es

Abstract

Kernel methods play a crucial role in machine learning and the Embedding Quantum Kernels (EQKs), an extension to quantum systems, have shown very promising performance. However, choosing the right embedding for EQKs is challenging. We address this by proposing a *p*-qubit Quantum Neural Network (QNN) based on data re-uploading to identify the optimal *q*-qubit EQK for a task (*p*-to-*q*). This method requires constructing the kernel matrix only once, offering improved efficiency. In particular, we focus on two cases: *n*-to-*n*, where we propose a scalable approach to train an *n*-qubit QNN, and *1*-to-*n*, demonstrating that the training of a single-qubit QNN can be leveraged to construct powerful EQKs. We will explore relevant applications in realistic scenarios such as satellite image classification and classification of neutrino flavors from IceCube.

References

[1] P. Rodriguez-Grasa, Y. Ban, & M. Sanz. Training embedding quantum kernels with data re-uploading quantum neural networks. ArXiv: 2401.04642 (2024).

[2] P. Rodriguez-Grasa, R. Farzan-Rodriguez, G. Novelli, Y. Ban, & M. Sanz. Satellite image classification with quantum neural network enhanced quantum kernels. *In preparation*.

[3] P. Rodriguez-Grasa, P. Zhelnin, G. Gatti, J. Lazar, C. A. Arguelles, & M. Sanz. Neutrino flavor classification with quantum processors. *In preparation*.

Figures

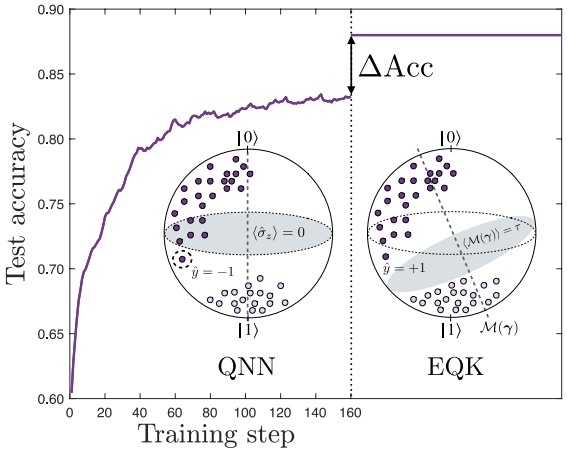


Figure 1: A schematic illustration of how a QNN can enhance classification accuracy.

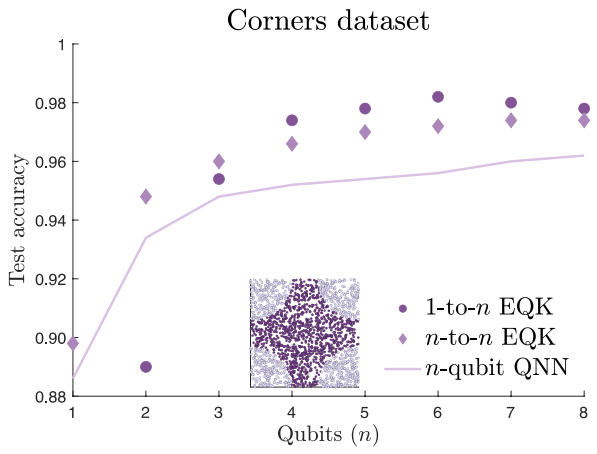


Figure 2: Test accuracies for two QNN-enhanced EQK architectures for synthetic data

Understanding of disorder for enhancement of superconducting topological gap

Javad Shabani

Center for Quantum Information Physics, New York University
726 Broadway, New York, USA

jshabani@nyu.edu

Abstract

Progress in the emergent field of topological superconductivity relies on synthesis of new material combining superconductivity, low density, and spin-orbit coupling (SOC). Theory indicates that the interface between a one-dimensional semiconductor with strong SOC and a superconductor hosts Majorana-modes with nontrivial topological properties [1]. We discuss the recent developments in epitaxial growth of Al on InAs nanowires was shown to yield a high-quality superconductor-semiconductor system with uniformly transparent interfaces. We have developed a two-dimensional (2D) surface InAs quantum wells with epitaxial superconducting Aluminum [2], yielding a planar system with exceptional structural and transport characteristics [3]. We present new qubits based on semiconductor weak links dubbed Gatemons. These qubits show great promise on this platform for realization of topological qubits where we unprecedented control over proximity effect in semiconductors using a gate voltage [4]. We discuss the role of disorder and how they could enable potential circuit applications for low power circuits, gate-based topological qubits as well as superconducting qubits for computation [5].

References

1. Alicea, Rep. Prog. Phys. 75, 076501 (2012).
2. Shabani et al., Phys. Rev. B 93, 155402 (2016).
3. W. Mayer, J. Yuan, K. Wickramasinghe, T. Nguyen, M. Dartiailh, J. Shabani, "Superconducting proximity effect in epitaxial Al-InAs heterostructures", Appl. Phys. Lett. **114**, 103104 (2019).
4. Matthieu C. Dartiailh, William Mayer, Joseph Yuan, Kaushini S. Wickramasinghe, Alex Matos-Abiague, Igor Žutić, Javad Shabani, "Phase signature of topological transition in Josephson Junctions", Phys. Rev. Lett. **126**, 036802 (2021).
5. Richardson, C., Lordi, V., Misra, S., & Shabani, J. Materials science for quantum information science and technology. MRS Bulletin, 45(6), 485-497 (2020).

Figures

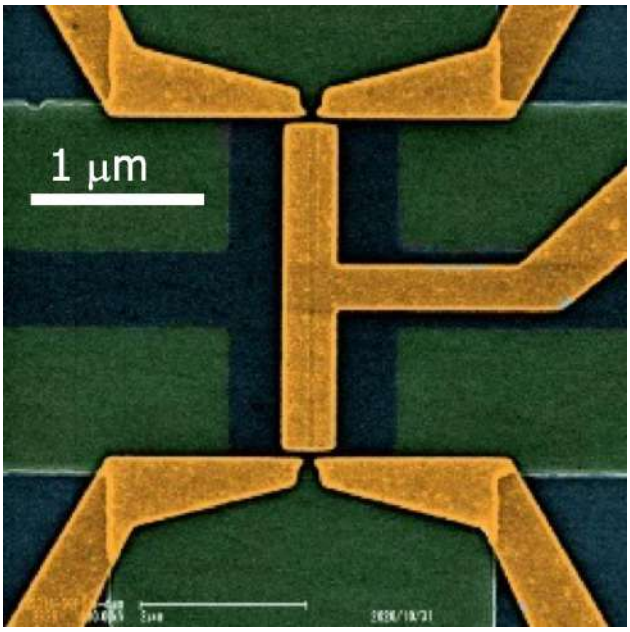


Figure 1: Planar Josephson Junctions exhibiting signatures of topological phase.

Dynamics beyond two-level approximation in transmon arrays

Matti Silveri

Nano and Molecular Systems Research Unit, University of Oulu, Pentti Kaiteran katu 1, Oulu, Finland

matti.silveri@oulu.fi

Transmons are inherently quantum multilevel systems. Being experimentally controllable with high fidelity, the higher excited states beyond the qubit subspace provide an important resource for hardware-efficient many-body quantum simulations, quantum error correction, and quantum information protocols.

With the higher levels included, a transmon array realizes the attractive Bose-Hubbard model. The dynamics of the full model has been difficult to study both numerically and analytically due to the unfavourable scaling of the dimensionality of the Hilbert space with the system size. In this work [1, 2], we first present an analytic and numerical framework for describing the effective unitary dynamics of highly excited states based on high-order degenerate perturbation theory. This allows us to describe various collective phenomena—such as bosons stacked onto a single site behaving as a single particle, edge localization, and effective longer-range interactions—in a unified, compact, and accurate manner.

Dissipation and dephasing yield a practical limiting factor for the utilization of the higher-excited states. We show in detail the primary consequences of single-transmon dissipation and dephasing to the higher-excited state dynamics [3]. We use analytical methods from perturbation theory and quantum trajectory approach together with numerical simulations. The three main non-unitary processes are many-body decoherence, many-body dissipation, and heating/cooling transitions. Of these, the many-body decoherence gives the strictest limit for observing effective unitary dynamics. Our results show that state-of-the-art transmon arrays should be ready for demonstrating coherent many-body dynamics using the higher excited states.

Furthermore, when a transmon array is in a waveguide, collective decay involving the higher-excited states yields stronger super/subradiance than with qubits [4].

Our results on the higher-excited state dynamics can help with the design of new qudit-based quantum protocols and enable transmon arrays to be used to explore additional lattice models besides the standard Bose-Hubbard one.

References

[1] O. Mansikkamäki, S. Laine, M. Silveri, Phys. Rev. B 103, L220202 (2021)

[2] O. Mansikkamäki, S. Laine, A. Piltonen, M.Silveri, PRX Quantum 3, 040314 (2022)

[3] O. Busel et al., Phys. Rev. Research 5, 023121 (2023)

[4] T. Orell et al., Phys. Rev. A 105, 063701 (2022)

Figures

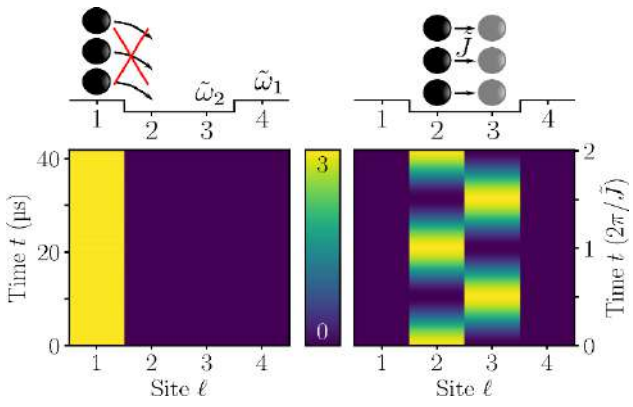


Figure 1: Schematic of boson stack localization and collective hopping in a transmon array.

Unconventional magnetism: the emergence of altermagnetism and its new variants

Jairo Sinova

Johannes Gutenberg University Mainz
Texas A&M University

sinova@uni-mainz.de

Inspired by anomalous spin transport in a peculiar compensated collinear magnet with d-wave symmetry of its spin-polarized band structure, we have developed the full delimitation and classification of collinear magnetic systems. From this, altermagnetism has emerged as a distinct and symmetry delimited new magnetic phase. Altermagnets exhibit an unconventional spin-polarized d/g/i-wave band structure in reciprocal space, originating from the local sublattice anisotropies in direct space. This gives properties unique to altermagnets (e.g., the spin-splitter effect), while also having ferromagnetic (e.g., polarized currents) and antiferromagnetic (e.g., THz spin dynamics and zero net magnetization) characteristics useful for spintronics device functionalities. I will cover the physics of their unconventional spin transport and magnetic dynamics, as well as how to possibly control them by different means.

References

[1] Libor Šmejkal, Jairo Sinova and Tomas Jungwirth, Phys. Rev. X 12, 031042 (2022).
[2] A. Chakraborty, et al. arXiv:2402.00151
[3] O. Gomonay, et. al. arXiv:2403.10218
[4] Zhou, et. al. Phys. Rev. Lett. 132, 056701 (2024).
[5] Badura, et. al. arXiv:2403.12929

Figures

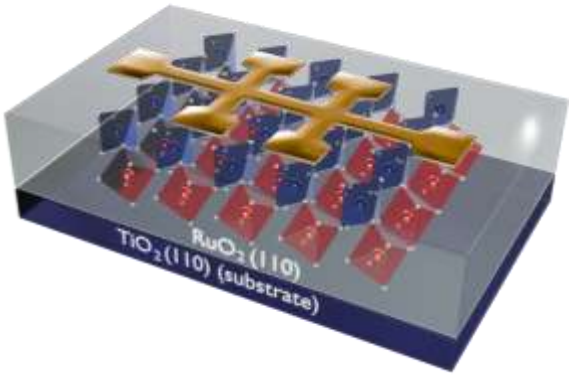


Figure 1: Hall device of altermagnetic RuO_2

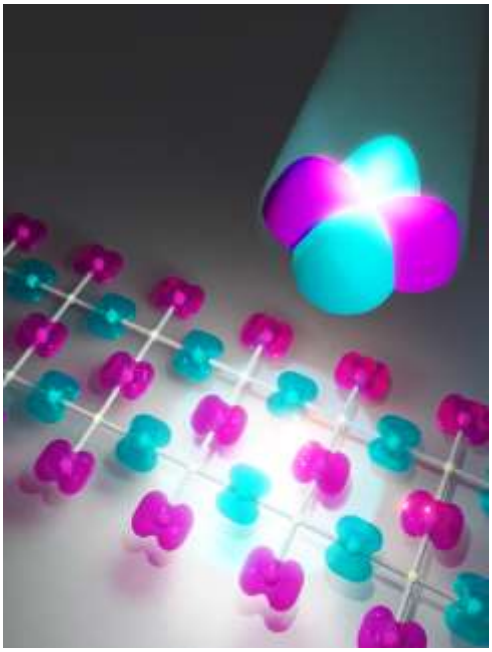


Figure 2: Crystal and momentum space representation of d-wave altermagnetism

Enhancing free space DI QKD via employing NPA hierarchy method

Magdalena Stobinska
Morteza Moradi, Maryam Afsary

Faculty of Mathematics, Informatics and Mechanics, University of Warsaw
Banacha 2, 02-097 Warsaw, Poland

mstobinska@mimuw.edu.pl

Introduction. Recently, there has been a growing focus on quantum communication due to its inherent security advantages [1,2]. However, there are still many challenges that need to be addressed, such as the distribution of entangled states over long distances, closing the Bell test loopholes, and increasing the key rate [3]. In this work, we present an innovative device-independent quantum key distribution (DI-QKD) protocol based on the distribution of near-maximally entangled multiphoton states across long distances. Our proposed strategy employs the resources available within the current landscape of integrated quantum photonic technology, including the utilization of squeezed vacuum states and photon-number-resolving detectors. Besides, this protocol enables entanglement sharing and quantum communication in free space.

Entanglement distribution. The distributed state using multi-photon bipartite entanglement is the Generalized Holland-Burnett (GHB) states, while the losses are due to quantum optical systems modelled with beam splitters [3].
Alice and Bob locally generate a photon-number-entangled two-mode squeezed vacuum state each, obtained by spontaneous parametric down-conversion (SPDC). They send their idler modes to a remote station Charlie, who holds a balanced beam splitter (BS), where the two modes interfere, and performs a photon-number-resolving (PNR) detection on the BS output modes. The state and the amount of shared entanglement are parametrized by the outcomes of Charlie's measurement. After Charlie informs the parties classically of the measurement outcome, Alice and Bob know which state they possess and may employ it for quantum applications.

Key generation and extraction. Alice and Bob interfere their signal with the coherent states. To this end, they use variable beam splitters. Alice repeatedly chooses between three coherent states as her setting while Bob uses two. In the homodyne limit, this setup allows them to perform a displacement operator on their modes. They interpret the readout obtained with photon-number-resolved (PNR) detectors as binary outcomes.

Alice and Bob apply post-selection on their key generation rounds in which they randomly and independently retain bits "0" with probability p and keep all bits "1". Then, they announce the discarded rounds through an authenticated classical channel.

Finally, they apply error correction and privacy amplification procedures. To find the key rate using the Devetak-Winter formula, they need to calculate their conditional entropy and maximize Eve's guessing probability based on the full behaviour of their statistics. This can be done by certifying quantum correlations leveraging SDP (i.e. NPA hierarchy method [4]).

References

[1] Ch. Portmann and Renato Renner, Reviews of Modern Physics 94 (2022) 025008.
[2] A. Acín et al., Physical Review Letters 98 (2007) 230501.
[3] M. Mycroft et al., Physical Review A 107 (2023) 012607.
[4] M. Navascués, S. Pironio, and A. Acín, New Journal of Physics 10 (2008) 073013.

Quantum Technolgy Initiative at CERN

Sofia Vallecorsa
Coordinator of the CERN Quantum Technology Initiative

CERN, Esplanade des Particules 1, Geneva, Switzerland

Sofia.Vallecorsa@cern.ch

Abstract (Century Gothic 11)

The CERN Quantum Technology Initiative (QTI) was launched in 2020 with the aim of investigating the role that quantum technologies could have within the High Energy Physics (HEP) research program. During this initial exploratory phase a set of results were gathered, outlining benefits, constraints and limitations of introducing technologies in different HEP domains, from advanced sensor for next generation detectors, to computing. These findings have been used to defineof a longer-term research plan, closely aligned with the technological development of quantum infrastructure and the HEP priorities.
The CERN QTI has now entered its second phase, dedicated to extending and sharing technologies uniquely available at CERN, while boosting development and adoption of quantum technologies in HEP and beyond.
This talk will summarize the experience accumulated through the past years, outlining the main QTI research results, focusing in particular the field of quantum computing, and provide a perspective of future research directions.

References

[1] Authors, Cea, M., et al. "Exploring the Phase Diagram of the quantum one-dimensional ANNNI model." arXiv preprint arXiv:2402.11022 (2024).

Figures

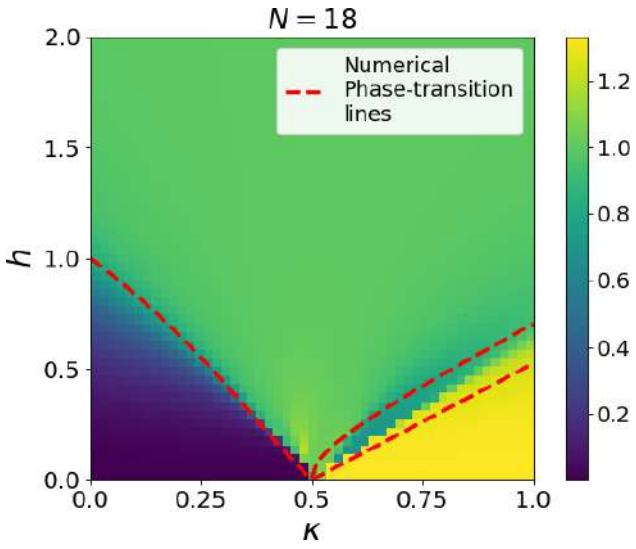


Figure 1: Unsupervised learning quantum architecture detects phase transitions of a ANNNI model [1]

Enabling technologies for large-scale cryogenic quantum computers: parametric amplifiers

Visa Vesterinen
Debopam Datta
Nils Tiencken
Robab Najafi Jabdaraghi
Janne Lehtinen
Mika Prunnila
Joonas Govenius

QTF Centre of Excellence, VTT Technical Research Centre of Finland Ltd, P. O. Box 1000, 02044 VTT, Finland

visa.vesterinen@vtt.fi

Superconducting parametric amplifiers have been widely adopted in cryogenic radio-frequency measurement laboratories worldwide. Operating near the quantum limit of added noise, these devices enable, e.g., single-shot readout of superconducting qubits. In this talk, we will present VTT's development of amplifiers based on niobium Josephson junction technology [1], along with various demonstrated applications in experimental quantum science and technology. Our primary device concept is a travelling wave parametric amplifier (TWPA, see Fig. 1) consisting of a transmission line where the centre conductor is composed of Josephson elements called Super-conducting Nonlinear Asymmetric Inductive eLements (SNAILs). The non-linearity of the Josephson inductance allows a 3-wave mixing process where the energy of a strong microwave pump tone is transferred to a weak signal. The pump is at twice the signal frequency, which is beneficial: quantum squeezing can be studied [2], and the pump power can be prevented from reaching the gain stages that follow the TWPA. A magnetic flux bias line has been fabricated on the TWPA chip. It provides homogeneous, static flux biasing for all the SNAILs and negligible fringing fields around the miniaturized device package (Fig. 2).

References

[1] Leif Grönberg et al., *Supercond. Sci. Technol.* **30**, 125016 (2017).
[2] M. R. Perelshtein, K. V. Petrovnin, V. Vesterinen, et al., *Phys. Rev. Appl.* **18**, 024063 (2022).

Figures

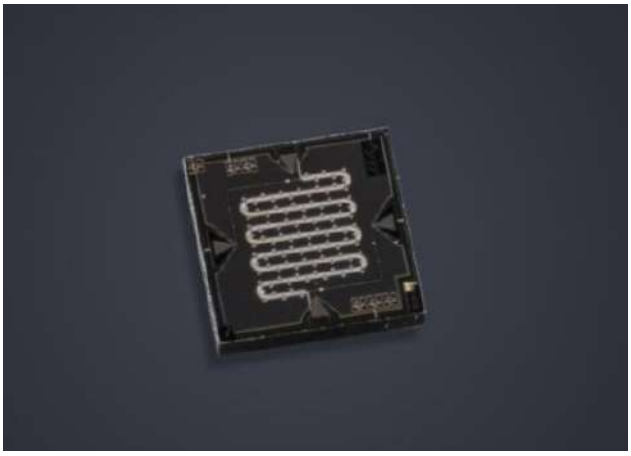


Figure 1: Photograph of a travelling wave parametric amplifier microchip. The chip size is 5 mm square.

Figure 2: Photograph of a travelling wave parametric amplifier in a connectorized microwave package. The dimensions are 17.7 mm x 21.7 mm x 13.4 mm.

Unlocking the Quantum Internet: Advancements in High-Efficiency Microwave-Optical Transduction

Silvia Zorzetti

Fermi National Accelerator Laboratory, Batavia, IL, 60510

zorzetti@fnal.gov

In the past decade, Quantum Information Science (QIS) has witnessed significant growth, driven by technological advancements that have given rise to the first generation of quantum processor units (QPUs). The next groundbreaking frontier in QIS involves the establishment of quantum networks and interconnections between these QPUs. A pivotal technology enabling the realization of distributed quantum networks is high-efficiency microwave-optical transduction, with wide-ranging applications encompassing cryptography, national security, and quantum sensing. At the DOE Fermi National Laboratory, part of our research is dedicated to developing this crucial enabling technology, employing superconducting cavities with long coherence times coupled to electro-optic non-linear materials. In this talk, we will present a comprehensive analysis and measurements that demonstrate the feasibility of achieving an impressive 50% efficiency while minimizing added noise. These findings represent a significant step forward in advancing quantum networks and sensor networks for the Quantum Internet era.

Quantum advantage via Classical Control

Yonatan Cohen[1]

[1]*Quantum Machines Inc., Tel Aviv, Israel*

yonatan@quantum-machines.co

Abstract

The past few years of quantum computers' development have demonstrated the need for classical computing to be an integral part of the road to quantum advantage. At Quantum Machines we specialized in quantum-classical integration, out of necessity, to produce controllers able to handle the most complex quantum sequences, while allowing for seamless scaling up. In this talk, we will discuss how we can offload some of the challenges from the QPU to the classical control and how such classical technology can enable quantum breakthroughs. Some of these challenges include the complexity of scaling up, pushing fidelities of gates as well as state preparation, mitigating and correcting errors, and building flexible systems for research and development. We will show how Quantum Machines has approached such control challenges and announce recent breakthroughs and technological advancements.

Exploring quantum materials with a neutral atom processor

Alexandre Dauphin

PASQAL, 7 rue Léonard de Vinci, 91300 Massy, France

Alexandre.dauphin@pasqal.com

In this talk, I will discuss two recent works exploring quantum materials that can be realized in PASQAL's quantum processing unit. I will discuss how one can study the physics of strongly correlated electrons with the help of a hybrid quantum-classical approach [1]. I will then discuss how the physics of amorphous quantum magnets can also be studied in our device [2].

References

[1] A. Michel, L. Henriet, C. Domain, A. Browaeys and T. Ayral arXiv:2312.08065 (2023)

[2] S. Julià-Farré, J. Vovrosh and A. Dauphin, arXiv:2402.02852 (2024)

ADR based sub-Kelvin cryostats for applied quantum technologies

Pau Jorba[1]
Felix Rucker[1], Steffen Säubert[1], Alexander Regnat[1], Jan Spallek[1], and Christian Pfleiderer[2]

1 kiutra GmbH, D-81369 Munich, Germany
2 Physics Department, Technical University of Munich, D-85748 Garching, Germany

pau.jorba@kiutra.com

In view of the increasing demand for the cooling of quantum electronic devices, the development of scalable cooling solutions providing low temperatures independent of rare helium-3 will be mandatory for the adoption and commercial use of next-generation quantum technologies. We present novel cryostats[1] specifically developed for the characterization and operation of quantum devices at sub-Kelvin temperatures, based on adiabatic demagnetization refrigeration (ADR). We describe how continuous sub-Kelvin cooling and wide-range temperature control can be achieved by combining multiple ADR units and mechanical thermal switches. We also present a novel sample loader mechanism[2] that allows cooling samples from room temperature to below 100 mK in less than 3 hours, as shown in Figure 1. Finally, we show how these novel tools can be used to study low-temperature characteristics of, e.g., superconducting films and resonators (Figure 2).

References

[1] Regnat et al. (2018) Cryogen-free cooling apparatus (EP 3163222). European Patent Office.
[2] Spallek et al. (2022) System and method for inserting a sample into a chamber (EP 3632560). European Patent Office.
[3] D. Zoepfl, et. al. | AIP Advances 7 | 2017 | 10.1063/1.4992070

Figures

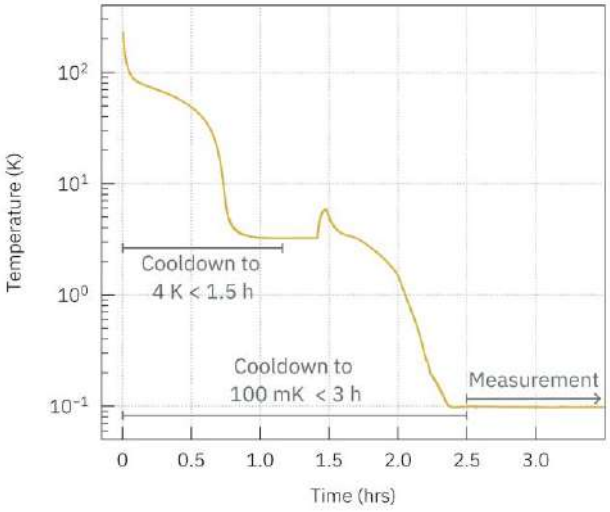


Figure 1: Sample cooldown curve from room temperature to 100 mK in less than 3 hours.

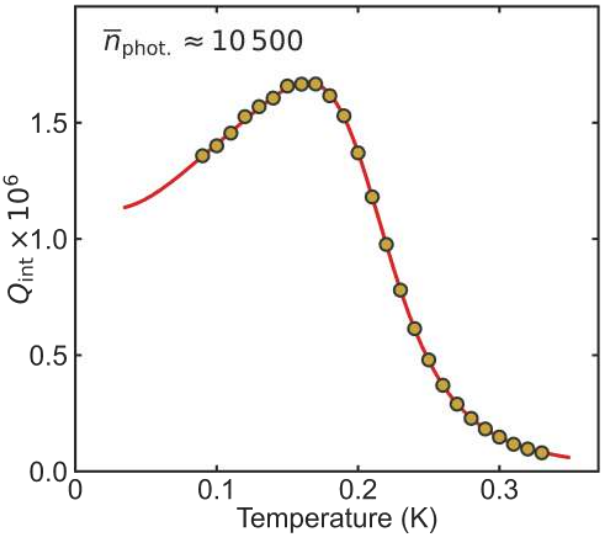


Figure 2: Temperature dependence of the internal Quality factor of an aluminium-based superconducting resonators at ~ 10 500 photon counts. The red line is a fit to a combined TLS + surface impedance model according to Ref. [3].

Integrated and Scalable Quantum Control

Yemliha Bilal Kalyoncu

Qblox BV, Delfttechpark 22, 2628 XH. Delft, The Netherlands

bilal@qblox.com)

Realizing intermediate-scale quantum computers and fault-tolerant quantum computers requires controlling 1000s of qubits. For this purpose, Qblox has developed a highly distributed control architecture, called the Cluster, where fully-integrated modules are incorporated in a massively scalable fashion. The Cluster modules are based on multiple cores of Q1 processors based on FPGAs and RF-SoCs that in real-time generate and sequence pulses, their parameters and measurement operations [1].

We here present a new level of scalability that paves the way for quantum computers with practical applications. The Qblox Cluster can control and readout up to 60 superconducting qubits in a 4U 19" rack with frequency multiplexing and calibration-free MW channels. Real-time IIR and FIR predistortion filters are further added to battle linear distortions like in-cable reflections, on-chip charging effects and the skin effect [2,3]. This enables back-to-back operations in arbitrary control flows (feedback and feedforward), which are not possible with in-software precompiled waveform programs. The proprietary SYNQ protocol, coupled with Q1 sequencer's real-time precision of 1 ns timegrid, allows generating advanced and coherent control pulse sequences with minimal jitter of a few picoseconds, low drift and low 1/f noise. The LINQ protocol assures fast-scalable feedback with all-to-all connectivity for active reset operations and error mitigation algorithms.

Together with the newly launched Qubit Timetag module that hosts 8 configurable digital input and output channels, Qblox's Quantum Control Stacks provide an integrated and scalable solution for most common qubit modalities to pave the way to quantum advantage.

References

[1] W. Vlothuizen et al. (TU Delft, APS MM P48.014, 2016)
[2] Rol et al. PRA 7, (2017) 041001
[3] Rol et al. APL 116, (2020) 054001

Multiverse Computing: Quantum and Quantum-Inspired AI and Beyond

Román Orús

Multiverse Computing, Paseo de Miramon 170, 20014 San Sebastian – Spain
DIPC, Paseo Mauel de Lardizabal 4, 20018 San Sebastian – Spain
Ikerbasque Foundation for Science, Maria Diaz de Haro 3, 48013 Bilbao, Spain

roman.orus@multiversecomputing.com

Abstract

Here I will present some of the latest developments being carried by the tech team of Multiverse Computing, the largest quantum software company in Europe. In particular, I will sketch briefly quantum and quantum-inspired AI applications such as the compression of Large Language Models [1], variational quantum attacks on cybersecurity protocols [2], classical simulation of quantum processors [3], and other industry-related topics. A brief explanation on the status of quantum and quantum-inspired software for industry will be discussed.

References

[1] Andrei Tomut, Saeed S. Jahromi, Sukhbinder Singh, Faysal Ishtiaq, Cesar Muñoz, Prabdeep Singh Bajaj, Ali Elborady, Gianni del Bimbo, Mehrazin Alizadeh, David Montero, Pablo Martin-Ramiro, Muhammad Ibrahim, Oussama Tahiri Alaoui, John Malcolm, Samuel Mugel, Roman Orus, arXiv:2401.14109 (2024)

[2] Borja Aizpurua, Pablo Bermejo, Josu Etxezarreta Martinez, Roman Orus, arXiv:2311.02986 (2023)

[3] Siddhartha Patra, Saeed S. Jahromi, Sukhbinder Singh, Roman Orus, arXiv:2309.15642 (2023)

Improving flux-based gates in superconducting QPUs through model learning of qubit and control stack parameters

Anurag Saha Roy[1]
Shinibali Bhattacharyya[1], William Steadman[1], Yousof Mardoukhi[1], Marc Bernot[1], André Melo[1], Shai Machnes[1], Nir Halay[2], Akiva Feintuch[2], Lior Ella[2], Yonatan Cohen[2]

1 *Qruise GmbH, Saarbrücken, Germany*
2 *Quantum Machines, Tel Aviv-Yafo, Israel*

anurag@qruise.com

The flux-based controlled-phase (CZ) gate offers potential speed-ups for two-qubit entangling gates, by operating at the speed limit of the transverse coupling between the computational and non-computational states. The scheme entails flux control of transmon frequency using a unipolar or bipolar square pulse. While ideally, the population exchange between the |1,1> and |0,2> states near resonance should show symmetric chevron-like oscillation patterns around the target flux amplitude, experiments reveal asymmetries that impact fidelity of flux-based gates. Using a physics-informed machine learning model to minimize the Euclidean distance between experimental and simulated chevrons, we learnt pulse distortions occurring down the control line, besides learning some relevant system Hamiltonian parameters. Our framework complements the Cryoscope technique of measuring the step response of flux control lines, as we also model pulse distortions after digital-to-analog conversion in the control stack. The model achieves a 99.5% match with experimental chevron data for unipolar flux pulses and was validated for chevrons obtained for bipolar pulses. We shed light on the physical implication of the learnt parameters and lay out actionable insights about correcting the pulse distortions to improve fidelity of the flux-based gates.

References

[1] Wittler, et al., Physical Review Applied, 15(3), 2021

Figures

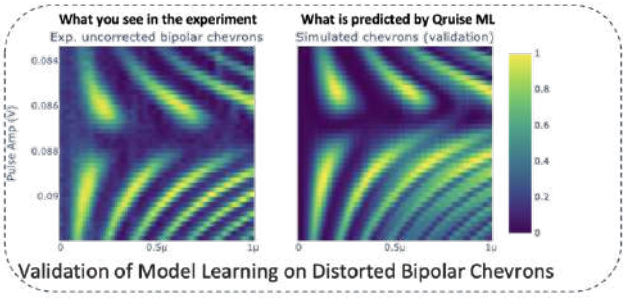


Figure 1: Validation of the Model Learning process through prediction of Bipolar CZ distorted chevrons from simulations.

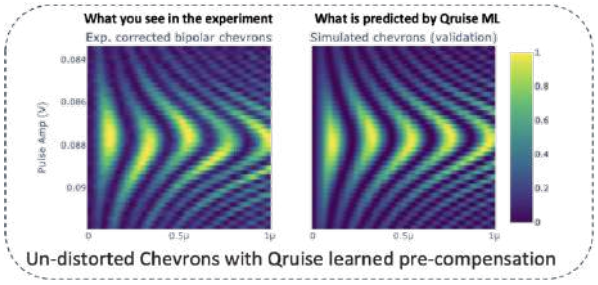


Figure 2: Application of Model Learning process to improve Bipolar CZ gates as demonstrated through correction of the chevron plots.

Accelerating the Quantum Workflow: from Design to Experiments

Felice Francesco Tafuri
Philip Krantz, Mohamed Hassan

Keysight Technologies, 1400 Fountaingrove Pkwy, Santa Rosa, CA 95403, United States

francesco.tafuri@keysight.com

In this talk we will discuss the latest solutions offered by Keysight to tackle the major challenges faced in the development of quantum systems. Such challenges impose several requirements on both the design tools and the quantum control system. We propose a holistic approach that can solve the development challenges from quantum bit (qubit) design to the measurement of fabricated devices [1, 2]. Our solution includes integrated design tools (Figure 1), excellent signal quality, precise phase coherency, fast real-time processing, and massive scalability to control and read out thousands of qubits (Figure 2). The talk will describe our completely integrated workflow based on the new design software QuantumPro [3] and the high-performance Quantum Control System (QCS) [4] from Keysight.

References

[1] J. Choi et al., "QuantumPro: An Integrated Workflow for the Design of Superconducting Qubits Using PathWave Advanced Design System (ADS)," 2023 IEEE International Conference on Quantum Computing and Engineering (QCE), Bellevue, WA, USA, (2023), pp. 224-225

[2] M. I. Abdelrahman et al., "Electromagnetic Modeling and Scripted Quantum Parameter Extraction of 3D Superconducting Qubits Using PathWave EMPro," 2023 IEEE International Conference on Quantum Computing and Engineering (QCE), Bellevue, WA, USA, (2023), pp. 352-353

[3] W3037E PathWave QuantumPro https://www.keysight.com/us/en/support/W3037E/pathwave-quantumpro.html

[4] Keysight Quantum Control System (QCS) https://www.keysight.com/zz/en/products/modular/pxi-products/quantum-control-system.html

Figures

Figure 1: Integrated EDA (Electronic Design Automation) tools from circuit design to EM (Electro-Magnetic) simulations and layout.

Figure 2: Implementation of a highly scalable modular quantum control system to measure thousands of qubits.

Accelerating the Development of Quantum Computers through Automation

Jelena Trbovic

QuantrolOx, Espoo, Finland

jelena@quantrolox.com

Quantum computation holds immense promise for revolutionizing physics research and our understanding of nature. However, the reliability of qubits, the basic building blocks of quantum computers, poses a significant challenge. Millions of physical qubits are required in quantum processing units (QPUs) to ensure robust and accurate computation. Presently, QPUs are limited to fewer than a hundred qubits and are hindered by tedious characterization and tune-up processes that rely on manual intervention. This slow development pace impedes progress in both QPU scalability and quantum computing applications.

To expedite QPU development, we require innovative tools and an automated approach. Quantum EDGE [1], a software platform developed by QuantrolOx streamlines QPU tune-up through automation, providing deep insights into qubit parameters, enhancing chip fabrication and characterization efficiency, and accelerating qubit advancements in academia and industry.

We develop Quantum EDGE at Bluefors lab [2] in Delft on 5-qubit Soprano [3] chips made by QuantWare. Qubits are flux tunable transmons with fixed coupling. The qubits are controlled and measured through Quantum EDGE that seamlessly integrates control electronics from Qblox [4], Quantum Machines [5], and Zurich Instruments [6], allowing users to focus on QPU development. During this presentation, we share latest results, demonstrating a two orders of magnitude improvement in QPU characterization speed, reducing it from days to minutes across the 5-qubit chip. Future developments include extending this speed enhancement to larger QPUs, verifying different superconducting qubit modalities, and implementing automation for 2-qubit gates.

.

References

[1] QuantrolOx Quantum EDGE, https://quantrolox.com
[2] Bluefors service lab Delft, https://bluefors.com/services/bluefors-lab
[3] QuantWare Soprano, https://www.quantware.com/product/soprano
[4] Qblox, https://www.qblox.com
[5] Quantum Machines, https://www.quantum-machines.co
[6] Zurich Instruments, https://www.zhinst.com

From Majorana to Andreev and back

Ramon Aguado

ICMM-CSIC, Spain

raguado@icmm.csic.es

Subgap Andreev bound states (ABS)s near zero energy are ubiquitous in semiconductor-superconductor hybrid devices due to various physical mechanisms, making unambiguous Majorana detection extremely difficult. Interestingly, this Majorana versus Andreev controversy [1] has helped us to understand that, far from being a disadvantage, the presence of ABSs can be used to design new qubit concepts. One promising route is to encode a qubit in the spin of a quasiparticle occupying an ABS in a quantum dot-based Josephson junction [2,3]. Embedding such superconducting spin qubit in a superconducting transmon circuit, allows an intrinsic spin-supercurrent coupling providing an optimal interface with circuit quantum electrodynamics for coherent control, readout and strong coherent qubit–qubit coupling [4]. By extending this idea to Josephson junctions based on a minimal chain of four quantum dots one could demonstrate a minimal Majorana-Transmon qubit based on non-local fermion parity [5].

References

[1] From Andreev to Majorana bound states in hybrid superconductor-semiconductor nanowires, Elsa Prada, Pablo San-Jose, Michiel WA de Moor, Attila Geresdi, Eduardo JH Lee, Jelena Klinovaja, Daniel Loss, Jesper Nygård, Ramón Aguado, Leo P Kouwenhoven, Nature Review Physics,2, 575–594 (2020).
[2] Singlet-Doublet Transitions of a Quantum Dot Josephson Junction Detected in a Transmon Circuit, Arno Bargerbos, Marta Pita-Vidal, Rok Žitko, Jesús Ávila, Lukas J. Splitthoff, Lukas Grünhaupt, Jaap J. Wesdorp, Christian K. Andersen, Yu Liu, Leo P. Kouwenhoven, Ramón Aguado, Angela Kou, and Bernard van Heck, PRX Quantum 3, 030311 (2022).
[3] Spectroscopy of Spin-Split Andreev Levels in a Quantum Dot with Superconducting Leads, Arno Bargerbos, Marta Pita-Vidal, Rok Žitko, Lukas J. Splitthoff, Lukas Grünhaupt, Jaap J. Wesdorp, Yu Liu, Leo P. Kouwenhoven, Ramón Aguado, Christian Kraglund Andersen, Angela Kou, and Bernard van Heck, Phys. Rev. Lett. 131, 097001 (2023)
[4] Direct manipulation of a superconducting spin qubit strongly coupled to a transmon qubit, Marta Pita-Vidal, Arno Bargerbos, Rok Žitko, Lukas J Splitthoff, Lukas Grünhaupt, Jaap J Wesdorp, Yu Liu, Leo P Kouwenhoven, Ramón Aguado, Bernard van Heck, Angela Kou, Christian Kraglund Andersen, Nature Physics, 19, 1110 (2023)
[5] Minimal Kitaev-transmon qubit based on double quantum dots, D Michel Pino, Rubén Seoane Souto, Ramón Aguado, Phys. Rev. B, 109, 075101 (2024)

MBE growth of 2D topological quantum materials

Athanasios Dimoulas

Institute of Nanoscience and Nanotechnology, NCSR DEMOKRITOS, 15341, Athens, Greece

a.dimoulas@inn.demokritos.gr

Abstract

In this tutorial, first a general review of molecular beam epitaxy (MBE) basics with a particular focus on 2D materials and van der Waals heterostructures will be presented. Emphasis will be given on the merits of MBE compared to other thin film deposition techniques. Subsequently, the focus will be on the influence of the substrate and in-situ surface preparation techniques on the structural quality and physical properties of the 2D materials. In-situ surface analytical techniques will be discussed such as STM and RHEED for the imaging of surfaces with atomic resolution and ARPES for the imaging of the electronic band structure. Particular attention will be given to 2D materials with non-trivial topology in reciprocal space such as topological insulators [1], T_d-$MoTe_2$ Weyl semimetals [2] and $HfTe_2$, $ZrTe_2$ Dirac semimetals [3]. Similarly, ferromagnetic 2D metals (e.g $Cr_{1+\delta}Te_2$, Fe_xGeTe_2) [4, 5] with skyrmion topological structures in real space will be discussed

Figures

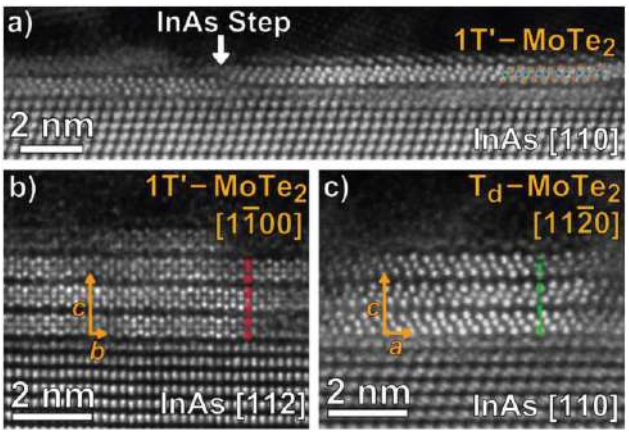


Figure 1: After Ref [2] MBE growth of Weyl semimetal orthorhombic non-centrosymmetric phase T_d-$MoTe_2$.

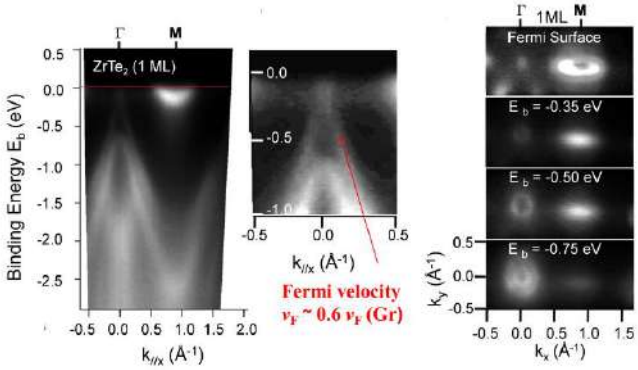


Figure 2: After Ref [3] In-situ ARPES of MBE grown 1T-$ZrTe_2$ showing massless Dirac fermions at the zone center

References

[1] S. Fragkos et al., *Phys. Rev. Mater.* (2021) **5**, 014203
[2] P. Tsipas et al., *Adv. Funct. Mater. (*2018), 1802084.
[3] P. Tsipas et al., *ACS Nano* **12** (2018) 1696
[4] N. Figueiredo-Prestes et al., Physical Review Applied (2023) 19, 014012
[5] E. Georgopoulou-Kotsaki et al., *Nanoscale* (2023) **15**, 2223

Topological Quantum Chemistry

Maia G. Vergniory

Max Planck for Chemical Physics of Solids, 01187 Dresden, Germany
Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain

maia.vergniory@cpfs.mpg.de

In this talk a new field that classifies all topological crystalline phases of all known materials will be introduced: Topological Quantum Chemistry (TQC). It links the chemical and symmetry structure of a given material with its topological properties. This field tabulates the data of the 10398 real-space atomic limits of materials, and solves the compatibility relations of electronic bands in momentum space. A material that is not an atomic limit or whose bands do not satisfy the compatibility relations, is a topological insulator/semimetal. We use TQC to find the topological stoichiometric non-magnetic, materials in the Inorganic Crystal Structure Database at any filling. Topologically nontrivial materials were once thought to be the exception rather than the rule. In this talk I will show you that, by means of high-throughput computations, many more materials are topological than was initially thought. We have made our results publicly accessible through the https://topologicalquantumchemistry.com/

References

[1] B. Bradlyn, L. Elcoro, J. Cano, M.G. Vergniory, Z. Wang, C. Felser, M.I. Aroyo, B.A. Bernevig, "Topological quantum chemistry", *Nature* 547 (7663), 298-305 (2017

[2] M.G. Vergniory, L. Elcoro, C. Felser, B.A. Bernevig y Z. Wang , "A complete catalogue of High-Quality Topological Materials " Nature 566 (7745), 480-485

[3] Maia G Vergniory, Benjamin J Wieder, Luis Elcoro, Stuart SP Parkin, Claudia Felser, B Andrei Bernevig, Nicolas Regnault, "All topological bands of all nonmagnetic stoichiometric materials", Science 376 (6595), eabg9094

Figures

Figure 1: Topological Materials Database: https://topologicalquantumchemistry.com/

Altermagnets: An unconventional magnetic class

Tomas Jungwirth

Institute of Physics, Czech Academy of Sciences, Cukrovarnick´a 10, 162 00 Praha 6, Czech Republic
School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, United Kingdom

jungw@fzu.cz

Conventional magnets can be divided in two basic classes – ferromagnets and antiferromagnets. In the first part of the talk, we will recall that the ferromagnetic order offers a range of phenomena for energy efficient IT, while the vanishing net magnetization in antiferromagnets opens a possibility of combining ultra-high energy efficiency, capacity and speed of future IT [1-4]. In the main part of the talk we will move on to our recent predictions of instances of strong time-reversal symmetry breaking and spin splitting in electronic bands, typical of ferromagnetism, in crystals with antiparallel compensated magnetic order, typical of antiferromagnetism [5-8]. We resolved this apparent fundamental conflict in magnetism by symmetry considerations that allowed us to classify and describe a third basic magnetic class [6,7]. Its alternating spin polarizations in both crystal-structure real space and electronic-structure momentum space suggested a term altermagnetism. A d-wave spin-polarization order in altermagnets is a direct counterpart of the unconventional d-wave superconducting order in cuprates. We will discuss predictions and initial experimental verifications [9,10] in which altermagnets combine merits of ferromagnets and antiferromagnets, that were regarded as principally incompatible, and have merits unparalleled in either of the two conventional magnetic classes. We will introduce the broad materials landscape of altermagnetism and show how its unconventional nature enriches fundamental concepts in condensed matter physics, such as the Kramers theorem [10]. We will show that this underpins a development of a new avenue in spintronics, elusive within the two conventional magnetic classes, based on strong and conserving spin phenomena, without magnetization imposed scalability limitations.

References

[1] P. Wadley, T. Jungwirth et al., Science 351, 587 (2016)
[2] T. Jungwirth et al., Nature Nanotech. 11, 231 (2016)
[3] Z. Kaspar, T. Jungwirth et al., Nature Electron. 4, 30 (2021)
[4] F. Krizek T. Jungwirth et al., Science Adv. 8, eabn3535 (2022)
[5] L. Smejkal, T. Jungwirth et al., Science Adv. 6, eaaz8809 (2020)
[6] L. Smejkal, T. Jungwirth et al., Nature Rev. Mater. 7, 482 (2022)
[7] L. Smejkal, J. Sinova, T. Jungwirth, Phys. Rev. X 12, 031042 (2022)
[8] L. Smejkal, J. Sinova, T. Jungwirth, Phys. Rev X (Perspective) 12, 040501 (2022)
[9] Z. Feng, T. Jungwirth et al., Nature Electron. 5, 735 (2022)
[10] J. Krempasky, T. Jungwirth et al., Nature 626, 517 (2024)

A Spin Qubit Coupled to a Collective Nuclear Quantum Register

Martin Hayhurst Appel[1]
Alexander Ghorbal[1], Noah Shofer[1], Leon Zaporski[1], Santanu Manna[2], Saimon Covre da Silva[2], Urs Haeusler[1], Armando Rastelli[2], Claire Le Gall[1], Dorian Gangloff[1], Mete Atature[1]

[1]. *Cavendish Laboratory, University of Cambridge, Cambridge, UK*
[2]. *Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Linz, Austria*

mha41@cam.ac.uk

Semiconductor quantum dots possess state-of-the-art single photon emission, making them highly attractive for quantum network applications. Their adoption as quantum nodes has however been limited by their lack of ancillary quantum registers. In this talk, I will present recent advances in realizing a many-body quantum register from the ~10^5 nuclear spins that constitute a quantum dot. In particular, I will highlight the transformative nature of the homogeneous nuclear environment provided by recent lattice-matched GaAs quantum dots.

A network of trapped-ion quantum computers

Gabriel Araneda

University of Oxford, UK

gabriel.aranedamachuca@physics.ox.ac.uk

Trapped ions are a leading platform for quantum computing due to their long coherence time, high level of control over internal and external degrees of freedom, and the natural full connectivity between qubits. Single and multi-qubit operations have been performed with high fidelity (>99.9%), enabling the demonstration of small universal quantum computers (approx. 10 atoms). However, scaling up to larger sizes remains a challenge. In our experiment, we aim to demonstrate the first operational and fully controllable two-node quantum computer, where each node consists of small-scale quantum processors connected via photonic entanglement. We use two ion trap systems to confine mixed chains of Strontium and Calcium ions. 43Ca+ has excellent qubit coherence properties, while 88Sr+ has a convenient internal structure for generating photonic entanglement. Single 422 nm photons emitted by the Strontium ion are used to generate remote entanglement. We recently achieved a remote Strontium-Strontium entanglement fidelity of 96.0(2) % at a rate of 100 entangled events/s, along with an average CHSH violation of 2.65.
In this talk, I will present our latest results using this elementary quantum networks, including the implementation of a long-lived (>10s) memory qubit into our mixed-species trapped-ion quantum network nodes [1]; and how to use one of these nodes to implement simple instances of Blind Quantum Computing [2].
Furthermore, I will present the demonstration of secure quantum communications between the nodes of our network, certified by continuous violation of the CHSH inequality (DIQKD), and the demonstration of the first quantum network of entangled optical atomic clocks

References

[1] Phys. Rev. Lett. 130, 090803 (2023)
[2] arXiv:2305.02936 [2023]
[3] Nature 609, 689–694 (2022)
[4] Nature 607, 682–686 (2022)

Superfluid stiffness of twisted graphene

Abhishek Banerjee[1]
Zeyu Hao[1], Mary Kreidel[1], Isabelle Y. Phinney[1], Jeong Min Park[2], Patrick Ledwith[1], Andrew Zimmerman[1], Robert M. Westervelt[1], Pablo Jarillo-Herrero[2], Pavel A Volkov[1], Ashvin Vishwanath[1], Kin Chung Fong[3], Philip Kim[1]

1. Harvard University, Cambridge, USA
2. MIT, Cambridge, USA
3. Raytheon-BBN Technologies, Cambridge, USA
abanerjee@fas.harvard.edu

Superfluid stiffness measurements offer a powerful probe of the superconducting state and a primary means to characterize their pairing symmetries. While a range of techniques are available for bulk materials to measure superfluid stiffness, for two-dimensional (2D) materials with a small sample volume and low transition temperatures, alternative methods are required. Inspired by recent advances in quantum measurement technologies, we develop a radio-frequency reflectometry technique adapted to measure the superconducting kinetic inductance in 2D materials at milliKelvin temperatures.

We apply this technique to twisted graphene where superconductivity is highly unusual, occurs at extremely low carrier densities, and shows strong parallels with high-Tc superconductors including proximity to a correlated insulating state [1,2,3]. Although hotly debated, superconductivity in this system has been investigated primarily using transport measurements which carry little information about the nature of superconductivity. Therefore, important questions such as the pairing symmetry and the role of interactions remain unanswered. We measure superfluid stiffness as a function of temperature, supercurrent bias and carrier density across the entire superconducting dome in both the electron and hole doped sectors of twisted multilayer graphene samples. We provide interpretations for possible superconducting pairing symmetries and discuss the role of electronic correlations towards superconductivity.

References

[1] Cao et al, Nature 556 (7699), 2018
[2] Hao et al, Science 371 (6534), 2021
[3] Park et al, Nature 590 (7845), 2021

Figures

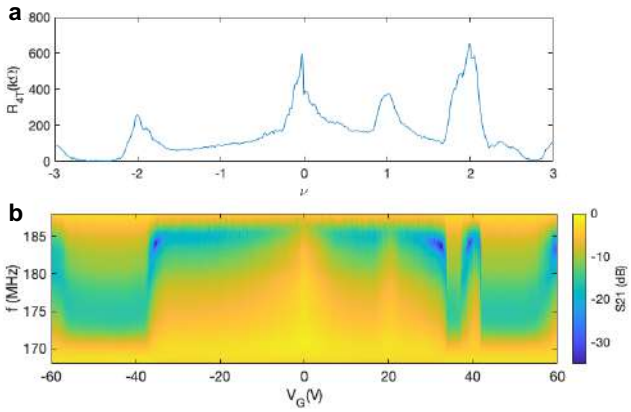


Figure 1: (a) Four-terminal resistance as a function of filling υ (b) Corresponding S_{21} measurement of the resonator as a function of gate voltage V_G, where $\upsilon = V_G/20$. The resonator shows clear frequency shifts at the transitions into superconducting states at υ=-2 and υ=2.

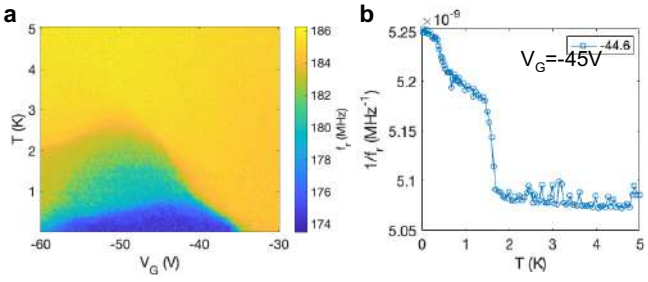


Figure 2: (a) Extracted resonator frequency f_r within the "hole-like" superconducting dome as a function of V_G and temperature T. (b) Inverse resonator frequency 1/fr as a function of temperature at V_G=-45 V (υ=-2.25). *The inverse resonance frequency is proportional to superfluid stiffness.*

Controlling a High-Q Cavity with a Kerr-cat Qubit

Benjamin L. Brock*
Andy Z. Ding*, Alec Eickbusch, Akshay Koottandavida, Nicholas E. Frattini, Rodrigo G. Cortiñas, Vidul R. Joshi, Stijn de Graaf, Benjamin J. Chapman, Suhas Ganjam, Volodymyr V. Sivak, Luigi Frunzio, Robert J. Schoelkopf, Michel H. Devoret
* Indicates equal contribution

Departments of Applied Physics and Physics, Yale University, New Haven, CT, 06520, USA

benjamin.brock@yale.edu

Biased-noise qubits have been proposed as a key resource for practical quantum error correction, enabling fault-tolerant measurements of error syndromes [1] and improved thresholds of surface codes [2]. One promising biased-noise qubit is the Kerr-cat, which is realized by squeezing a Kerr-nonlinear oscillator [3]. Kerr-cats have been experimentally realized [4] but to date have not been coherently coupled to another system, which is essential for delivering on the proposed applications of biased-noise qubits. Here we experimentally realize driven parametric coupling of a Kerr-cat qubit to a high-quality-factor microwave cavity and demonstrate universal control of the combined system. We measure the decoherence of the cavity in the presence of the Kerr-cat and discover excess dephasing due to heating of the Kerr-cat outside its computational subspace. By engineering frequency-selective dissipation to counteract this heating [5] we are able to mitigate this dephasing. Our results pave the way toward integrating Kerr-cats into practical quantum computing architectures.

References

[1] Puri et al., PRX 9, 041009 (2019)
[2] Tuckett et al., PRL 120, 050505 (2018)
[3] Puri et al., npj Quantum Inf 3, 18 (2017)
[4] Grimm, Frattini, et al., Nature 584, 205-209 (2020)
[5] Putterman et al., PRL 128, 110502 (2022)
[6] Eickbusch et al., Nat. Phys. 18, 1464-1469 (2022)

Figures

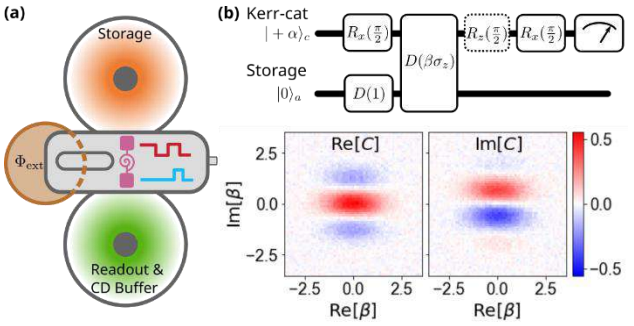


Figure 1: (a) Schematic of the experimental architecture for coupling a Kerr-cat qubit (realized in a SNAIL mode, pink) to a high-Q storage cavity. (b) Experimental characteristic function tomography of a coherent state in the storage cavity, demonstrating universal control of the composite Kerr-cat-cavity system [6].

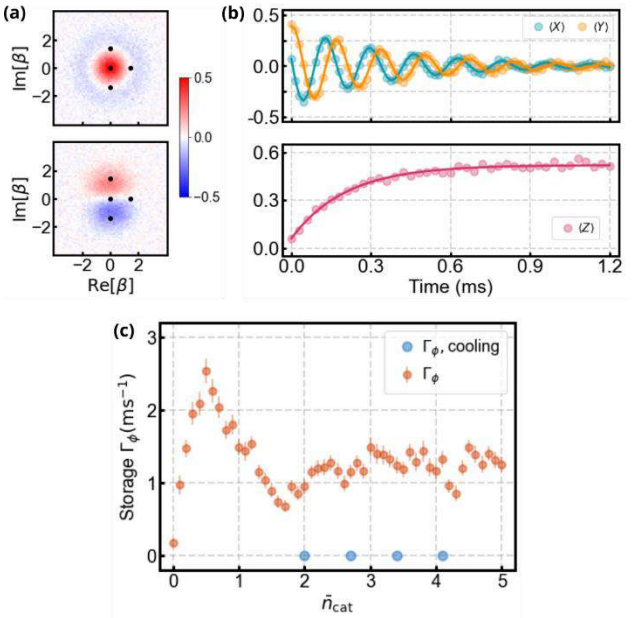


Figure 2: (a) Measured characteristic function (CF) of the $(|0\rangle + |1\rangle)/\sqrt{2}$ state prepared in the storage cavity. By measuring the CF at four distinct points we can reconstruct the expectation values of the Pauli operators of the cavity fock qubit (spanned by the $|0\rangle$ and $|1\rangle$ states). (b) Evolution of the expectation values $\langle X\rangle, \langle Y\rangle, \langle Z\rangle$ of the cavity fock qubit as a function of time, from which we can determine T_1 and T_2. (c) Excess dephasing of the storage cavity in the presence of the Kerr-cat, which we are able to mitigate by engineering frequency-selective Kerr-cat cooling [5].

A gate tunable transmon qubit in planar Ge

Alessandro Crippa[1,2]
Oliver Sagi[1], Marco Valentini[1], Marian Janik[1], Levon Baghumyan[1], Lucky Kapoor[1], Farid Hassani[1], Stefano Calcaterra[3], Daniel Chrastina[3], Giovanni Isella[3], and Georgios Katsaros[1]

ISTA, Am Campus 1, Klosterneuburg, Austria
NEST, Piazza San Silvestro 12, Pisa, Italy
L-NESS, via Anzani 42, Como, Italy

alessandro.crippa@nano.cnr.it

Gate-tunable transmons (gatemons) employing semiconductor Josephson junctions have emerged as new building blocks for hybrid quantum circuits [1-3]. Here, we demonstrate and characterize a gatemon on planar Ge. We induce superconductivity in Ge by evaporating aluminum atop a thin spacer, which separates the superconductor from the quantum well [4]. The Josephson junction is capacitively coupled to a transmission line resonator. We reach the qubit-resonator strong coupling regime and showcase the qubit's tunability in a broad frequency range with one and two-tone spectroscopy. Time-domain measurements reveal energy relaxation and coherence times up to 75 ns. Our results, combined with the recent advances in Ge spin qubits [5, 6], pave the way towards Andreev spin qubits in a group-IV, CMOS-compatible material.

References

[1] T. W. Larsen, et al., Phys. Rev. Lett., 115, (2015) 127001
[2] G. de Lange, et al., Phys. Rev. Lett. 115, (2015) 127002
[3] L. Casparis, et al., Nature Nanotech. 13, (2018) 915
[4] M. Valentini, et al, Nature Comm. 9, (2024) 169
[5] D. Jirovec, et al., Nature Mat. 20, (2021) 1106
[6] F. Borsoi, et al, Nature Nanotech. 19, (2024) 21

Figures

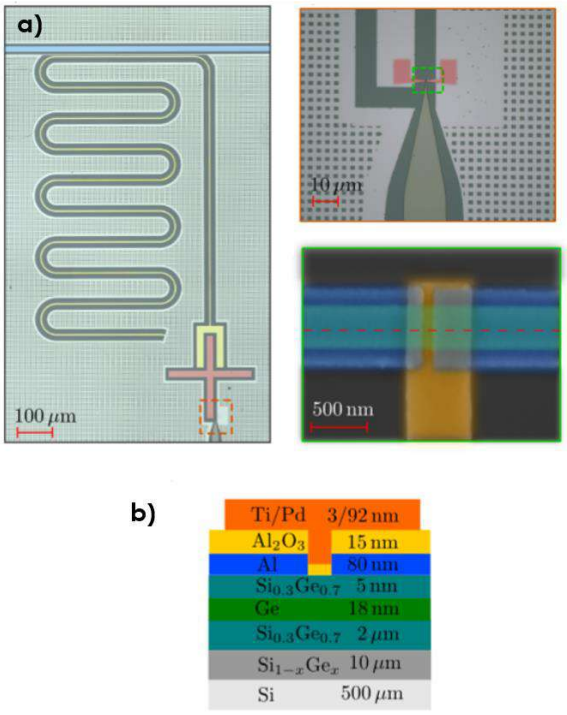


Figure 1: a) Device layout from the cQED parts down to the nanosized Ge junction. b) Cross-section of the wafer stack along the red line in the panel above.

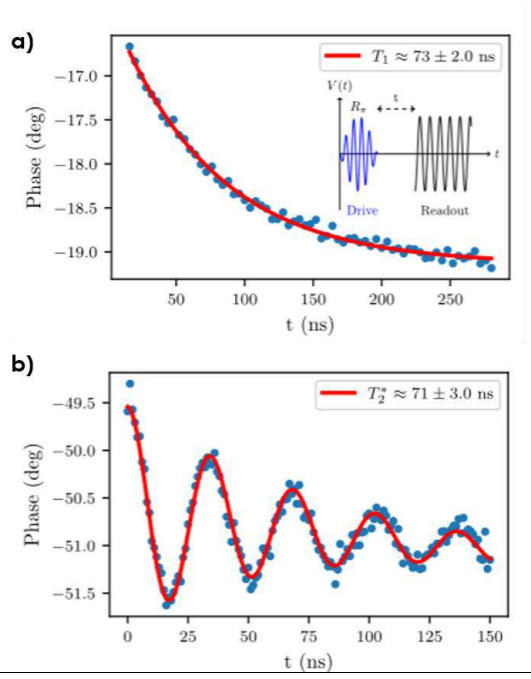


Figure 2: Characterization of the qubit times T1 and T2* in panel a) and b), respectively. Both dataset acquired at a qubit frequency of 2.8 GHz.

Single electron interferometric sensing of quantum electromagnetic noise

Pascal Degiovanni (1)
Hubert Souquet-Basiège (1), Benjamin Roussel (3), Inès Safi (4), Gerbold Ménard (2) and Gwendal Fève (2)

1. *CNRS - ENS Lyon, 46 allée d'Italie, 69007 Lyon, France.*
2. *Département de Physique de l'Ecole Normale Supérieure, 24 rue Lhomond, 75005 Paris - France.*
3. *Applied Physics Dept., Allot University, P.O. Box 11000 (Otakaari 1B)n, FI-00076 Aalto - Finland.*
4. *Laboratoire de Physique des solide, University Paris Saclay, Batiment 510, 91405 Orsay - France.*

Pascal.Degiovanni@ens-lyon

The on-chip sensing of electromagnetic fields on very short time scales is a notoriously difficult challenge. On chip systems such as rf-SETs, QPC, rf-SQUIDS or quantum dots have a bandwidth in the tens of MHz. On the other hand, the development of solid state quantum technologies in the microwave to THz range calls for the development of sub-nanosecond time resolved sensors of the electromagnetic field.

In this presentation, we discuss how recent progress in the generation and characterization of single electron wave packets in quantum conductors [1,2,3] can help us reach such short time scales. We will show how single electron interferometers be used as a time resolved sensors of the quantum noise of an electromagnetic field with a few tens of pico-second time resolution [3]. As an example, we will explain how a single electron wave packet can be used to detect sub vacuum fluctuations (squeezing) of microwave radiation as well as to map the energy profile of a single microwave photon in the time domain [4].

References

1. R. Bisognin *et al*, Nature Communications **10**, 3379 (2019).
2. C. Bauerle *et al*, Reports on Progress in Physics, **81**, 056603 (2018).
3. V. Kashchaeyvevs, P. Degiovanni, B. Roussel, M. Kataoka, J.D. Fletcher, L. Freise, N. Ubbelohde, G. Fève, H. Bartolomei, F. Couëdo, A. Kakykov, W. Poirier, P. Roulleau, F.D. Parmentier, and F. Hohls, *Single electron wave packets for quantum metrology, concepts, implementations and applications*, Technical Report of the EMPIR project SEQUOIA (17FUN04).
4. H. Souquet-Basiège *et al*, *Quantum sensing of time dependent electromagnetic fields with single electron excitations* (in preparation).

Figures

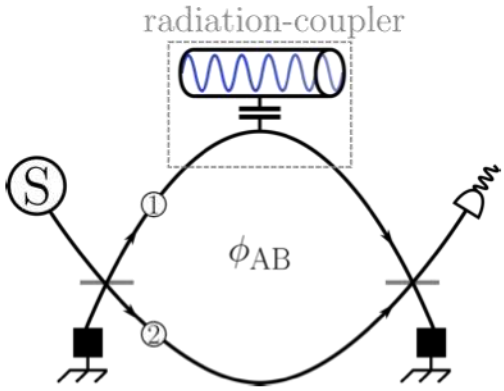


Figure 1: Scheme of principle for sensing electromagnetic fields with single electrons: an electronic Mach-Zehnder interferometer is fed by a single electron source S. The interference pattern is then sensitive to the external radiation interacting with one branch of the interferometer via capacitive coupling within the radiation coupler. The quantum noise of the radiation then alters@ the interference pattern

High indistinguishability of two dissimilar and independent cold-atomic quantum nodes.

Félix Hoffet, Jan Lowinski, Lukas Heller, Auxiliadora Padrón-Brito and Hugues de Riedmatten

ICFO – The Barcelona Institute of Science and Technology,
Av. Carl Friedrich Gauss, 3 - 08860 Castelldefels, Barcelona - SPAIN

Felix.hoffet@icfo.eu

In quantum communication research, the ultimate goal is to distribute entanglement between remote quantum nodes [1]. In this prospect, the indistinguishability of single photons emitted from these nodes is a crucial parameter that dictates the overall entanglement rate one can achieve in a quantum network.
Here, we demonstrate highly indistinguishable two-photon interference involving single photons emitted from two different and completely independent cold-atomic quantum nodes.
The first quantum node is a quantum repeater link based on the generation of atom-photon entanglement while the second node consist of a fully-blockaded Rydberg cold atomic ensemble as a deterministic source of photons [2].
This experiment opens up new possibilities for the interconnection of hybrid quantum nodes via entanglement.

References

[1] H. J. Kimble, "The quantum internet," Nature 453, 1023 (2008).
[2] J. Lowinski, L. Heller, F. Hoffet, A. Padrón-Brito, K. Theophilo, and H. de Riedmatten "Strongly Nonlinear Interaction between Nonclassical Light and a Blockaded Rydberg Atomic Ensemble," Phys. Rev. Lett. 132, 53001 (2024)

Figures

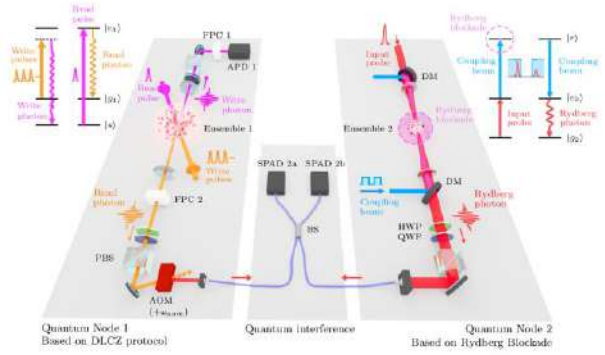


Figure 1: Experimental setup and relevant level scheme. Node 1 is a cold atomic ensemble based on probabilistic generation of atom-photon entanglement. Node 2 is based on the deterministic generation of single photons via Rydberg blockade.

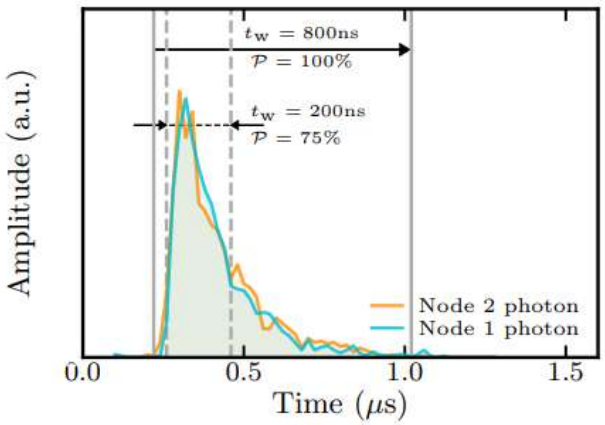


Figure 2: Temporal modes of the single photons emitted from Node 1 and Node 2. Grey lines indicate the windows used for the interference analysis. We compare the visibility we obtain when analyzing the full pulse with the case when we analyse 75% of all photon counts.

Photonic heat transport and the Schmid transition in Josephson junctions

A. Levy Yeyati,
Diego Subero, Jukka Pekola and Rafael Sánchez

Departamento de Física Teórica de la Materia Condensada, Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, Madrid, Spain

a.l.yeyati@uam.es

The Josephson junction is a building block of quantum circuits. Its behavior, well understood when treated as an isolated entity, is strongly affected by coupling to an electromagnetic environment. In 1983 Schmid [1] predicted that a Josephson junction shunted by a resistance exceeding the resistance quantum RQ = h/4e2 ≈ 6.45 kΩ for Cooper pairs would become insulating since the phase fluctuations would destroy the coherent Josephson coupling. Such transition is nowadays a matter of big experimental and theoretical debate [2,3].

In spite of this intense activity little is known regarding this system properties beyond dc charge transport. Motivated by recent experiments [4] in this work we analyze photonic heat transport through a Josephson junction in a dissipative environment. For this purpose we derive the general expressions for the heat current in terms of non-equilibrium Green functions for the junction coupled in series or in parallel with two environmental impedances at different temperatures. We show that even on the insulating side of the Schmid transition the heat current is sensitive to the Josephson coupling exhibiting an opposite behavior for the series and parallel connection and in qualitative agreement with experiments. We also predict that this device should exhibit heat rectification properties and provide simple expressions to account for them in terms of the system parameters. .

References

[1] A. Schmid, Diffusion and localization in a dissipative quantum system. Phys. Rev. Lett. 51, 1506 (1983).
[2] A. Murani et al. Absence of a dissipative quantum phase transition in Josephson junctions. Phys. Rev. X. 10, 021003 (2020).
[3] Kuzmin, R.et al. Observation of the Schmid-Bulgadaev dissipative quantum phase transition. arXiv:2304.05806 (2023).
[4] D. Subero et. al., Bolometric detection of Josephson inductance in a highly resistive environment, Nature Comm. 14, 7924 (2023)

Integration of Magnons into Superconducting Circuits for Sensing Applications

María José Martínez-Pérez D. García-Pons, J. Pérez-Bailón, S. Martínez-Losa del Rincón, J. Sesé, F. Luis, D. Zueco
Instituto de Nanociencia y Materiales de Aragón CSIC-Universidad de Zaragoza, Calle Pedro Cerbuna 12, 50009 Zaragoza, España
pemar@unizar.es

Circuit Quantum Electrodynamics (QED) is enormously powerful, allowing, e.g., the manipulation and interrogation of superconducting or magnetic qubits and quantum sensing of individual spins. All these interesting applications are built upon the condition of strong coupling between the qubit and a quantized field of excitations. Besides photons, the solid state offers a wide variety of bosonic excitations that can be emitted or absorbed such as, e.g., magnons, the quantum version of spin waves. Magnonic cavities are expected to play an important role since they shall allow building coherent qubit-qubit interactions between distant spin qubits, a challenge difficult to overcome with conventional electromagnetic cavities. One fundamental step towards achieving this goal is the integration of magnonic cavities into superconducting circuits, commonly employed for qubit manipulation and readout.

In this context, we present our progress in integrating patterned magnetic nanostructures into superconducting devices and their coupling to spin qubits. We perform broadband ferromagnetic resonance measurements and cavity experiments that demonstrate that the magnon-photon coupling strength can be estimated using either open superconducting transmission lines or resonant cavities, yielding very good agreement [1]. Finally, we investigate the coupling between topologically protected magnons and spin qubits (see Figure). The former are extremely stable magnetic textures exhibiting a very rich dynamical behavior in the sub-GHz to tens of GHz range. We focus on the coupling of individual spin qubits to vortex cavities for sensing and quantum computing applications [2].

References

[1] Sergio Martinez-Losa del Rincon, Ignacio Gimeno, Jorge Perez-Bailon, Victor Rollano, Fernando Luis, David Zueco, Maria Jose Martinez-Perez Phys. Rev. Applied, 19 (2023) 014002
[2] Carlos A. González-Gutiérrez, David García-Pons, David Zueco, María José Martínez-Pérez ACS Nano (2024) https://arxiv.org/abs/2401.06549

Figures

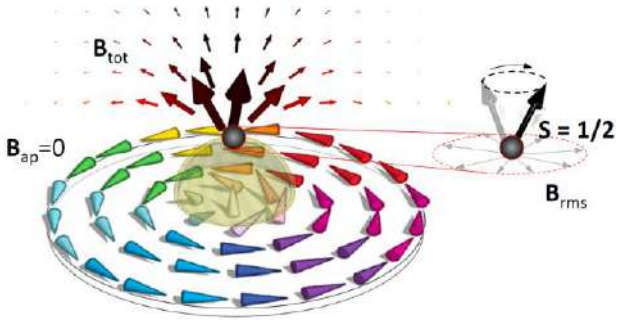


Figure: Spin qubit coupled to a magnetic vortex

Evidence for chiral supercurrent in quantum Hall Josephson junctions

David Perconte
Hadrien Vignaud, Wenmin Yang, Bilal Kousar, Edouard Wagner, Frédéric Gay, Kenji Watanabe, Takashi Taniguchi, Hervé Courtois, Zheng Han, Hermann Sellier, and Benjamin Sacépé

Institut Néel, CNRS, 25, avenue des martyrs, Grenoble, France.

david.perconte@neel.cnrs.fr

We present evidence that ultra-narrow Josephson junctions defined in encapsulated graphene nanoribbons exhibit a chiral supercurrent, visible up to 8 T, and carried by the spin-degenerate QH edge channel. $2\Phi_0$ periodic oscillation of the supercurrent emerge at constant filling factor that is when the area of the loop formed by the QH edge channel is constant. By varying the junction geometry, we show that reducing the superconductor/normal interface length is pivotal to obtain a measurable supercurrent on QH plateaus, in agreement with theories predicting dephasing along the superconducting interface. Our findings mark a critical milestone along the path to explore correlated and fractional QH-based superconducting devices that should host non-Abelian Majorana and parafermion zero modes.

References

[1] Vignaud, H., Perconte, D., Yang, W. et al. Evidence for chiral supercurrent in quantum Hall Josephson junctions. Nature 624, 545–550 (2023). https://doi.org/10.1038/s41586-023-06764-4

Figures

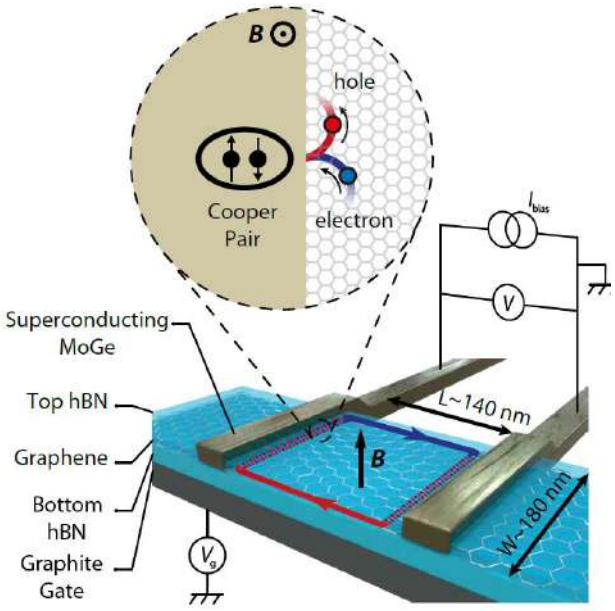


Figure 1: Schematics of the Josephson junction consisting of a graphene nanoribbon encapsulated in hexagonal boron nitride (hBN) resting atop a graphite back-gate electrode. Edge contacts are made of superconducting MoGe electrodes. Under magnetic field, charge carriers of the QH edge channel undergo successive Andreev reflections along the superconducting electrode, which convert incident quasi-electrons (blue channel) into quasi-holes (red channel) and vice-versa, as illustrated with semi-classical cyclotron trajectories in the insert. This electron-hole mixture forms a CAES (dashed blue-red channel) along the interface.

Generating highly entangled states and synthetic gauge fields on a superconducting processor

Ilan T. Rosen[1*], Cora Barrett[1], Patrick M. Harrington[1], Max Hays[1], Amir H. Karamlou[1], Sarah Muschinske[1], Jeffery A. Grover[1], William D. Oliver[1]

[1]*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
*itrosen@mit.edu

Recently, the application of transmon arrays as analog quantum simulators has received growing interest. Here, photonic excitations in the array behave as strongly interacting particles according to the Bose-Hubbard model. Work in this area has centered around one- and quasi-one-dimensional dynamics problems [1-6].

We study a two-dimensional, 4-by-4 square array of tunable transmon superconducting qubits with capacitive coupling between nearest neighbors. Rather than preparing a definite state, we simultaneously drive all lattice sites, generating highly entangled many-body states [7]. We extract the entanglement entropy of the states, observing volume-law entanglement scaling for states at the center of the energy spectrum and a crossover to the onset of area-law scaling near its edges [8].

Second, we discuss the emulation of magnetic fields in the superconducting processor. Magnetic fields are a central ingredient in many Hamiltonians of interest. Here, we introduce a scheme to generate synthetic magnetic fields by parametrically modulating the transmon qubits [9]. We verify key signatures of the field's presence, including the Aharonov-Bohm effect, gauge invariance, and the Faraday effect.

References

[1] R. Ma et al. Nature 566, 51 (2019)
[2] Y. Ye et al. Phys. Rev. Lett. 123, 050502 (2019)
[3] E. Kim et al. Phys. Rev. X 11, 011015 (2021)
[4] A. Karamlou et al. npj Quantum Inf. 8, 35 (2022)
[5] X. Mi et al. Science 378, 785 (2022)
[6] B. Saxberg et al. 612, 435 (2022)
[7] Y. Yanay et al. npj Quantum Inf. 6, 58 (2020)
[8] A. Karamlou et al. arXiv:2306.02571 (2023)
[9] I. T. Rosen et al., in preparation (2024)

Figures

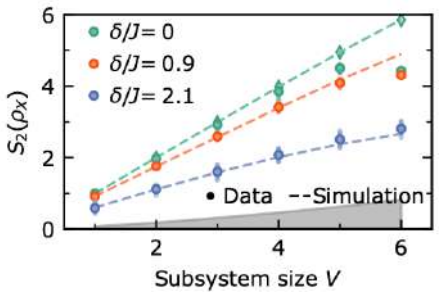


Figure 1: The second Renyi entropy, as extracted from full state tomography of subsystems, versus subsystem volume. Entropies of superposition states with three different energies are shown.

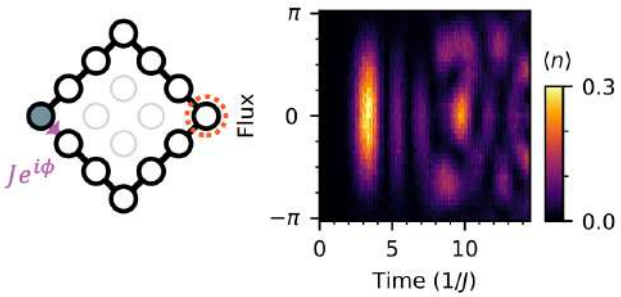


Figure 2: Aharonov-Bohm interference in a 12-site ring. A photon is prepared on one corner of the ring (teal). The population at the opposing corner (orange circle) is measured as a function of time and synthetic magnetic flux.

Analog quantum simulation of quantum chemical dynamics with a trapped-ion system

Ting Rei Tan
C. H. Valahu, V. C. Olaya-Agudelo, R. J. MacDonell, T. Navickas, A. D. Rao, M. J. Millican, Tim F. Wohlers-Reichel, J. B. Pérez-Sánchez, J. Yuen-Zhou, M. J. Biercuk, I. Kassal.

The University of Sydney, Sydney, Australia
tingrei.tan@sydney.edu.au

Abstract

Quantum computers (QC) promise to solve computational challenges in chemistry by requiring only linear resource scaling. However, almost all chemical applications of QC have focused on *static* molecular properties, usually energies, making them unsuitable for addressing chemical *dynamic* problems, especially in strong vibronic (vibrational + electronic) coupling regimes where the Born-Oppenheimer approximation breaks down. Here, we show that vibronic Hamiltonians representing ultrafast molecular dynamics can be scalably and efficiently simulated on a mixed qudit-boson (MQB) simulator that provides order-of-magnitude resource savings compared to conventional qubit-only approaches [1]. We performed two experiments in a programmable trapped-ion MQB simulator. First, shown in Fig. 2, we observed geometric-phase interference in the dynamics of a nuclear wavepacket travelling around an engineered conical intersection [2]. Second, we extended the MQB approach to predict the molecular vibronic absorption spectrum of a sulphur dioxide molecule, see Fig. 2 [3]; our method offers better scalability by performing quantum simulation in the time domain; the number of required measurements depends on the desired spectral range and resolution, not molecular size.

References

[1] R. J. MacDonell *et al.*, Chem. Sci., **12** (2021) 9794.
[2] R. J. MacDonell *et al.*, Chem. Sci., **14** (2023) 9439.
[3] C. H, Valahu *et al.*, Nat. Chem., **15** (2023) 1503.
[4] D. M. P. Holland *et al.*, Chem. Phys. **118** (1994), 317.

Figures

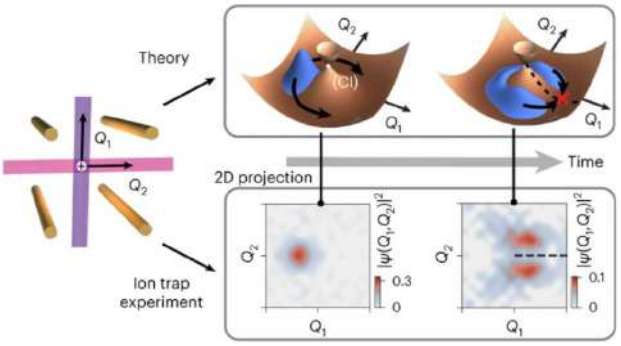


Figure 1: We performed a trapped-ion experiment directly detecting a geometric phase in dynamics around a conical intersection (CI). Our results track the wavepacket evolution dynamics, revealing the clear destructive interference as the wavepacket originally displaced from the CI (at $t = 0$) encircles the CI at $t = T$. Our work demonstrated remarkable hardware efficiency; we performed using a single trapped ion to solve a problem that otherwise would have required many qubits on a qubit-based QC.

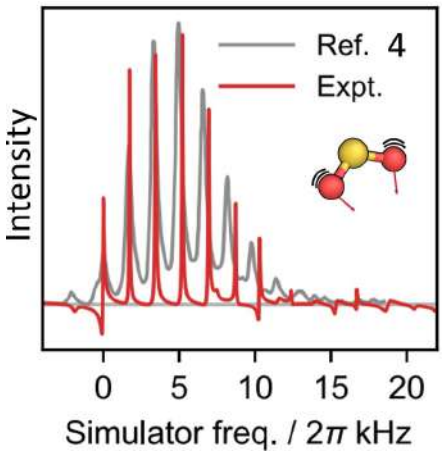


Figure 2: We predict the vibrational-electronic spectrum of a sulphur dioxide (SO2) molecule (red) with exceptional accuracy when compared to the spectroscopically observed spectrum at 320 K (grey).

Cavity-Enhanced on-demand Spin-Wave Solid State Quantum Memory

Leo Feldmann, **Sören Wengerowsky**, Stefano Duranti, Hugues de Riedmatten

ICFO – The Institute for Photonic Sciences, Mediterranean Technology Park, Avinguda Carl Friedrich Gauss 3, 08860 Castelldefels, Barcelona, Spain
soeren.wengerowsky@icfo.eu

The realization of large scale quantum networks requires the distribution of entanglement over large distances. In this long-range regime, direct transmission is prohibitive due to losses in optical fibers. Quantum repeaters are predicted to overcome direct transmission and allow entanglement distribution at a continental scale. Most quantum repeater schemes rely on the storage of quantum states into quantum memories. In order for memories to be useful in practical implementations, they must exhibit several features including a long storage time, a high storage efficiency and a large multiplexing capability. Solid-state quantum memories based on rare-earth doped solids promise excellent performances in terms of storage time and multiplexing capability [1].

The efficiency of quantum memory protocols decays exponentially with storage time due to the limited coherence time of the material. This severely limits the applicability of the quantum memory. Storage in a spin-state has the advantage, that spin-rephasing techniques can be applied to mitigate the decay of the efficiency with longer storage time.

The efficiency for spin-wave storage at the single photon level in a crystal was so far limited to around 31% using the spectral-hole memory protocol [2] which does not allow temporal multiplexing. The highest efficiency using spin-wave-storage with the atomic frequency comb protocol (AFC), which features intrinsic temporal multiplexing capability, was reported by Jobez et al [3] with 12% for bright classical pulses.

To compensate for the limited optical depth available in rare-earth doped crystals, it was suggested to place a weakly absorbing sample in an impedance matched optical cavity [4]. So far, this technique was demonstrated at quantum level only for storage in excited state, without on-demand read-out. Here we report the first demonstration of a cavity enhanced spin-wave quantum memory with on-demand read-out. Using the AFC in a Pr doped crystal, we reached a device efficiency over 38% for storage in the spin-state. Maintaining a good signal-to-noise ratio is more challenging for storage in the spin-state than in the excited state. In our case, we reached a signal-to-noise ratio of about 18 with a mean input photon number of 0.9, making it feasible to store photons from a SPDC source. We further investigated the effect of the impedance-matched cavity on the noise level and characterized efficiency and signal-to-noise ratio as a function of the input photon's bandwidth and storage time (see Figure 1).

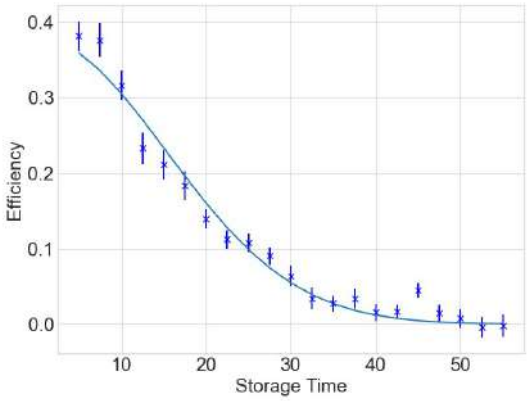


Figure 1: Scan of the device efficiency as a function of the on-demand storage time.

References

[1] M. Afzelius et al, Phys. Rev. A, 79 (2009) 052329
[2] K. Kutluer et al, Phys. Rev. A 93, 040302(R) (2016)
[3] P. Jobez et al, New J. Phys. 16 (2014) 083005
[4] M. Afzelius, and C. Simon, Phys. Rev. A, 82.2 (2010) 022310

Quantum Materials optolelectronics

Z. Zanolli

Utrecht University, Princetonplein 1, 3584 CC Utrecht, The Netherlands

z.zanolli@uu.nl

Controlling the properties of quantum materials via external stimuli is a key topic in modern condensed-matter physics. Due to its intrinsic quantum nature, light plays several roles: generating and controlling excited states, and forming hybrid quasiparticles with other excitations in solids. To unlock quantum advantage in electronic, photonic and energy technologies it is required to create new materials and manipulate their properties. To reach this goal we develop theory and simulation techniques to fully describe the interaction between light (photons), bound electron-holes pairs (excitons) and lattice vibrations (phonons) without adjustable parameters in a quantum many-body framework [1]. Using this approach, we compute optical properties of 2D materials and heterostructures and predict how these properties can be controlled by defect engineering, strain, or twisting. For instance, we find that vacancies in Transition Metal Dichalcogenides can univocally be identified by their absorption spectra and used as carriers of quantum information [2]. Further, we demonstrate the essential role played by exciton-phonon interaction in photoluminescence of negatively-charged boron vacancy in 2D hexagonal boron nitride [3], in achieving long spin-relaxation times in TMDs [4], and in characterizing the valley profile in TMDs [5]. We find intralayer and interlayer excitons in TMD heterostructures and use twisting to tune their absorption energy. Tunable materials are promising platforms for application in quantum information, quantum sensing, and quantum transport.

References

[1] D. Sangalli, *et al.*, J. Condens. Matter Phys. **31** (2019) 325902

[2] P.M.M.C. de Melo, Z. Zanolli, M. J. Verstraete, Adv. Quantum Technol. **3** (2021) 2000118

[3] F. Libbi, P.M.M.C. de Melo, Z. Zanolli, M. J. Verstraete, N. Marzari, Phys. Rev. Lett. **128**, 167401 (2022)

[4] M. Ersfeld, *et al.* Nano Lett. **196**, 4083-4090 (2019).

[5] T. Sohier, P. M.M.C. de Melo, Z. Zanolli, M. J. Verstraete, 2D Mater. **10**, 025006 (2023)

Figures

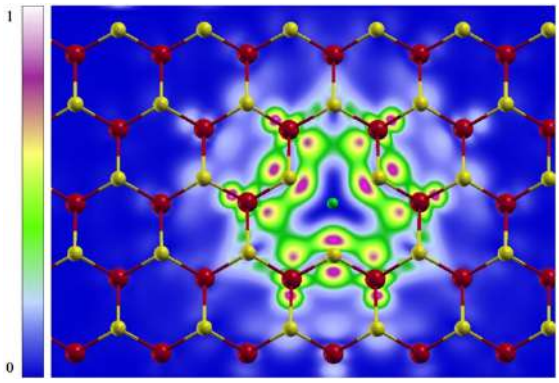


Figure 1: Excitonic wavefunction for an excitonic state localized on a W vacancy in WS_2. The electronic charge is highly localized near the missing W atom, indicating the formation of a quantum dot. Ref. [2]

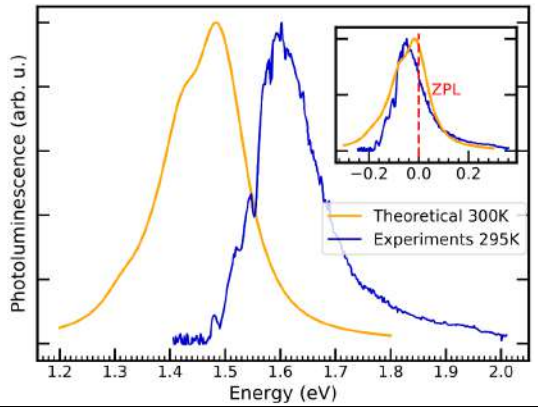


Figure 2: Theoretically predicted phonon-assisted luminescence normalized and compared to experiments. The insets shows the theoretical and experimental curves after aligning the zero phonon lines (ZPLs). Ref. [3]

Role of Lifshitz transitions and Berry curvature dipole on nonlinear Hall effect in low symmetry Bilayer graphene

Tanweer Ahmed[a]

Bao Q. Tu[a], Takashi Taniguchi[b], Kenji Watanabe[b], Marco Gobbi[c,d] , Félix Casanova[a,d] and Luis E. Hueso[a,d]

[a]*CIC nanoGUNE BRTA, 20018 Donostia-San Sebasti´an, Basque Country, Spain.*
[b]*National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan.*
[c]*Centro de Física de Materiales (CSIC-EHU/UPV) and Materials Physics Center (MPC), 20018 Donostia-San Sebastián, Basque Country, Spain*
[d]*IKERBASQUE, Basque Foundation for Science, 48009 Bilbao, Basque Country, Spain*

t.ahmed@nanogune.eu

Abstract

The second harmonic (2ω) nonlinear Hall effect (NLHE) [1,2] is both technologically relevant[2] and fundamentally important. On one hand, it can potentially bring a paradigm shift in logic and energy-harvesting technologies by replacing the age-old interface-based devices with their bulk crystal-based counterparts [3]. On the other hand, it provides rich information on the locations of saddle points [4] and flat bands and directly probes topological phase transitions in atomically thin Chern insulators [5]. Obtaining such information on electronic properties is crucial in the case of heterostructures of atomically thin quantum materials, where structural symmetry engineering and thermo-dynamically tunable complex quasiparticle bands coexist. In this work, we experimentally study NLHE on inversion symmetry broken high-quality bilayer graphene (BLG) as a function of doping (n) dielectric displacement filed (D) and temperature (T). Our results reveal an unforeseen duopoly of extrinsic scattering and interfacial strain-induced intrinsic Berry curvature dipole (BCD), whose sign and magnitude can be tuned by n and/or D near the low energy band edge of BLG. The second harmonic generation efficiency $V_{xx(Y)}^{2\omega}/V_{xx}^{\omega\ 2}$ in BLG is ~ 50 V^{-1}, highest among all scalable materials. Moreover, n − D dispersion of the sign change of $V_{xx(Y)}^{2\omega}$ traces out the topologically relevant Lifshitz transitions in BLG. Our work establishes BLG as a highly tunable platform to generate NLHE, which in turn probes the fascinating low-energy electronic structure in Bilayer graphene.

References

[1] Z. Z. Du *et al.* Nat. Commun. 10, 3047 (2019).

[2] M. S-Rodríguez *et al.* Phys. Rev. Lett. 132, 046303 (2024)

[3] H. Isobe *et al.* Sci Adv. 6, 13 (2020).

[4] P. He *et al.* Nat. Nanotechnol. 17, 378–383 (2022).

[5] S. Sinha *et al.* Nat. Phys. 18, 765–770 (2022).

Figures

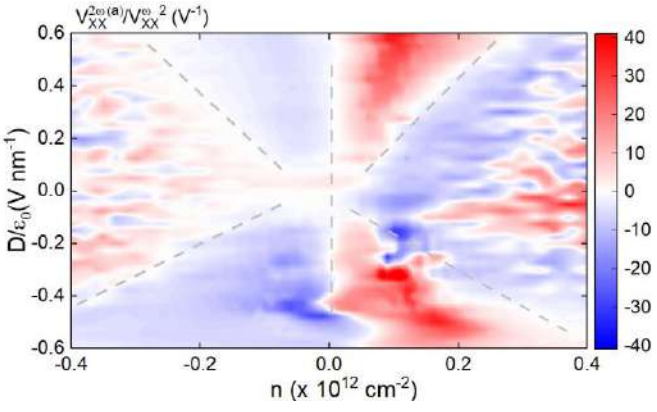


Figure 1: n-D phase space of $V_{xx}^{2\omega}/V_{xx}^{\omega\ 2}$ collected from one of our samples. The dashed lines indicate sign changes at charge neutrality and at Lifshitz transitions.

Orbital origin of hidden spin textures in centrosymmetric $PtSe_2$ monolayer and their proximity applications

Luis M. Canonico A.[1]
Jose Hugo García[1] and Stephan Roche[1,2]
[1]*ICN2, Universitat Autònoma de Barcelona, Edifici ICN2 Campus de la, Av. de Serragalliners, s/n, 08193 Bellaterra, Barcelona, Spain.*
[2]*Institució Catalana de Recerca i Estudis Avançats, 08070 Barcelona, Spain*
Luis.canonico@icn2.cat

Harnessing the quantum degrees of freedom has become an essential paradigm for sustainable technological development. In 2D materials, the combination of spin-orbit coupling and reduced crystalline symmetries gives rise to the Rashba-Eddelstein which enables electrical control of the spin degree of freedom of electrons. It is a common belief that global inversion asymmetry is required to the existence of such effect. However, there is experimental data has confirmed this prediction and evinced the existence of opposite helical spin textures on the atomic planes of centrosymmetric 1T $PtSe_2$ [1,2]. The 1T family of TMDs has not received as much attention as the other TMD polytypes and their topological aspects and properties are just being explored. Recent works from orbitronics -the orbital angular momentum analogue of spintronics- have inquired into their topological properties and demonstrated that the orbital angular momentum transport in these systems coexists with a higher-order topological phase [3]. In this work, we leveraged first-principles calculations and tight-binding models extracted from these, with symmetry analyses and large-scale transport simulations to demonstrate that the electrostatic origin of helical layer-localised spin and orbital textures and demonstrate their overlooked applicability for proximity effects and present an electrical probe for it.

References

[1] Yao, W., *et al. Nature communications*, *8,* 1, (2017), 14216.
[2] Clark, O. J., *et al.*, *Nature Communications*, *13,* 1, (2022), 4147.
[3] Costa, M., *et al.* Physical Review Letters, 130(11), (2023)116204.

Figures

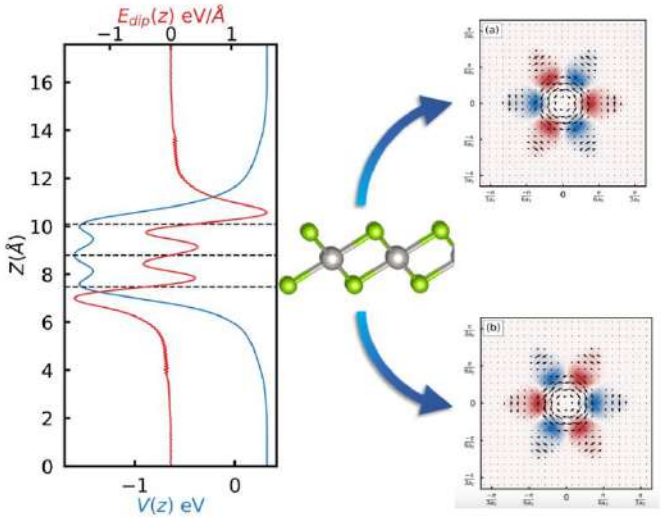


Figure 1 Real-space representation of the dipolar electric field in $PtSe_2$ monolayers and schematic depiction of layer-projected spin textures.

Artificial quantum systems based on semi-conducting quantum dots chains: towards quantum simulations in a SSH chain.

Pierre Capiod
Clément Barbot, Ludovic Desplanque, Xavier Wallart, Bruno Grandidier

Univ. Lille, CNRS, Centrale Lille, Univ. Polytechnique Hauts-de-France, Junia-ISEN, UMR 8520 - IEMN, F-59000 Lille, France

pierre.capiod@junia.com

Creating artificial quantum systems by choosing the position of atoms and their coupling is attracting as it opens to new band structure topologies. By carefully designing the artificial system, exotic phases could emerge such as topological insulating phases[1,2], Mott to superconductivty phase transition using flat band systems[3] or mimicking heavy fermion phases in a Kondo lattice[4]. Artifical systems have been realized using cold atom, polaritons and electrons[5-7]. Artificial electronic systems usually requires cryogenic temperature and nanometer scale size systems which make them incompatible with existing electronic setups. Moreover, designer artificial systems using the tip of a scanning tunnelling microscope to move atoms or molecules on a metallic surfaces, prevent any modification of the fermi level. Hence, no quantum simulations of exotic phase are possible. Patterning III-V semiconductors using e-beam lithography and etching is a promising top-down approach to create artificial systems in 2D materials by structuring it with an anti-dot lattice[8]. However, even if the Fermi level and the carrier density can be tuned, this technique suffer from high density defects after preparation, possibly hindering the emergence of topological properties. Bottom-up approaches such as Selective-Area Molecular Beam Epitaxy (SAMBE) proposes an alternative by depositing III-V semiconductors with controlled surfaces[9].

This talk will present first, the SAMBE growth of in-plane InGaAs and InSb quantum dots chains and second the characterization of the chains using scanning probe techniques. The morphology characterizations are done using atomic force microscopy (AFM) and scanning tunnelling microscopy (STM). The electronic properties are probed by tunnelling spectroscopy and finally, preliminary results on the modification of the Fermi level using side electrodes are measured using kelvin-probe force microscopy. The electronic properties will be compared to atomistic tight-binding calculations.

This preliminary work is a step towards the quantum simulation of a Su-Schrieffer-Heeger model using III-V semi-conducting quantum dots chains.

References

[1] **Kempkes, S. N. et al.** In: Nat. Mater. 18.12 (2019), 1292–1297.
[2] **Kempkes, S. N., Capiod, P. et al.** In: Quantum Front 2.1 (2023).
[3] Kerelsky, A. et al. In: Nature 572.7767 (2019), 95–100.
[4] Figgins, J et al. In: Nat. Comm. 10.5588 (2019).
[5] Gomes, K. K. et al. In: Nature 483 (2012), p. 306.
[6] Atala, D. et al. In: Nat. Phys. 9 (2013), p. 795-800.
[7] St-Jean, P. et al. In: Nat. Photon. 11 (2017), p. 651-656.
[8] **Franchina Vergel, N. A. et al.** In: Phys. Rev. Mater. 3 (2019), p. 094604.
[9] **Bucamp, A. et al.** In: J. Crys. Growth 512 (2019), 11–15.

Figures

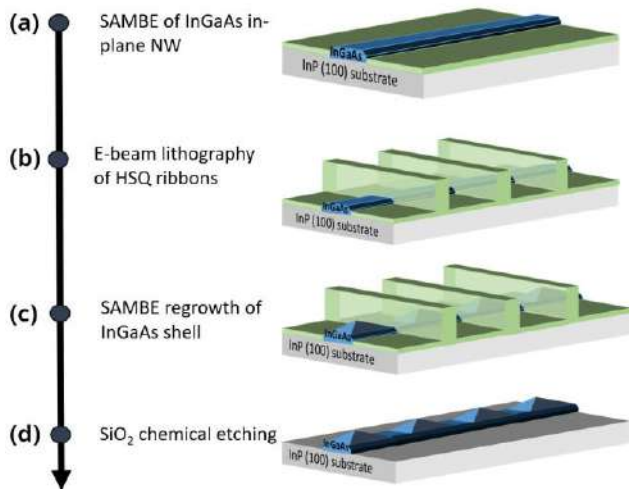


Figure 1: Selective-Area Molecular Beam Epitaxy step to create III-V quantum dots chains.

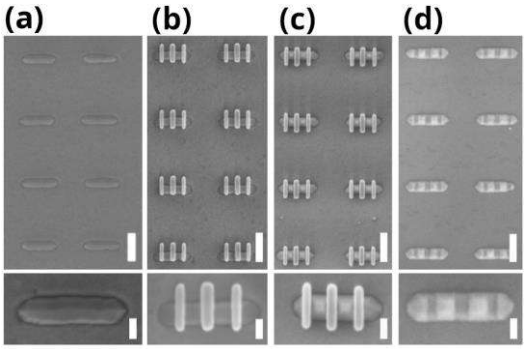


Figure 2: Scanning electron microscopy images of the SAMBE steps illustrated in figure 1.

Hydrodynamic electron flow in graphene

Enrique Diez[1]

Juan Salvador-Sánchez,[1] Jorge Estrada Álvarez,[2] Carlos Sánchez-Sánchez,[1] Abhay Gupta,[3] Ana Pérez-Rodríguez,[1] Vito Clericò,[1] Oleh Klochan,[3] Feixiang Xiang,[3] Daniel Vaquero,[1] Kenji Watanabe,[4] Takashi Taniguchi,[5], Aydin Keser,[3] Oleg Sushkov,[3] Alexander Hamilton,[3] Francisco Domínguez-Adame,[2] Elena Díaz García,[2] Mario Amado.[1]

[1]*Nanotechnology Group, USAL-Nanolab, Universidad de Salamanca, E-37008 Salamanca, Spain.*
[2]*GISC, Departamento de Física de Materiales, Universidad Complutense de Madrid, E-28040 Madrid, Spain.*
[3]*School of Physics, University of New South Wales, Sydney, New South Wales 2052, Australia*
[4]*Research Center for Functional Materials, National Institute for Materials Science Tsukuba 305-0044, Japan.*
[5]*International Center for Materials Nano-architectonics, National Institute for Materials Science, Tsukuba 305-0044, Japan.*

enrisa@usal.es

Abstract

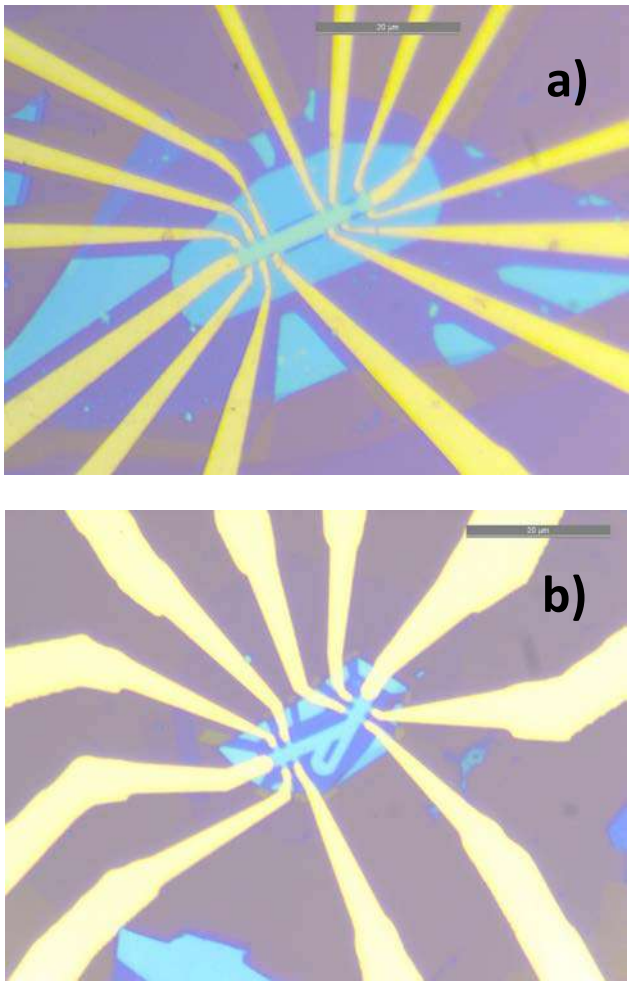
Viscous electron flowing in graphene exhibits exotic signatures such as superballistic conduction. Twisting the geometry of the device is a must to observe hydrodynamic effects, and so, we have built different samples with different geometries, like nanoconstrictions, crenellated channels, Tesla valves and some others, designed to enhance hydrodynamic effects. We will show their electrical response as function of tempe-rature, carrier density and external magnetic field, finding for some of them scaling laws which help us discuss the different transport regimes. We support our findings with detailed simulations of the Boltzmann transport equation and have found an enhanced superballistic effect with a non-monotonic behaviour with the magnetic field. Our simulations provide the explanation for our experimental results contributing to a better under-standing of hydrodynamic transport and super-ballistic conduction.

References

[1] M. Polini and A. K. Geim, *Viscous electron fluids*, Phys.Today **73**, 28 (2020).
[2] G. Varnavides, A. Yacoby, C. Felser, and P. Narang, *Charge transport and hydrodynamics in materials*, Nat. Rev. Mater. **8**, 726 (2023).
[3] Aydın Cem Keser et al. *Geometric Control of Universal Hydrodynamic Flow in a Two-Dimensional Electron Fluid.* Phys. Rev. X **11,** 031030 (2021).
[4] Vito Clericò et al. *Quantum nanoconstrictions fabricated by cryo-etching in encapsulated graphene*. Sci Rep **9**, 13572 (2019).

Figures

Figure 1: Optical images of two of our typical devices: **a)** Crenellated channel with a nano-constriction. **b)** Tesla valve geometry.



Large Anomalous Ettingshausen effect in a micron-sized magnetic Weyl semimetal on-chip cooler

Pascal Gehring[1]
Mohammadali Razeghi[1], Jean Spiece[1], Valentin Fonck1, Yao Zhang[3], Michael Rohde[1], Rikkie Joris[2], Philip S. Dobson[4], Jonathan M. R. Weaver[4], Lino da Costa Pereira[2], Simon Granville[3]

[1]*IMCN/NAPS, Université Catholique de Louvain (UCLouvain), Louvain-la-Neuve, 1348, Belgium.*

[2]*QSP, KU Leuven, Leuven, 10587, Belgium.*

[3]*Robinson Research Institute, Victoria University of Wellington, Wellington, 610101, New Zealand.*

[4]*James Watt School of Engineering, University of Glasgow, Glasgow, G12 8LT, United Kingdom.*

pascal.gehring@uclouvain.be

Solid-state cooling devices offer compact, quiet, reliable and environmentally friendly solutions that currently rely primarily on the thermoelectric (TE) effect. Despite more than two centuries of research, classical thermoelectric coolers suffer from low efficiencies which hampers wider application. In this study, the less researched Anomalous Ettingshausen effect (AEE), a transverse thermoelectric phenomenon, is presented as a new approach for on-chip cooling. This effect can be boosted in materials with non-trivial band topologies as demonstrated in the Heusler alloy Co_2MnGa. Enabled by the high quality of our material, in situ scanning thermal microscopy experiments reveal a record-breaking anomalous Ettingshausen coefficient in µm-sized on-chip cooling devices at room temperature. A significant boost of 44% of the effect by the intrinsic topological properties, in particular the Berry curvature of Co_2MnGa, emphasises the unique potential of magnetic Weyl semimetals for high-performance spot cooling in nanostructures.

Figures

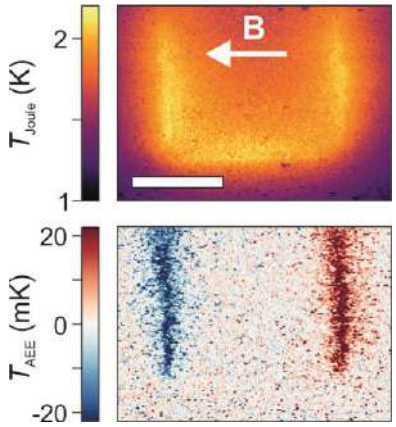


Figure 1: Anomalous Ettingshausen effect (bottom panel) and Joule heating (top panel) in "U"-shaped Co_2MnGa micro devices. Scale bar: 10µm.

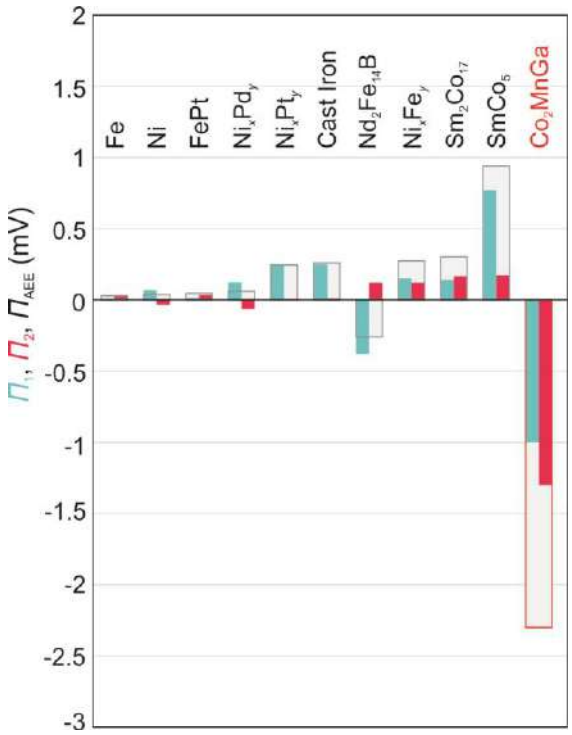


Figure 2: Total Ettingshausen coefficient Π_{AEE} (grey bars) and its contributions Π_1 (from Berry phase, blue bars) and Π_2 (from spin-orbit scattering, red bars).

Large tunable kinetic inductance in a twisted graphene superconductor

Paritosh Karnatak[1]
Rounak Jha[1,2], Martin Endres[1], Kenji Watanabe[3], Takashi Taniguchi[4], Mitali Banerjee[2] and Christian Schönenberger[1,5]

1 Department of Physics, University of Basel, Basel, Switzerland
2 Laboratory of Quantum Physics (LQP), École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland
3 Research Center for Functional Materials, National Institute for Material Science, 1-1 Namiki, Tsukuba 305-0044, Japan
4 International Center for Materials Nanoarchitectonics, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan
5 Swiss Nanoscience Institute, University of Basel, Basel, Switzerland

paritosh.karnatak@unibas.ch

Abstract

The discovery of emergent phases such as correlated insulators and superconductors in graphene-based moiré heterostructures offers a playground with a rich phase space that is electrostatically tunable.
Here, we investigate superconductivity in magic angle twisted trilayer graphene (MATTG) by integrating it as the weak link in a SQUID (superconducting quantum interference device) loop. We study the current phase relation (CPR) of MATTG in various configurations by electrostatically tuning the two weak links. We show that superconducting MATTG has a large kinetic inductance up to 150~nH per square which is electrostatically tunable. This opens avenues for using MATTG as a tunable element in superconducting circuits.

References

[1] Bistritzer, R., MacDonald, A.H.,Proceedings of the National Academy of Sciences, 108(30) (2011) 12233–12237
[2] Cao, Y., Fatemi, V., Fang, S., Watanabe, K., Taniguchi, T., Kaxiras, E., Jarillo-Herrero, P., Nature 556(7699) (2018) 43–50
[3] Cao, Y., Fatemi, V., Demir, A., Fang, S., Tomarken, S.L., Luo, J.Y., Sanchez-Yamagishi, J.D., Watanabe, K., Taniguchi, T., Kaxiras, E., et al., Nature 556(7699) (2018) 80–84
[4] Khalaf, E., Kruchkov, A.J., Tarnopolsky, G., Vishwanath, A., Phys. Rev. B 100 (2019) 085109
[5] Lu, X., Stepanov, P., Yang, W., Xie, M., Aamir, M.A., Das, I., Urgell, C., Watanabe, K., Taniguchi, T., Zhang, G., et al., Nature 574(7780) (2019) 653– 657
[6] Park, J.M., Cao, Y., Watanabe, K., Taniguchi, T., Jarillo-Herrero, P., Nature 590(7845) (2021) 249–255
[7] Hao, Z., Zimmerman, A., Ledwith, P., Khalaf, E., Najafabadi, D.H., Watanabe, K., Taniguchi, T., Vishwanath, A., Kim, P., Science 371(6534) (2021) 1133–1138

Implementation of the Bilayer Hubbard Model in a Moiré Heterostructure

Borislav Polovnikov
J. Scherzer, S. Misra, H. Schlömer, J. Trapp, X. Huang, C. Mohl, Z. Li, J. Göser, J. Förste, I. Bilgin, K. Watanabe, T. Taniguchi, A. Bohrdt, F. Grusdt, A. S. Baimuratov, and A. Högele

Ludwig-Maximilians-Universität, Geschwister-Scholl-Platz 1, 80539 Munich, Germany

borislav.polovnikov@physik.uni-muenchen.de

Moiré materials provide a unique platform for studies of correlated many-body effects, implementing the two-dimensional Fermi-Hubbard model on a triangular spin-charge lattice. In that context, bilayer systems present particular interest concerning exotic states of matter, but their experimental implementation has so far remained elusive. here, we demonstrate the realization of a staggered bilayer triangular lattice of electrons in an antiparallel $MoSe_2/WS_2$ heterostructure. The bilayer lattice emerges due to strong electron confinement in the moiré potential minima and the near-resonant alignment of conduction band edges in $MoSe_2$ and WS_2. As a result, charge filling proceeds layer-by-layer, with the first and second electron per moiré cell consecutively occupying first the $MoSe_2$ and then the WS_2 layer. We describe the observed charging sequence by an electrostatic model and provide experimental evidence of antiferromagnetic spin correlations on the vertically offset and staggered bilayer lattice, yielding absolute exciton Landé factors as high as 600 at lowest temperatures. The bilayer character of the implemented spin-charge lattice allows for electrical tunability of the spin exchange coupling and establishes antiparallel $MoSe_2/WS_2$ heterostructures as a valuable system for studies of strongly coupled bilayer Hubbard model physics, enabling future studies of exotic magnetic phases in frustrated lattices.

References

[1] Tang et al., Nature 579, 353 (2020)
[2] K. F. Mak, J. Shan, Nat. Nanotech 17, 686 (2022)
[3] Ciociaro, Smolénski et al., Nature 623, 509 (2023)
[4] Polovnikov, Scherzer, Misra et al., Phys. Rev. Lett. 132, 076902 (2024)

Figures

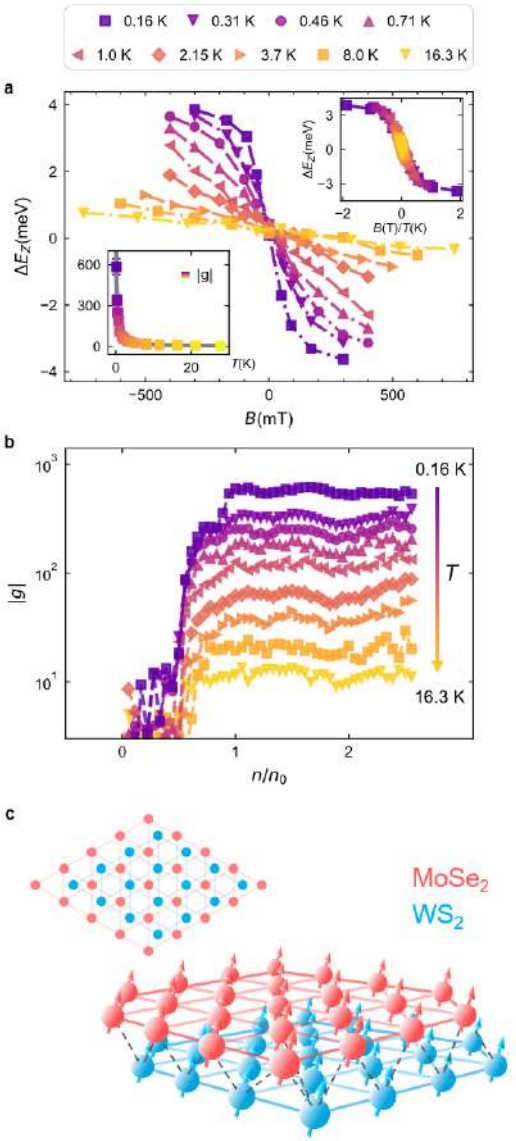


Figure 1: Electrically controlled, doping-dependent spin-susceptibility of a bilayer moiré heterostructure probed at mK temperatures.

Tunable Edge Magnetoplasmon Resonator

Quantum Hall (QH) systems are platforms of choice when it comes to study topological properties of condensed matter systems. Edge magnetoplasmons (EMPs) are the low-energy excitations of a 2DEG in the QH regime. These chiral collective excitations propagate along the electrostatic edge of the 2DEG at a velocity v fixed by the magnetic field B. In an isolated Hall island, these trajectories are closed loops, making it possible to create a resonant cavity for EMPs. Such resonance depends on both the velocity v of the EMPs and the perimeter L of the cavity through the relation f=v/L. Since the EMPs propagate along the edge of the QH island, it is possible to tune the resonant frequency by changing the perimeter of the resonator. Varying the perimeter is made possible by a set of QPCs and top gates deposited on the sample. Applying a strong enough potential on a top gate changes locally the electronic density of the 2DEG and a new edge arises at the interface. With a few top gates, it is possible to design various cavities in the same sample, thus changing the resonance frequency.
In this seminar, we present our results on tunable micrometer-sized resonators with resonances in the GHz range and we show how the gates couple capacitively to the QH island. This allows us to fully control the properties of our resonator, making it possible to develop an EMP interferometer. Such device would be a valuable tool to investigate the properties of quasiparticles in the fractional QH regime.

Annihilation operators for 2D non-abelian anyons

Nicetu Tibau Vidal
Lucia Vilchez Estevez

Clarendon Laboratory, University of Oxford, Parks Road, OX1 3PU, Oxford, United Kingdom

nicetutv@gmail.com

Abstract

2D non-abelian anyons are formalised in a diagrammatic formalism [1]. Topological quantum computing proposes to use these systems to encode quantum information. Such method obtains a natural shielding from decoherence [2]. We present a completely new perspective on these systems proposed in [3].

In this talk, we define annihilation operators for any 2D non-abelian anyon theory. Such characterization has been desired for many years. We explicitly construct the annihilation operators for Fibonacci anyons.

We express the Fibonacci-Hubbard Hamiltonian in terms of the Fibonacci annihilation operators and study their properties.

Very interestingly we find that any non-abelian anyon type has more than a single annihilation operator associated to it. The number of annihilation operators is linked to the possible fusion channels of the anyon type.

We discuss the implications of our findings for topological quantum computing and possible future realisations of non-abelian anyons in the lab.

References

[1] P. Bonderson. " Non-Abelian Anyons and Interferometry". Dissertation (Ph.D.) Caltech. (2007)

[2] A. Y. Kitaev. "Fault tolerant quantum computation by anyons". Annals Phys. 303. (2003) 2-30

[3] N. Tibau Vidal and L. Vilchez-Estevez. "Creation and annihilation operators for 2D non-abelian anyons". ArXiv. /abs/2304.10462 (2024). Sent to Phys. Rev. B

Figures

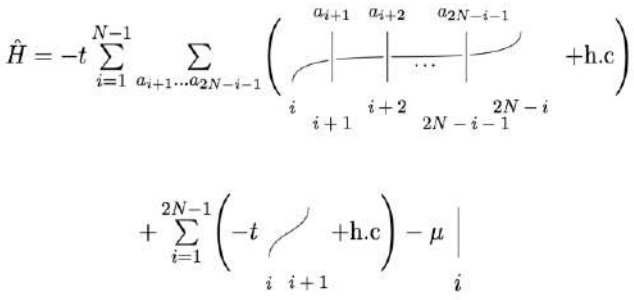


Figure 1: Fibonacci Hubbard model in the diagrammatic formalism.

$$\hat{H} = -t \sum_{i=1}^{N-1} \left(\alpha^{\dagger}_{2N-i+1} \alpha_i + \beta^{\dagger}_{2N-i+1} \beta_i \right) + \text{h.c.}$$
$$-t \sum_{i=1}^{2N-1} \left(\alpha^{\dagger}_{i+1} \alpha_i + \beta^{\dagger}_{i+1} \beta_i \right) + \text{h.c.}$$
$$-\mu \sum_{i=1}^{2N} \left(\alpha^{\dagger}_i \alpha_i + \beta^{\dagger}_i \beta_i \right)$$

Figure 2: Fibonacci Hubbard model with the annihilation operators α and β.

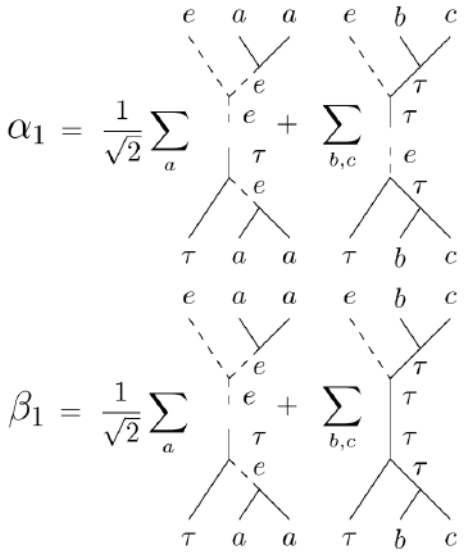


Figure 3: Fibonacci annihilation operators α and β on the first mode.

Theory of non-conserved density accumulations in the anomalous Hall effects

Presenting Author: Giovanni Vignale[1]
Co-Authors: Hao Sun[1], Alexander Kazantsev[2], Alessandro Principi[2]

1. I-FIM, National University of Singapore, 4 Science Drive 2, Singapore 117544
2. Department of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK

Contact@E-mail: vgnl.g@nus.edu.sg

Abstract

We present a comprehensive theory of the stationary density accumulations that arise in anomalous transport phenomena such as the spin Hall effect, the valley Hall effect, and the orbital Hall effect, where the transported density underlying "charge" (spin, valley imbalance, orbital magnetic moment respectively) is not protected by a conservation law [1]. The theory affords a unified treatment of metals and insulators, topologically trivial or nontrivial, while carefully keeping track of distinct contributions from bulk and edge states as well as under-gap and dissipative currents. We show that the under-gap current does not produce any density accumulation for time-reversal invariant systems: only dissipative currents arising from states at the Fermi surface can do so. We refer to this result as the *"no-dissipation-no-accumulation theorem"*. For time-reversal non-invariant systems, we show that non-dissipative density accumulations can appear (e.g., magnetoelectric polarization) both at the edge and in the bulk. In either case, it is found that the net density accumulation integrated over the sample does not necessarily vanish: as a result of "charge" non-conservation, the density accumulations can have the same sign on both edges of a nanoribbon. In this context, we discuss previous proposals to treat charge non-conservation by a redefinition of the current [2] and show why they are insufficient. We discuss how the formalism for periodic systems is extended to include the effects of disorder. Finally, we illustrate the formalism by applying it to simple two-dimensional models with edge terminations. In this context, we discuss the peculiar status of the anomalous Hall effect in which the redistribution of the electric charge density, protected by electric charge conservation, allows non-dissipative under-gap currents to coexist with edge density accumulations.

References

[1] A. Kazantsev et al., Phys. Rev. Lett 2024 (in press)
[2] J. Shi et al., Phys. Rev. Lett.96, 076604 (2006)

Figures

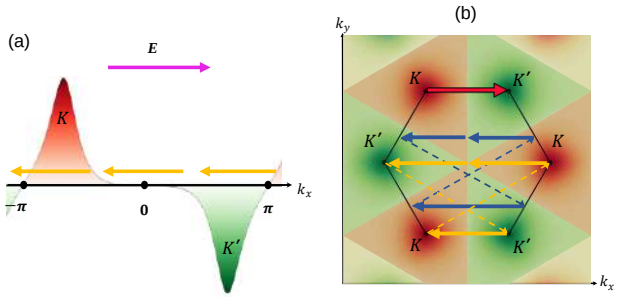


Figure 1: Illustration of the no-dissipation-no-accumulation theorem. Panel (a): The cyclic flow of electrons (yellow arrows) in the one-dimensional Brillouin zone of a ribbon subject to the electric field E (pink arrow). The valley charge changes sign whenever k_X crosses the boundaries between the red and green regions ($k_X = 0, \pm\pi$). Each electron performs half the cycle as a "left-valley electron" and half as a "right-valley electron". Also shown are the Berry curvature hot spots with positive (negative) value near K (K'). Due to opposite Berry curvatures in the two valleys, the result is a steady valley Hall current. However, in a fully gapped insulator, at the end of the cycle each electron returns to its initial state, thus no valley redistribution occurs and there is no valley density accumulation. Panel (b): Two examples (blue and yellow arrows) of the same flow in the two-dimensional Brillouin zone of the infinite system.

Giant Resistance Switch in Twisted Transition Metal Dichalcogenide Tunnel Junctions

Marc Vila

Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA.
Department of Physics, University of California, Berkeley, California 94720, USA.

marcvila@berkeley.edu

Resistance switching in multilayer structures are typically based on materials possessing ferroic orders. Here we predict an extremely large resistance switching based on the relative spin-orbit splitting in twisted transition metal dichalcogenide (TMD) monolayers tunnel junctions. Because of the valence band spin splitting which depends on the valley index in the Brillouin zone, the perpendicular electronic transport through the junction depends on the relative reciprocal space overlap of the spin-dependent Fermi surfaces of both layers, which can be tuned by twisting one layer. Our quantum transport calculations reveal a switching resistance of up to 10^6 % when the relative alignment of TMDs goes from 0° to 60° and when the angle is kept fixed at 60° and the Fermi level is varied. By creating vacancies, we evaluate how inter-valley scattering affects the efficiency and find that the resistance switching remains large (10^4 %) for typical values of vacancy concentration. Not only should this resistance switching be observed at room temperature due to the large spin splitting, but our results also show how twist angle engineering and control of van der Waals heterostructures could be used for next-generation memory and electronic applications.

Figures

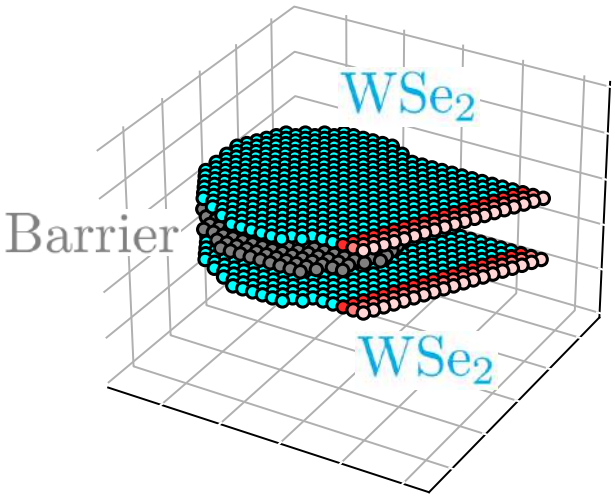


Figure 1: Schematic of the tunnel junction comprised of a TMD monolayer, a barrier and another TMD monolayer that can be rotated. Red sites correspond to the semi-infinite leads.

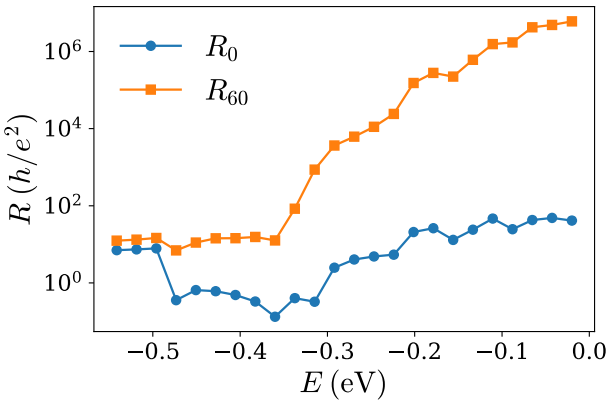


Figure 2: Tunneling resistance for twist angle of 0° (blue) and 60° (orange).

References

[1] Marc Vila, arXiv:2311.08397 (2023)

Secure key rate improvement methods in DI-QKD protocols

Maryam Afsary
Morteza Moradi, Magdalena Stobińska

Institute of Informatics, Faculty of Mathematics, Informatics and Mechanics, University of Warsaw, Banacha 2c, 02--097 Warsaw, Poland

m.afsary@uw.edu.pl

Abstract

Secure communication is of paramount importance in various fields, ranging from government and military to financial and healthcare. Quantum Key Distribution (QKD) leverages the unique properties of quantum mechanics to offer a promising solution. In conventional QKD protocols, the security relies on the specific implementation of the devices used by the legitimate parties. However, device-independent QKD (DI-QKD) protocols offer a more robust security guarantee by eliminating the need for trusted devices. DI-QKD protocols are based on the violation of Bell inequalities, which ensures security against any eavesdropping attempt, irrespective of the devices employed.

Two key factors in any QKD protocol are the distance over which secure keys can be distributed and the rate at which keys can be generated. The distance is limited by the attenuation of quantum signals, while the key rate is affected by various factors, including the channel noise and the efficiency of the detector. On the other side, by optimizing the post-processing stage, we can improve the key rate and distance of existing protocols, making DI-QKD more practical for real-world applications. These techniques involve manipulating the raw data generated by the protocol to extract a secure key, like what happens in post-selection [1] and noisy pre-processing [2].

In this work, we employed post-processing techniques to improve key rate in the DI-QKD protocol based on photon number counting [3]. We investigate three different methods to fulfill this goal.

In the first method, we leverage the CHSH inequality to calculate an analytical lower bound on the key rate[4], reaching approximately to 0.71 for the specified protocol. While simple, this method often underestimates the full existing correlations. To improve the results, we explore other methods. A more sophisticated approach numerically calculates a reachable lower bound on the key rate by considering conditional von Neumann entropy [5]. It significantly improves the rate to around 0.95, demonstrating substantial potential. However, this method may not always be feasible depending on numeric complexity, requiring alternative approaches in such cases. This method focuses on the entire raw key statistics to establish a lower bound on the key rate based on Eve's guessing probability. While the obtained rate of 0.93 is slightly lower than the numerical method, this approach guarantees its validity regardless of the parameters. Both numerical methods employed optimization techniques such as the NPA hierarchy and Semidefinite Programming (SDP) to further refine the results.

Overall, our analysis demonstrates that post-processing techniques can significantly boost the key rate of the photon-counting DI-QKD protocol. Each method offers distinct advantages and drawbacks, allowing researchers to choose the most suitable approach depending on their specific needs and priorities.

References

[1] F. Xu, Y. Zhang, Q. Zhang, and J. Pan, PRL, 128 (2022) 110506
[2] M. Ho, P. Sekatski, E. Tan, R. Renner, J. Bancal, and N. Sangouard, PRL, 124 (2020) 230502
[3] M. Mycroft, T. McDermott, A. Buraczewski, and M. Stobińska, PRA, 107 (2023) 012607
[4] S. Pironio, A. Acin, N. Brunner, N. Gisin, S. Massar, V. Scarani, New Journal of Physics, 11 (2009) 045021
[5] P. Brown, H. Fawzi, and O. Fawzi, arXiv preprint arXiv:2106.13692 (2021)

Combining Matrix Product States and Noisy Quantum Computers for Quantum Simulation

Baptiste ANSELME MARTIN
Thomas Ayral (Eviden), François Jamet (National Physical Laboratory/IQM), Marko Rancic (TotalEnergies/Heidelberg), Pascal Simon (University Paris-Saclay)

Eviden Quantum Lab, Clayes-sous-Bois, France

baptiste.anselmemartin@eviden.com

Matrix Product States (MPS) and Operators (MPO) have proved to be powerful tools to simulate quantum many-body systems. While MPS can efficiently find ground states of 1D systems, they fail to simulate their dynamics, where the entanglement can increase ballistically with time. On the other hand, quantum devices are natural platforms to perform time evolution but are strongly hampered by noise. In this work [1], we use the best of both worlds: the short-time dynamics is efficiently performed by MPSs, compiled into short-depth quantum circuits, and is performed further in time on a quantum computer thanks to efficient MPO-optimized quantum circuits (Fig.1). In this scheme (that we call "QMPSO"), tensor networks provide all the ingredients to the quantum computer for a resource-efficient quantum simulation, and drastically lower the noise requirements for a practical advantage. Finally, we successfully demonstrate our method on an actual quantum device (Fig.2) from IBM: we simulate experimentally a 10-qubit system over a longer time scale than low-bond-dimension MPSs and purely quantum Trotter evolution.

References

[1] B. Anselme Martin, T. Ayral, F. Jamet, M. Rancic, P. Simon, arXiv pre-print [2305.19231] (2023)

Figures

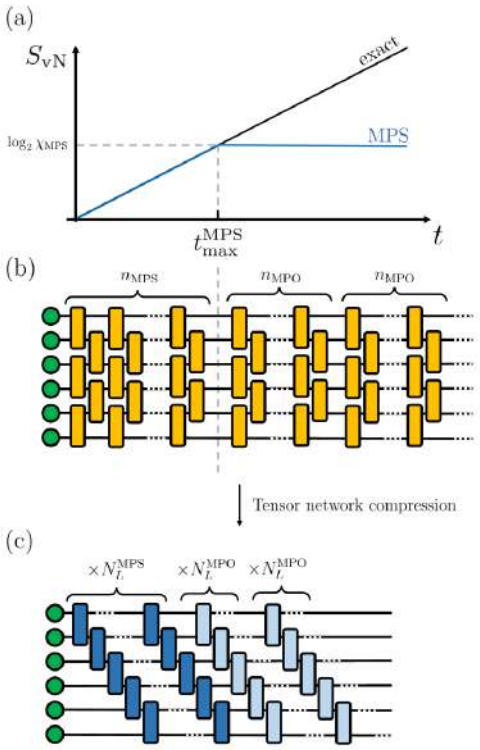


Figure 1: (a) The entanglement entropy increases with time using the Trotter quantum circuit in (b). Using tensor network techniques, we compress the circuit (b) into a short-depth entanglement-efficient quantum circuit (c).

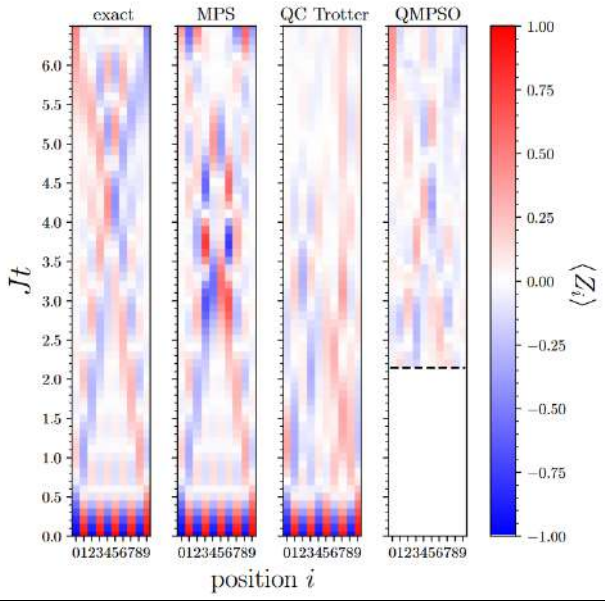


Figure 2: Evolution in time of the local magnetization in time for a L = 10 quantum Ising chain for the exact solution versus MPS, Trotter and QMPSO simulations on IBM devices.

Mixed quantum-classical dynamics for near term quantum computers

Daniel Bultrini
Oriol Vendrell

University of Heidelberg, Grabengasse 1, 69117, Heidelberg, Germany

Daniel.bultrini@pci.uni-heidelberg.de

Mixed quantum-classical dynamics is a set of methods often used to understand systems too complex to treat fully quantum mechanically. Many techniques exist for full quantum mechanical evolution on quantum computers, but mixed quantum-classical dynamics are less explored. We present a modular algorithm for general mixed quantum-classical dynamics where the quantum subsystem is coupled with the classical subsystem. We test it on a modified Shin-Metiu model in the first quantization through Ehrenfest propagation. We find that the Time-Dependent Variational Time Propagation algorithm performs well for short-time evolutions and retains qualitative results for longer-time evolutions.

Figures

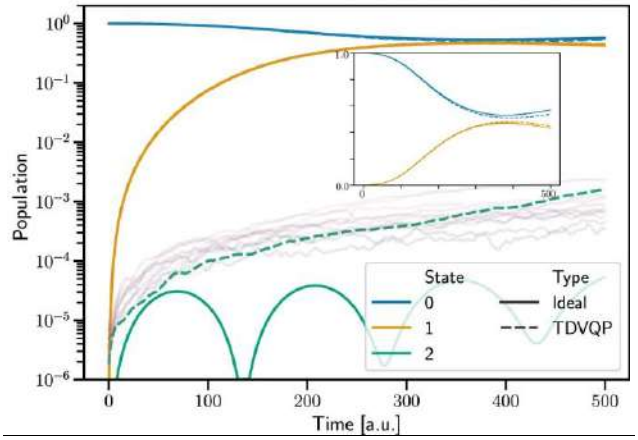
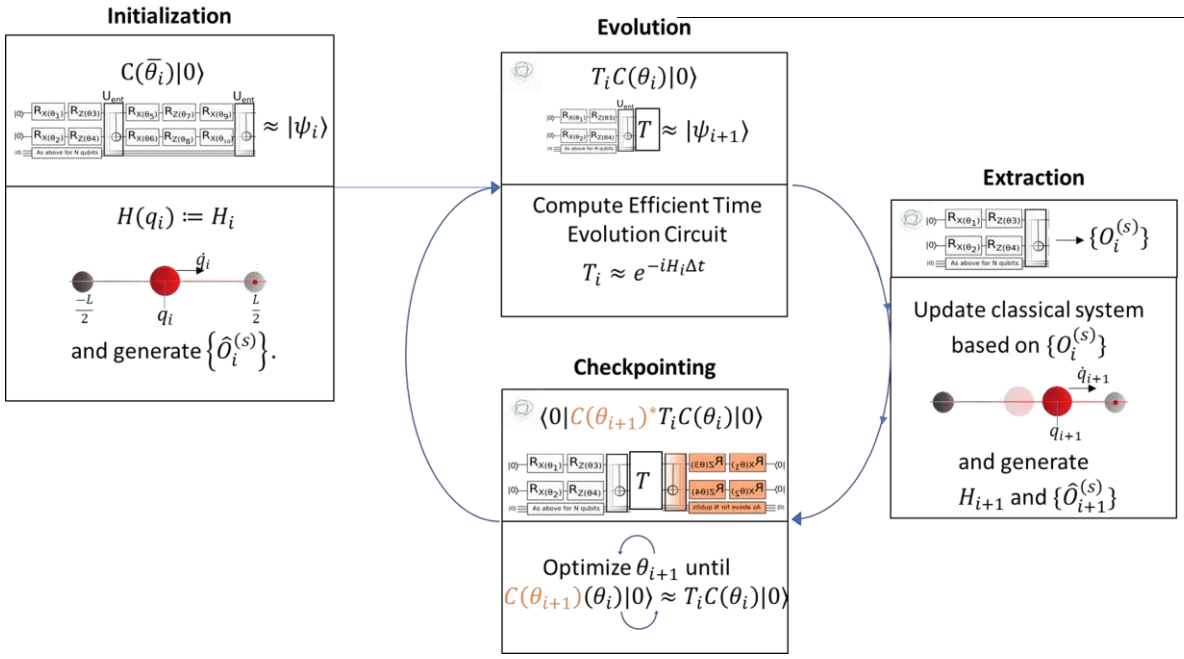


Figure 1: Plot showing the state population (colours) dynamics populations of the Shin-Metiu Model with exact evolution (solid) compared to evolution on the quantum computer (dashed).

Figure 2: Cartoon showing the algorithm cycle. This includes initialization of the state, evolution of the quantum system, evolution of the classical system and the checkpointing of the algorithm which allows for long time evolution in a constant depth circuit.



Hierarchies of quantum metrology bounds beyond Cramér-Rao

Manuel Gessner
Departamento de Física Teórica, IFIC, Universidad de Valencia, CSIC, C/ Dr. Moliner 50, 46100 Burjasot (Valencia), Spain

Augusto Smerzi
QSTAR, INO-CNR and LENS, Largo Enrico Fermi 2, 50125 Firenze, Italy

manuel.gessner@uv.es

The cornerstone of modern quantum metrology is the quantum Cramér-Rao bound (QCRB). This bound identifies a lower limit on the variance of unbiased estimators for an unknown parameter that is encoded into a quantum state. Under generic conditions, this bound can be saturated by an optimal estimator and measurement, provided that many repeated measurements on the system are performed.

However, in the presence of small data sets the QCRB typically largely underestimates the error that can actually be achieved in practice. In this talk, we present a family of generalized bounds on the variance of unbiased estimators that are larger than the QCRB when the sample is small and thereby provide a more realistic limit on the achievable precision of a finite-sample quantum measurement.

Generalized bounds are obtained by imposing stricter unbiasedness conditions. These can be formulated in the form of constraints (i) on the average estimator at different test points within the range of possible values, or (ii) on higher-order derivatives of the estimator. Both of these approaches lead to rich hierarchies of bounds that contain the QCRB at the lowest order. All quantum bounds are derived by optimizing classical bounds over all possible quantum measurements. We provide analytical expressions for the explicit construction of the bounds and of the optimal measurements.

The generalized bounds identify threshold behavior at small data sets by revealing tighter precision limits than the QCRB (see Fig. 1). In the large-data limit, the hierarchy of bounds collapses back onto the QCRB.

From the inverse of these bounds we identify quantum information functions that generalize the quantum Fisher information (QFI). The QFI has widespread applications in quantum information theory beyond its immediate scope in quantum metrology. Our results therefore open up a wide spectrum of new quantum information functions whose full potential still remains to be uncovered.

References

[1] M. Gessner and A. Smerzi, *Hierarchies of Frequentist Bounds for Quantum Metrology: From Cramér-Rao to Barankin*, Phys. Rev. Lett. **130**, 260801 (2023).

Figures

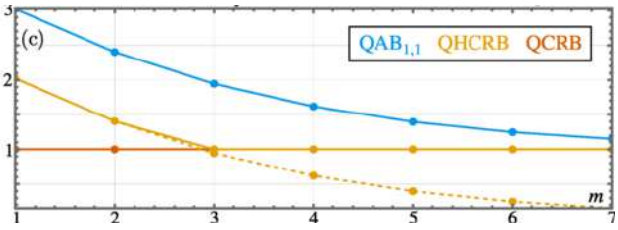


Figure 1: Comparison between the QCRB (orange) and generalized bounds known as the quantum Abel bound (QAB, blue) and the quantum Hammersley-Chapman-Robbins bound (QHCRB, yellow) for a single qubit (see Ref. [1] for details). The plots show the quantum bounds as a function of the number of measurements m (bottom): We observe that for small m, the QCRB is too optimistic.

Quantum control of continuous systems via nonharmonic potential modulation

Piotr T. Grochowski[1,2,*]
Hannes Pichler[1,2]
Cindy A. Regal[3,4]
Oriol Romero-Isart[1,2]

[1]*Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria*
[2]*Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria*
[3]*JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado 80309, USA*
[4]*Department of Physics, University of Colorado, Boulder, Colorado 80309, USA*
[*]piotr.grochowski@uibk.ac.at

The preparation of a continuous-variable system in a non-Gaussian quantum state is of paramount importance in various aspects of quantum science. The generation of non-Gaussian states requires a nonlinear resource, often introduced through coupling to an auxiliary degree of freedom, such as a two-level system. On the other hand, some continuous-variable systems already possess intrinsic nonlinearity in the potential of a canonical variable. These nonharmonicites in the potential are typically used to define a qubit within continuous-variable systems. In contrast, we explore methods for utilizing this intrinsic nonlinearity to generate and control states beyond the two-dimensional subspace.

Specifically, we present a theoretical proposal for preparing and manipulating a state of a single continuous-variable degree of freedom confined to a nonharmonic potential [1]. By utilizing optimally controlled modulation of the potential's position and depth, we demonstrate the generation of non-Gaussian states, including Fock, Gottesman-Kitaev-Preskill, multi-legged-cat, and cubic-phase states, as well as the implementation of arbitrary unitaries within a selected two-level subspace. Additionally, we propose protocols for single-shot orthogonal state discrimination and algorithmic cooling and analyze the robustness of this control scheme against noise. Since all the presented protocols rely solely on the precise modulation of the effective nonharmonic potential landscape, they are relevant to several experiments with continuous-variable systems, including the motion of a single particle in an optical tweezer or lattice, or current in circuit quantum electrodynamics. Moreover, the proposed protocols can be utilized in systems with very weak nonharmonicities, e.g., levitated nanoparticles.

References

[1] P. Grochowski et al., arXiv:2311.16819

Figures

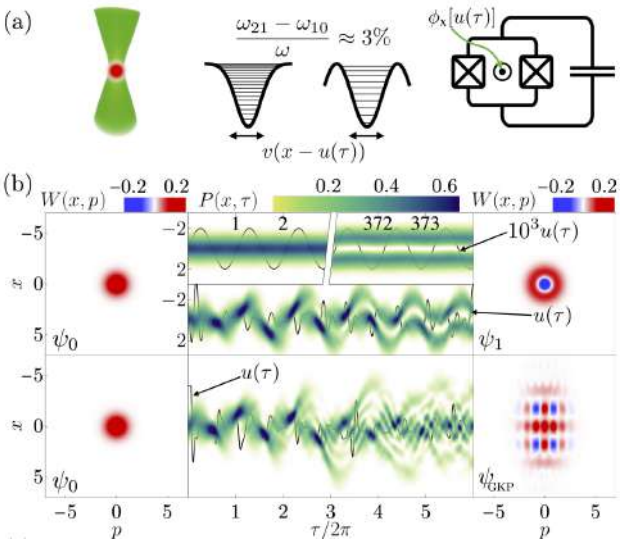


Figure 1: (a) Examples of systems that can be optimally controlled without the need of auxiliary systems—single atoms in optical tweezers and flux-tunable transmons. (b)Time-evolved probability density during the state preparation with the snapshots of Wigner functions. The potential's controlled position is depicted via a solid black line. The top panel shows a comparison between sinusoidal drive resonant with the ground-first excited state transition and an optimized much faster control. The bottom panel presents an optimal control leading to the GKP state.

Comparative study of quantum error correction strategies for the heavy-hexagonal lattice

César Benito, Esperanza López, Borja Peropadre, Alejandro Bermudez

Topological quantum error correction is a milestone in the scaling roadmap of quantum computers, which targets circuits with trillions of gates that would allow running quantum algorithms for real- world problems. The square-lattice surface code has become the workhorse to address this challenge, as it poses milder requirements on current devices both in terms of required error rates and small local connectivities. In some platforms, however, the connectivities are kept even lower in order to minimise gate errors at the hardware level, which limits the error correcting codes that can be directly implemented on them. In this work, we make a comparative study of possible strategies to overcome this limitation for the heavy-hexagonal lattice, the architecture of current IBM superconducting quantum computers. We explore two complementary strategies: the search for an efficient embedding of the surface code into the heavy-hexagonal lattice, as well as the use of codes whose connectivity requirements are naturally tailored to this architecture, such as subsystem-type and Floquet codes. Using noise models of increased complexity, we assess the performance of these strategies for IBM devices in terms of their error thresholds and qubit footprints. An optimized SWAP-based embedding of the surface code is found to be the most promising strategy towards a near-term demonstration of quantum error correction advantage.

arXiv:2402.02185

Quantum Time Series Similarity Measures and Quantum Temporal Kernels

Vanio Markov[1]
Vladimir Rastunkov[2], and Daniel Fry[2]

[1]*Wells Fargo, New York, NY, USA*
[2]*IBM Quantum, IBM Research, Yorktown Heights, NY, USA*

vanio.markov@wellsfargo.com

Abstract

This article presents a quantum computing approach to the design of similarity measures and corresponding kernels for classification of stochastic symbolic time series. An effective strategy for designing problem-specific kernels is to leverage a generative model of the example space. In this approach, the state space of the generative model serves as the feature space of the kernel. In our study, we use a stochastic quantum generative model known as a Quantum Hidden Markov Model (QHMM) [1] to parameterize the underlying symbolic stochastic process. A QHMM is a Completely Positive Trace-Preserving (CPTP) map defined by a set of Kraus operators associated with observed symbols. Examples are described by the application of corresponding Kraus operators resulting in sequences of mixed quantum states referred to as *generative state sequences*. Sequence similarity is evaluated by appropriate divergence measures within the quantum state space.

We introduce two types of kernels designed for specific classification tasks. Tasks in which the class of a sequence depends on its future stochastic evolution are referred to as *prediction tasks*. Given the assumption of a Markovian process, a sequence's future behaviour depends solely on the final state in its generative state sequence. In such scenarios, the kernel evaluates the sequence similarity using a distance measure between their final generative states. Positive semidefinite distance measures, such as the trace distance, Bures distance, and Frobenius norm are proposed to define these kernels. We refer to these kernels as "predictive kernels".

In another category of tasks, the class of a sequence depends exclusively on its structure, such as the presence of specific patterns. We denote these tasks as 'structural tasks'. In such instances, the kernel maps a sequence to the expectation (or average) of the quantum states in the generative state sequence. This design reflects the assumption that sequence features depend on the full generative state sequence. We refer to these kernels as "structural kernels".

To compare the performance of the proposed kernels against classical ones, we defined classification tasks using a simplified model of directional movements in a stock market. Two common kernel-based algorithms, Support Vector Machine and k-Nearest Neighbours, were implemented with classical and quantum kernels.

In all structural and predictive task scenarios, the quantum kernels exhibited superior performance compared to their classical counterparts. We have implemented predictive quantum kernel on *ibm_nazca* device (Fig. 1).

References

[1] V. Markov et al., "Implementation and learning of quantum hidden Markov models," arXiv:2212.03796 (2022).

Figures

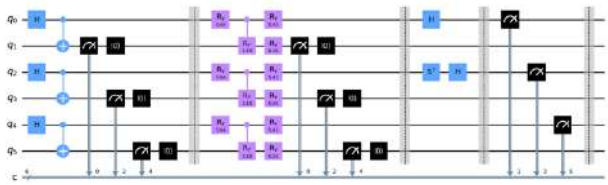


Figure 1: Implementation of projective quantum kernel for market model

Estimation of entanglement monotones in spin systems

Julia Mathé
Giuseppe Vitagliano, Ayaka Usui

TU Wien, Atominstitut, Stadionallee 2, 1020 Vienna, Austria

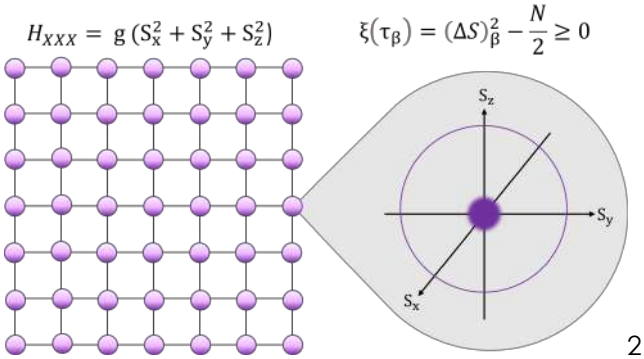
julia.mathe@tuwien.ac.at

We are interested in finding optimal entanglement witnesses and entanglement monotones for interacting many-body systems that can be connected to experimentally relevant collective observables. For spin observables corresponding to two-body correlators, generalized spin squeezing inequalities [1, 2] are generally considered optimal witnesses. To begin with, we study thermal states of fully connected spin systems in the mean-field approximation. These states are typically permutationally invariant, as are their marginals that correspond to fully separable states which is known as the quantum de Finetti theorem. We illustrate how this connection can be used to estimate entanglement monotones of such states, how this connects to the spin squeezing inequalities, and how this approach compares to numerical studies. In addition, we explore the use of non-Hermitian collective spin observables, and how the breaking of permutational symmetry impacts entanglement detection and quantification, in particular using spin squeezing inequalities.

References

[1] G. Tóth, C. Knapp, O. Gühne, H.J. Briegel, Journal, Physical Review A, 79.4 (2009) 042334
[2] G. Vitagliano, I. Apellaniz, I. Egusquiza, G. Tóth, Physical Review A, 89(3), 032307

Figures



2

Figure 1: Spin squeezing in the fully connected XXX model (left). Up to a critical temperature T_c, thermal states close to many-body singlets can be detected using the spin squeezing criterion (right).

Avoiding exponential bottlenecks in the measurement-induced entanglement phase transition

Teemu Ojanen
Ali G. Moghaddam, Kim Pöyhönen

Laboratory of computational physics, Tampere University, Korkeakoulunkatu 7, Tampere, Finland

Teemu.ojanen@tuni.fi

Abstract

Measurement-induced entanglement phase transitions in monitored quantum circuits have stimulated activity of an unusually diverse research community. However, a direct verification of the phenomenon requires exponentially complex postselected ensemble preparation as well as exponentially complex quantum state tomography. These issues limit experimental studies of entanglement properties to modest systems. We propose a solution to this impasse by introducing a protocol, with which the entanglement volume law- area law transition can be probed in U(1) conserving circuits without exponential cos.

First, the state tomography can be avoided by studying the fluctuations of conserved quantity, as shown in Ref. [1]. The fluctuations faithfully reproduce the entanglement entropy behaviour without needing to resort to the state tomography. Moreover, we employ a steering protocol to approximate a single pure state trajectory with a mixed state, from which one can efficiently filter out coherent U(1) charge fluctuation in a subsystem. The coherent subsystem fluctuations exhibit the same spatial scaling as the entanglement entropy of the target pure state. This protocol avoids the need to carry out the exponentially costly postselection ensemble preparation, providing a scalable method to explore entanglement phase transitions. Thus, the method introduced in our work removes the fundamental obstacles impeding experimental progress in monitored circuits [2].

References

[1] A. G. Moghaddam, K. Pöyhönen and T. Ojanen, Physical Review Letters, 131 (2023), 020401.
[2] K. Pöyhönen, M. N. Ivaki, A. G. Moghaddam and T. Ojanen, in preparation

Stochastic Optical Quantum Circuit Simulator: model, design and implementation

Javier Osca[1,2,3,*]
Jiri Vala[1]

1 Department of Theoretical Physics, Maynooth University, Ireland
2 Tyndall National Institute, University College Cork, Lee Maltings, Dyke Parade, Cork, Ireland
3 University of the Balearic Islands, Palma de Mallorca, Spain.

* javier.osca@uib.cat

SOQCS is a Python and C++ library of modular design [1] aimed at the simulation of optical circuits where photonic states are modeled as Fock wavepackets. The objectives of the library are to provide a design tool for photonic circuits and to allow for calculations of different imperfections in the circuit operation. These include, for example, effects associated with unbalanced beamsplitters or partial distinguishability of photons [2] among others.

Arbitrary optical circuits are defined in the code by means of listing their non-ideal basic components and their interconnections. The operation of these circuits can be simulated using different numerical methods [3].

The library also provides support for the definition of non-ideal emitters and physical detectors. Detectors can also be configured to establish various conditions for post-selection in the circuit. Measurements provide detection statistics via probability outcomes and density matrices. We will present details of the library software structure and how the different imperfections are dealt with to provide a meaningful set of outcomes for arbitrary circuit definitions and initial states.

Acknowledgements.

This work has received funding from the Enterprise Ireland's DTIF programme of the Department of Business, Enterprise and Innovation, project QColr Quantum Computing in Ireland: A Software Platform for Multiple Qubit Technologies No. DT 2019 0090B. We acknowledge discussions and support from Tyndall National Institute and Rockley Photonics Ltd.

References

[1] Stochastic Optical Quantum Circuit Simulator (SOQCS), https://www.soqcs.com

[2] Javier Osca and Jiri Vala. Implementation of photon partial distinguishability in a quantum optical circuit simulation**. Comput. Phys. Commun. Volume 289, 108773** (2023).

[3] Javier Osca and Jiri Vala. SOQCS: A Stochastic Optical Quantum Circuit Simulator**. SoftwareX. Volume 25, 101603** (2024)**.**

Quantum algorithms in collider particle physics

Germán RODRIGO

Instituto de Física Corpuscular, Universitat de València – Consejo Superior de Investigaciones Científicas, Parc Científic, 46980 Paterna, Spain

german.rodrigo@csic.es

Abstract

We motivate the use of quantum algorithms in particle physics and provide a brief overview of the most recent applications at high-energy colliders. In particular, we discuss in detail how a quantum approach reduces the complexity of jet clustering algorithms, such as anti-kT, in particle collisions and show how quantum algorithms efficiently identify causal configurations of multiloop Feynman diagrams, where each Feynman propagator has been identified with a qubit, and their connection with directed acyclic graphs (DAG) in graph theory. We also present a multivariate quantum integration algorithm, dubbed Quantum Fourier Iterative Amplitude Estimation (QFIAE), which is successfully applied to the evaluation of one-loop Feynman integrals in a quantum simulator or in a real quantum device.

References

[1] G. Rodrigo, *Quantum algorithms in particle physics*, e-Print: 2401.16208

[2] J.J. Martínez de Lejarza, L. Cieri, M. Grossi, S. Vallecorsa, G. Rodrigo, *Loop Feynman integration on a quantum computer*, e-Print: 2401.03023

[3] G. Clemente, A. Crippa, K. Jansen, S. Ramírez-Uribe, A.E. Rentería-Olivo, G. Rodrigo, G.F.R. Sborlini, L. Vale Silva, *Variational quantum eigensolver for causal loop Feynman diagrams and acyclic directed graphs*, Phys. Rev. D 108 (2023) 096035 [2210.13240]

[4] S. Ramírez-Uribe, A. E. Rentería-Olivo, G. Rodrigo, G. F. R. Sborlini and L. Vale Silva, *Quantum algorithm for Feynman loop integrals*, JHEP **05** (2022) 100, [2105.08703].

[5] J. J. Martínez de Lejarza, L. Cieri and G. Rodrigo, *Quantum clustering and jet reconstruction at the LHC*, Phys. Rev. D **106** (2022) 036021, [2204.06496].

Figures

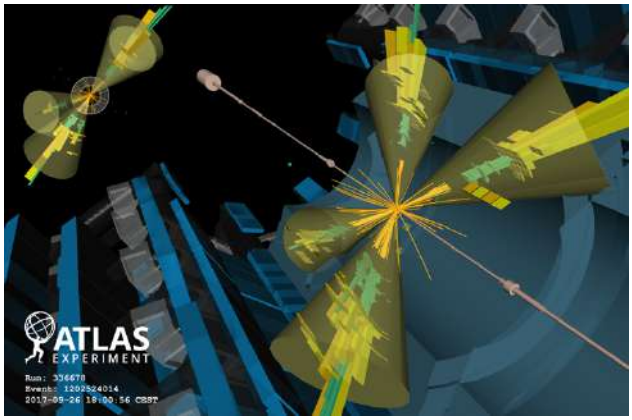


Figure 1: Formation of jets in proton collisions at the CERN´s Large Hadron Collider. Credit: ATLAS Event Displays Repository.

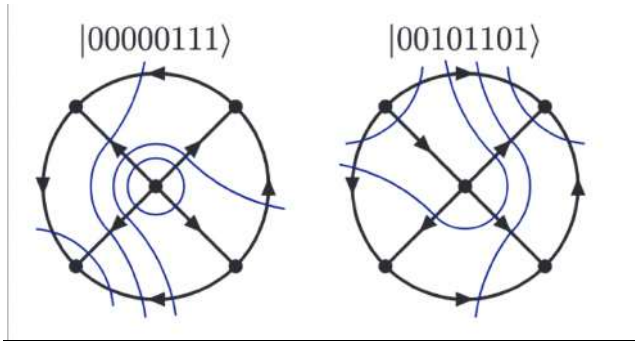


Figure 2: Causal interpretation of a four-loop Feynman diagram from a quantum algorithm.

Quantum Backtracking in Qrisp applied to Sudoku Problems

Raphael Seidel[1]
René Zander[1]
Matic Petrič[1]
Niklas Steinmann[1]
David Q. Liu[2]
Nikolay Tcholtchev[1]
Manfred Hauswirth[1]

[1]*Fraunhofer Institute for Open Communication Systems, Kaiserin-Augusta-Allee 31, 10589 Berlin, Germany*

[2]*Purdue University Fort Wayne, 2101 East Coliseum Blvd., ET 125G, Fort Wayne, Indianapolis, USA*

raphael.seidel@fokus.fraunhofer.de

Montanaro's quantum backtracking algorithm is likely to provide a quantum speed-up for a class of classical optimization algorithms. Unaffected by Barren-Plateaus, this algorithm bodes well for the fault-tolerant era, as it requires only a limited number of arbitrary angle gates. Despite its potential, the algorithm has seen limited implementation efforts, presumably due to its abstract formulation. In this work, a detailed instruction on implementing the quantum step operator for arbitrary backtracking instances is provided. We also detail the process of constructing accept and reject oracles for Sudoku problems using our interface to quantum backtracking. The implementation is written in Qrisp, a high-level quantum programming language, making it executable on current quantum backends. As far as we are aware, this is the first instance of a compilable implementation of this generality, marking a significant and exciting step forward in quantum software engineering.

References

[1] R. Seidel, R. Zander, M. Petrič, N. Steinmann, et al., (to appear)
[2] A. Montanaro, Theory of Computing, 14 (2018) 1-24
[3] R. Seidel, N. Tcholtchev, S. Bock, M. Hauswirth, Lecture Notes in Computer Science (2023) 150-165

Figures

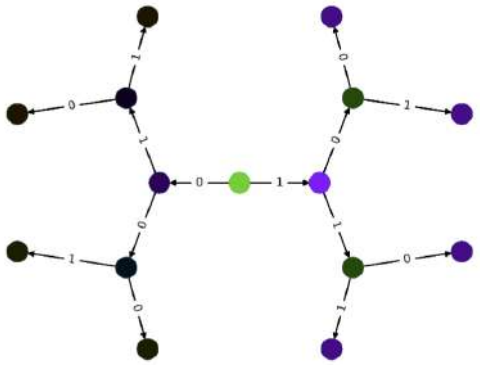


Figure 1: A binary backtracking tree in a state of superposition. Note that the 0-branch of the root is not explored, allowing more structured optimizations compared to Grover's algorithm.

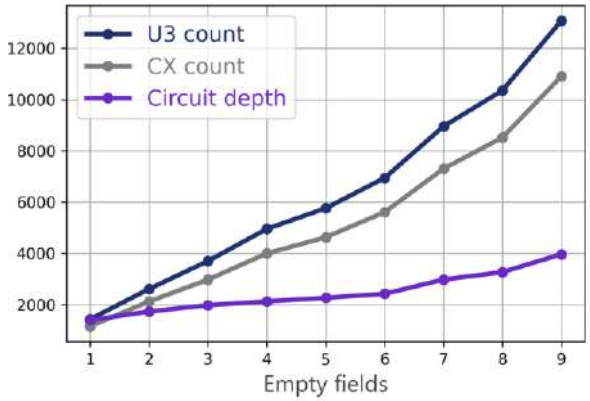


Figure 2: Calculated metrics of solving a 4x4 Sudoku puzzle with up to 9 empty cells.

Figure 3: Unsolved 4x4 Sudoku problem: A solution to this Sudoku with 9 empty fields is found on a simulator using the Qrisp implementation of Montanaro's algorithm with 91 qubits and circuit depth of 3968.

1		3	
3		1	
	1		3
4			

Authors: Andrés Ulibarrena,Alejandro Sopena, Russell Brooks, Daniel Centeno, Joseph Ho, Germán Sierra, and Alessandro Fedrizzi

Title: Photonic Implementation of the Quantum Morra Game

To appear in Physical Review Research

Abstract: We will present a faithful translation of a two-player quantum Morra game, building upon previous work that includes the classical game as a special case. Introducing a natural deformation of the game in the quantum regime, we give Alice a winning advantage, disrupting the balance of the classical game. In certain cases, a Nash equilibrium can be reached using a pure strategy, a departure from the classical game where a mixed strategy is always necessary. We prepared our states using photonic qubits in a linear optics setup, achieving an average deviation of less than 2% from the measured outcome probabilities. Finally, we explore potential applications of the quantum Morra game in the realm of quantum information and communication.

Causal influence versus signalling for interacting quantum channels

AlessandroTosini, [1]
Kathleen Barsse,[12] Paolo Perinotti,[1] and Leonardo Vaglini[1]
[1] *QUIT group, Physics Dept., Pavia University, and INFN Sezione di Pavia, via Bassi 6, 27100 Pavia, Italy*
[2] *Université Paris-Saclay, ENS Paris-Saclay, 91190, Gif-sur-Yvette, France*

alessandro.tosini@unipv.it

Abstract based on Ref. [1]

A causal relation between quantum agents, say Alice and Bob, is necessarily mediated by an interaction. Modelling the last one as a reversible quantum channel, an intervention of Alice can have causal influence on Bob's system, modifying correlations between Alice and Bob's systems. *Causal influence* between quantum systems necessarily allows for *signalling*. However, a largely unexplored side of quantum information processing is the scaling between the strength of correlations and the amount of signalling activated by a quanutm interaction.

Here we prove a *mismatch* between causal influence and signalling via direct computation of the two quantities for the Cnot gate. We show that, for the quantum Cnot, signalling is strictly smaller than causal influence, thus indicating that the "extra" causal effect beyond signalling has to be sought in the leverage that it enables on correlations.

Finally we show a *continuity theorem* for causal effects of unitary channels: a channel has small causal influence iff it allows for small signalling.

References

[1] A Kathleen Brasse, Paolo Perinotti, Alessandro Tosini, Leonardo Vaglini, arXiv:2309.07771

Quantum Wasserstein distance based on an optimization over separable states

Presenting Author: Géza Tóth
Co-Author: József Pitrik

University of the Basque Country UPV/EHU

geza.toth@ehu.eus

Abstract

Most distance measures for quantum states are maximal for two orthogonal states, thus the distance of, say, states |1> and |2> is the same as the distance of |1> and |100>. The quantum Wasserstein distance is different, since it is sensitive to the underlying metric. It might offer a new type of distance for quantum states, with advantageous properties for machine learning and many areas of quantum physics.

The quantum Wasserstein distance is typically defined as an optimization of a cost function over bipartite quantum states with given marginals. In this work, we define the quantum Wasserstein distance such that the optimization of the coupling is carried out over bipartite separable states rather than bipartite quantum states in general, and examine its properties. Surprisingly, we find that the self-distance is related to the quantum Fisher information. We present a transport map corresponding to an optimal bipartite separable state. We discuss how the quantum Wasserstein distance introduced is connected to criteria detecting quantum entanglement.

References

[1] Géza Tóth and József Pitrik, Quantum 7, 1143 (2023).

Figures

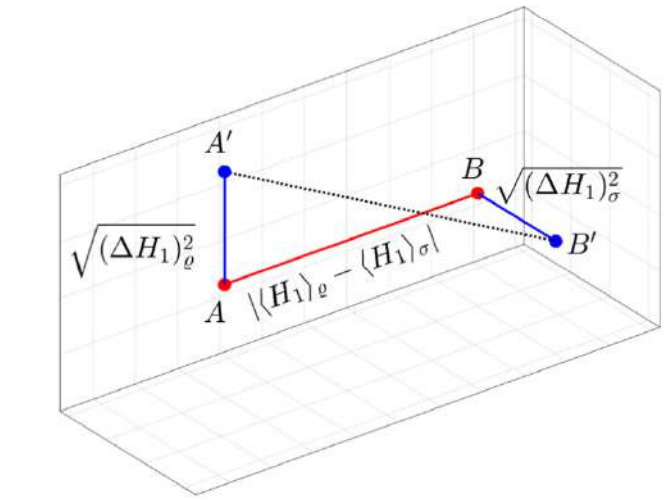


Figure 1: Geometric representation of the quantum Wasserstein distance between a pure state ρ and a mixed state σ for the case of a single H_1 operator. The quantum Wasserstein distance equals 1/ 2 times the usual Euclidean distance between A' and B'.

Detecting Measurement-Induced Entanglement Transitions With Unitary Mirror Circuits

Yariv Yanay[1]
Charles Tahan[1]
Brian Swingle[2]

[1]*Laboratory for Physical Sciences, 8050 Greenmead Dr., College Park, MD 20740, USA*
[2]*Department of Physics, Brandeis University, Waltham, MA 02453, USA*

yanay@umd.edu

Monitored random circuits, consisting of alternating layers of entangling two-qubit gates and projective single-qubit measurements applied to some fraction p of the qubits, have been a topic of recent interest [1]. In particular, the resulting steady state exhibits a phase transition from highly correlated states with "volume-law" entanglement at $p < p_c$ to localized states with "area-law" entanglement at $p > p_c$. It is hard to access this transition experimentally, as it cannot be seen at the ensemble level. Naively, to observe it one must repeat the experiment until the set of measurement results repeats itself, with likelihood that is exponentially small in the number of measurements. To overcome this issue, we present [2] a hybrid quantum-classical algorithm which creates a matrix product state (MPS) based "unitary mirror" of the projected circuit. Polynomial-sized tensor networks can represent quantum states with area-law entanglement, and so the unitary mirror can well-approximate the experimental state above p_c but fails exponentially below it. The breaking of this mirror can thus pinpoint the critical point.

References

[1] B. Skinner, J. Ruhman, and A. Nahum, Phys. Rev. X 9 031009 (2019)
[2] Y. Yanay, B. Swingle and C. Tahan, arXiv:2401.17367 (2024)

Figures

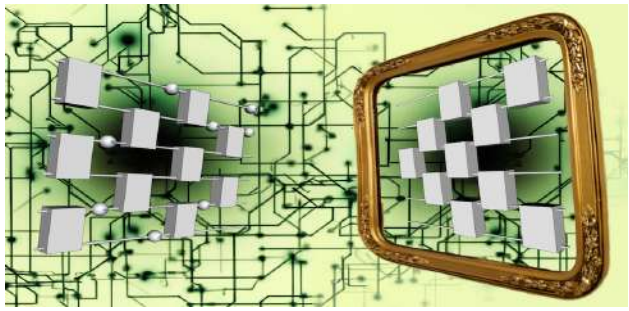


Figure 1: The output of a monitored random circuit, consisting of alternating layers of entanglers and projection operators (left) deterministically generates a state that can be approximated by its "unitary mirror" (right), a circuit composed purely of unitary gates. From the overlap between the two we can learn about the state's entanglement properties.

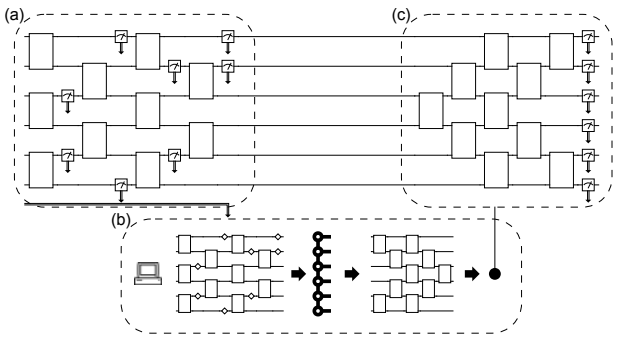


Figure 2: The proposed scheme: (a) A randomly monitored circuit is run on a quantum device generating a state $|\psi\rangle$. (b) The circuit and measurement results are fed into a classical processor. We classically calculate an MPS $|\psi_D\rangle$ approximating the output of this circuit, and from it the "unitary mirror" circuit. (c) Finally, we apply the inverted mirror to $|\psi\rangle$ and measure the probability of returning to the initial state to obtain the overlap $F = |\langle\psi|\psi_D\rangle|^2$.

Quantum information jet in the infinite temperature Hubbard model

Gergely Zaránd[1]
P. Penc,[1,2] M.A. Werner,[1,2] C.P. Moca,[1,3] M. Kormos,[1] Ö. Legeza,[2] T. Prosen[4]
[1]*Budapest University of Technology and Economics, Budafoki ut 8., H-1111 Budapest, Hungary*
[2]*Wigner Research Centre for Physics, H-1525, Budapest, Hungary*
[3]*University of Oradea, 410087, Oradea, Romania*
[4]*University of Ljubljana, Jadranska 19, SI-1000 Ljubljana, Slovenia*

Zarand.gergely.attila@ttk.bme.hu

In this presentation, I focus on the impact of interactions on quantum information generation within the infinite temperature Hubbard model. We study the formation and propagation of operator entanglement as well as mutual information in the presence of localized particle loss (sink) at the end of a semi-infinite Hubbard chain. We use a non-abelian approach to simulate this open system, while exploiting the SU(2)xU(1) symmetry of the Hubbard chain. In the non-interacting limit, a 3d quantization approach is used to benchmark our numerics.

The initial infinite temperature state has no entanglement. Incoherent loss at the end of the chain, however, amounts in a stream of particles towards the sink, accompanied by entanglement generation. A ballistic *depletion* and *current front propagation* is observed with *strongly reduced front velocity* in the presence of interactions.

In contrast, operator *entanglement* and *mutual information* are found to propagate *faster* than the depletion profile, and a mutual information jet appears that propagates with a velocity independent of U (see Figure 1).

The dynamics of the slow front can be captured quantitatively by a cellular automaton model, and is thus found to carry classical correlations. The fast mutual information front appears, in contrast, to have an intrinsic quantum-mechanical nature, and persists at infinite temperature and interaction. We understand the propagation of the fast front as being due to spinless fermionic excitations on the background of spinons.

References

[1] C.P. Moca, M.A. Werner, Ö. Legeza, T. Prosen, M. Kormos, G. Zaránd, Phys. Rev. B 105 (2022) 195144
[2] P. Penc, C.P. Moca, T. Prosen, G. Zaránd, M.A. Werner, arXiv:2402.19390 (submitted to Phys. Rev. Lett.)

Figures

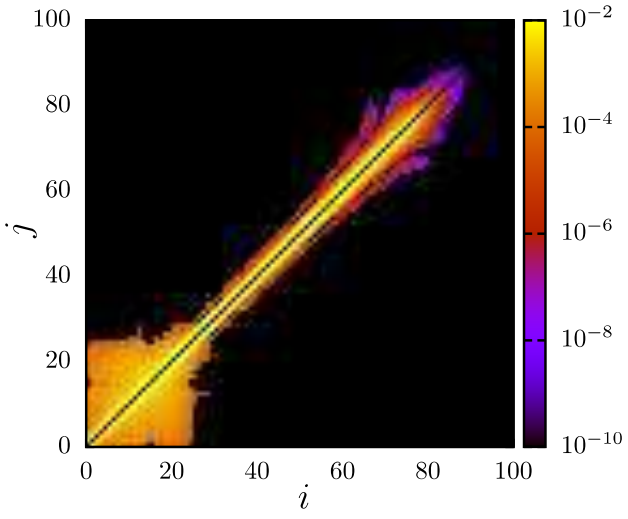


Figure 1:
Two-site mutual information, S(i,j), at time t = 80 for interaction U/J = 10. Long-range correlations appear for sites i,j ≲ 30, while a narrow, short-range correlated jet signal reaches i,j ≈ 80, and propagates with unrenormalized velocity.

Growth of Iron selenide layers via salt-assisted chemical vapour deposition

Nilanthy Balakrishnan
Lewis J. Adams

School of Chemical and Physical Sciences, Keele University, Keele,, ST5 5BG, UK

n.balakrishnan@keele.ac.uk

Abstract

Iron selenide compounds (Fe_xSe_y) are an emerging class of materials known for their remarkable superconducting, catalytic and magnetic properties. It has been established that single-layer tetragonal iron selenide (FeSe) on strontium titanate ($SrTiO_3$) has proven to be an excellent superconductor at a critical temperature of ~55 K [1]. While other stoichiometries can have drastically different properties, for example, Fe_3Se_4 presents metallic features similar to that of other transition metal chalcogenides (TMCs) having an average conductivity of 9.54×10^4 S m^{-1} for thin layers of 8 nm [2]. Other stable stoichiometric compounds exhibit similar properties, for instance $FeSe_2$ and therefore it is clear that Iron selenides have untapped potential for quantum technologies [3]. In this work, we present the epitaxial growth of a range of 2D iron selenide compounds, Fe_xSe_y on silicon dioxide (SiO_2) substrate using a salt-assisted chemical vapour deposition (CVD) method. The iron and selenium ratio can be finely tuned by the weight ratio of precursors selenium and Iron oxide (FeO) powders, and the growth promotor ammonium chloride salt. Furthermore, allowing the growth of various layer thicknesses with triangle and hexagonal morphologies (Figure 1) which have the potential to be scaled up to wafer-scale coverage. The as-grown structures were characterized using X-ray diffraction (XRD), Raman and Energy dispersive X-ray (EDX) techniques (Figure 2), showing clear stochiometric control and chemical stability under ambient conditions. These characterization techniques allow the opportunity to explore the role of the growth-promoting ammonium chloride salt in the synthesis process and how this influences the formation of iron selenides or Iron oxide. The successful growth of 2D iron selenide with different stoichiometry and morphologies offers the prospect of applications in quantum technology.

References

[1] Liu, D., et al., Nature Communications (2012) 931.
[2] Huan, Y., et al., Advanced Materials, 1 (2023) 2207276.
[3] Liu, H., & Xue, Y., Advanced Materials 17 (2021) 2008456.

Figures

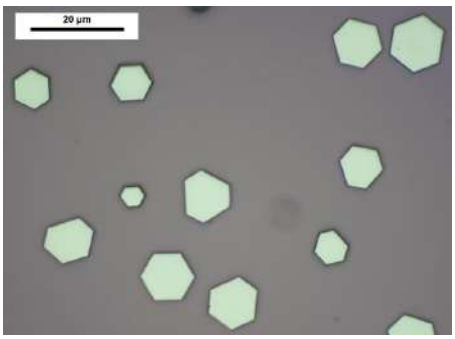


Figure 1: Optical image of Fe_xSe_y grown on SiO_2.

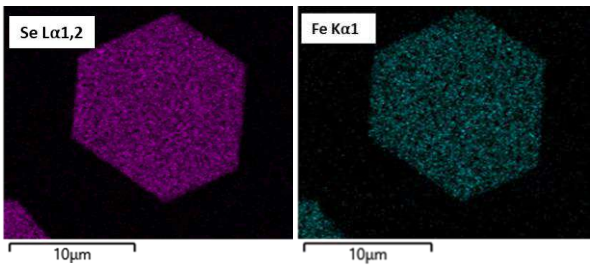


Figure 2: EDX map of FeSe grown on SiO_2.

Lithium niobate-on-insulator integrated photonics for linear optical quantum computing

Robert J. Chapman
Tristan Kuttner, Jost Kellner, Alessandra Sabatti, Andreas Maeder, Giovanni Finco, Fabian Kaufmann, Rachel Grange
Optical Nanomaterial Group, Institute for Quantum Electronics, Department of Physics, ETH Zurich, CH-8093 Zurich, Switzerland
rchapman@ethz.ch

Linear optical quantum computing utilizes single photons or squeezed light and quantum interference to achieve an advantage in certain tasks such as boson sampling. Despite significant advances in integrated quantum photonics that can miniaturize table-top experiment to centimetre-scale chips, today's leading optical quantum computing experiments still use free-space and fibre optics [1, 2].

Lithium niobate-on-insulator (LNOI) is an emerging integrated photonics platform that has the potential of enabling a new generation of quantum photonic devices able towards demonstrating an on-chip quantum advantage. LNOI photons has a strong $\chi^{(2)}$ nonlinearity for efficient photon-pair or squeezed-state generation, high-speed electro-optic and thermo-optic phase control, low optical loss and a high index contrast for dense waveguide circuits [3]. While impressive experiments with LNOI have been performed, investigations into quantum computing applications remain limited.

Here, we report quantum interference between two nonlinear photon-pair sources in a programmable LNOI photonic circuit. We coherently pump two periodically poled LNOI waveguides to generate a two-photon entangled state and perform quantum interference in a Mach-Zehnder interferometer (MZI).

Our device is shown in Fig. 1a. By injecting a 781 nm wavelength laser into both spontaneous parametric down-conversion (SPDC) sources, we generate telecom-wavelength photons in the state $\frac{1}{\sqrt{2}}(|20\rangle + e^{2i\phi}|02\rangle)$, which is a coherent superposition of two photons in the upper and two photons in the lower waveguide [4]. The phase ϕ is controller with an on-chip thermo-optic phase shifter.

We manipulate this state with a programmable MZI to output either bunched or anti-bunched photons due to quantum interference. We measure quantum interference visibility of $95 \pm 1\%$, as shown in Fig. 1b, and perform Hong-Ou-Mandel (HOM) interference after the chip with $83.2 \pm 0.1\%$ visibility as shown in Fig. 1c.

Our results are a milestone in the development of LNOI quantum photonics, and the first step to scaling up towards dozens of sources and waveguides for the first demonstration of an on-chip quantum computation advantage with photonics.

References

[1] Zhong *et al.* Science **370** 1460 (2020)
[2] Madsen *et al.* Nature **606** 1476 (2022)
[3] Zhu *et al*. Adv. Opt. Photon. **13** (2021)
[4] Silverstone *et al.* Nat. Photon. **8** (2014)

Figures

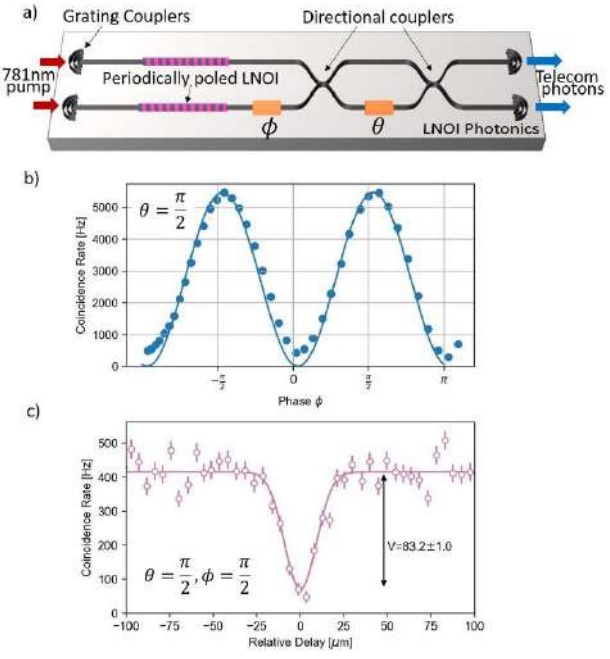


Figure 1: a) Schematic of our integrated LNOI quantum photonic circuits. b) Quantum interference between two LNOI SPDC sources. c) HOM interference with the generated photons

Nanomagnet-induced Synthetic Spin-Orbit Coupling in a Superconductor-Semiconductor Nanowire

M. R. Connolly[3]
M. P. Hynes[1,2], D. Burke[3], A. Vekris[4], J. Nygård[4], K. Moors[5], J. C. Gartside, W. R. Branford[3], M. R. Buitelaar[1,2]

[1]*London Centre for Nanotechnology, University College London, United Kingdom*
[2]*Department of Physics and Astronomy, University College London, London, United Kingdom*
[3]*Blackett Laboratory, Imperial College London, London, United Kingdom*
[4]*Centre for Quantum Devices, Niels Bohr Institute, Copenhagen, Denmark*
[5]*Peter Grünberg Institut (PGI-9), Forschungszentrum, Jülich, Germany*

m.connolly@imperial.ac.uk

Inhomogeneous magnetic fields generated by nanomagnet arrays are predicted to induce a synthetic spin-orbit coupling (s-SOC) in hybrid superconductor-semiconductor nanowires commonly used in the search for Majorana bound states [1]. By obviating the need for intrinsic SOC, nanomagnets could thus widen the range of materials available for realising topological superconductivity, for instance to include lower-disorder materials such as carbon nanotubes or silicon nanowires. Here we present conductance measurements of a proximitized Al/InAs nanowire (Figure 1) fabricated adjacent to an array of nanomagnets. In the Coulomb-blockade regime we observe tunnelling resonances at low source-drain bias consistent with the presence of sub-gap Andreev bound states [2]. Using a sequence of externally applied fields to switch the nanomagnets, we verify the expected shift in bound state energy between the anti-aligned and aligned nanomagnet configuration. Our results are consistent with quantum transport simulations and demonstrate the viability of using local magnetic textures to induce s-SOC in hybrid superconductor-semiconductor devices.

References

[1] Kjaergaard et al., Phys. Rev. B 85, 020503(R) (2012)

[2] Higginbotham et al., Nature Physics 11, 1017–1021 (2015)

Figures

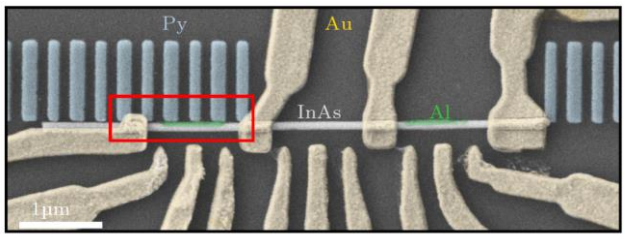


Figure 1: Scanning electron micrograph of the device, comprising an Al/InAs nanowire adjacent to an array of Py nanomagnets used to induce s-SOC.

Record carrier mobility in group IV semiconductor materials.

Davide Costa[1], Lucas Stehouwer[1], Davide Degli Esposti[1], Karina Hudson[1], Menno Veldhorst[1], Amir Sammak[2], Giordano Scappucci[1].

[1]*QuTech and Kavli Institute of Nanoscience, Delft University of Technology, PO Box 5046, Delft, 2600 GA, The Netherlands.*
[2]*QuTech and Netherlands Organisation for Applied Scientific Research (TNO), Delft, The Netherlands.*

d.costa@tudelft.nl

Holes in strained Ge/SiGe heterostructures have emerged as a leading platform for spin qubits and hold promise for hybrid semiconductor-superconductor devices [1]. We recently departed from the mainstream approach and started epitaxy directly from Ge rather than Si substrates. With this strategy we reduce substantially the lattice mismatch between the substrate and the active layers of the heterostructure. As a result, we demonstrated an order of magnitude reduction of threading dislocations and a 10x boost in 2D hole gas mobility due to suppression of short range scattering [2]. Carrier mobility is a key qualifier of static disorder of the semiconductor material host. In this talk, I will focus on the latest experiments aimed at mitigating scattering from remote impurities, by positioning the quantum well at an increased distance from the semiconductor-dielectric interface. We demonstrate a reproducible mobility exceeding 4.5 millions cm^2/Vs over several heterostructure field effect transistors and observe a plethora of fractional quantum hall states which survive to low density [3]. The achieved mobility sets a new benchmark for any type of carriers (holes/electrons) in group IV semiconductor material stacks. We use this heterostructure as a testbed to identify the remaining scattering mechanisms affecting 2D hole transport, underlining a path forward to further reduce disorder and improve materials for hole spin qubits.

References

[1] G. Scappucci, *et al*., Nature Reviews Materials **6**, 926–943 (2021)
[2] L. E. A. Stehouwer, *et al*., Applied Physics Letter, **123**, 092101 (2023)
[3] D. Costa *et al*, in preparation (2024)

Ultra-long relaxation of a Kramers qubit formed in a bilayer graphene quantum dot

Artem Denisov, Hadrien Duprez, Veronika Reckova, Solenn Cances, Max J. Ruckriegel, Michele Masseroni, Christoph Adam, Chuyao Tong, Jonas D. Gerber, Wei Wister Huang, Kenji Watanabe Takashi Taniguchi, Thomas Ihn and Klaus Ensslin

Solid State Physics Laboratory, ETH Zurich, 8093 Zurich, Switzerland
adenisov@phys.ethz.ch

Abstract

The intrinsic valley degree of freedom makes bilayer graphene a unique platform for emerging types of semiconducting qubits. The single-carrier quantum dot ground state exhibits a two-fold degeneracy where the two states have opposite spin and valley quantum numbers. By breaking the time-reversal symmetry of this ground state with an out-of-plane magnetic field, a novel type of qubit (Kramers qubit), encoded in the two-dimensional spin–valley subspace, becomes accessible. The Kramers qubit is robust against known spin- and valley-mixing mechanisms, as it requires a simultaneous change of both quantum numbers, potentially resulting in long relaxation and coherence times. We measure the relaxation time of a single carrier in the excited states of a bilayer graphene quantum dot at small (~ mT) and zero magnetic fields. We demonstrate ultra-long spin-valley relaxation times of the Kramers qubit exceeding 30 s, which is about two orders of magnitude longer than the spin relaxation time of 400 ms. The demonstrated high-fidelity single-shot readout and long relaxation times are the foundation for novel, long-lived semiconductor qubits [1].

References

[1] Artem O. Denisov, Veronika Reckova, Solenn Cances, Max J. Ruckriegel, Michele Masseroni, Christoph Adam, Chuyao Tong, Jonas D. Gerber, Wei Wister Huang, Kenji Watanabe, Takashi Taniguchi, Thomas Ihn, Klaus Ensslin, Hadrien Duprez., 10.48550/arXiv.2403.08143

Figures

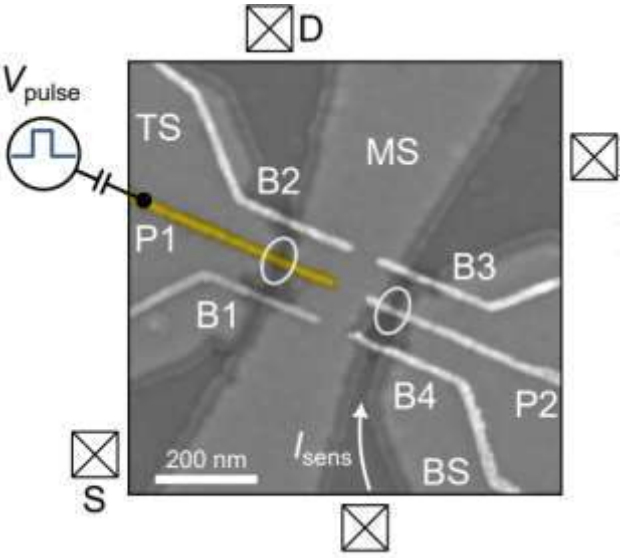


Figure 1: SEM false-colour image of the device. All labelled metallic gates and the graphite back gate (not shown) are DC-biased. The plunger gate P1 is additionally controlled by AC pulses.

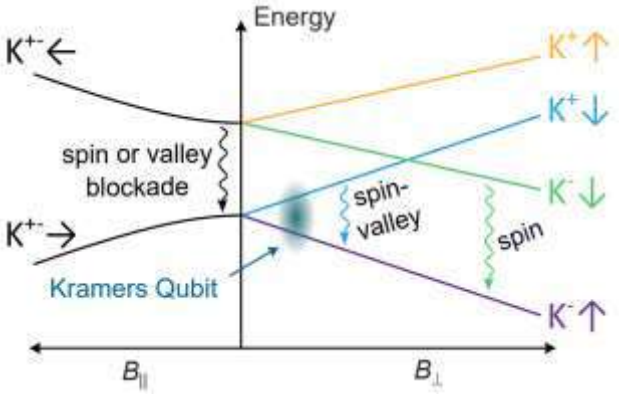


Figure 2: The energy spectrum of a single carrier in the BLG QD plotted as a function of in-plane and out-of-plane magnetic fields.

Understanding Inherent Structural Defects and Chemical Distribution at Topological Superconductor-Semiconductor Interfaces and Heterostructures Using Electron Microscopy

Rosa E Diaz[1,3]
Roy D. Peña[2]; Michael Manfra[1,3,4]

[1]*School of Electrical and Computer Engineering, Purdue University, West Lafayette, USA*
[2] *Department of Electrical, Electronics, Informatic, UNSAAC, Cusco, Peru*
[3]*Birck Nanotechnology Centre, Purdue University, West Lafayette, USA*
[4]*Department of Physics and Astronomy, Purdue University, West Lafayette, USA*

Contact: rdiazri@purdue.edu

Abstract

In the zoo of quantum systems that might disrupt the storage and manipulation of information, topological superconductors have received significant interest for their potential application in quantum computing, mainly due to their capacity to harbor non-Abelian states and provide fault-tolerant computation. One of the possible platforms for topological superconductivity is the interface between a superconductor and a semiconductor (SS)[1] with strong spin-orbit scattering[1] – where topological qubits are manifested. However, epitaxially interfacing two dissimilar materials such these, generate inherent challenges in the form of grain boundaries (GB arrow in Fig. 1), grain misorientations (grains G1/G2 in Fig. 1), atomic distortions across the SS interface (circle in Fig. 1), which might be detrimental to the device performance. Additionally, precise control of the semiconductor heterostructure interfaces and their chemical distribution is also needed to improve electron mobility and device performance. Thus, identifying and understanding these inherent structural defects at the multiple interfaces of these hybrid devices, and connecting our findings with growth process, might contribute to better performance of such hybrid devices. Here we explore a combination of electron and ion microscopy together with advance image processing and mathematical modelling using Python libraries to understand structural properties at the SS interface, quantify roughness and chemical distribution across the semiconductor heterostructure interfaces. Our findings deliver metrology parameters to assess the quality of hybrid systems and highlight the relationship between such parameters and growth conditions.

References

[1]] L. Fu, C.L. Kane, Phys. Rev. Lett **100** (2008) 096407

Figures

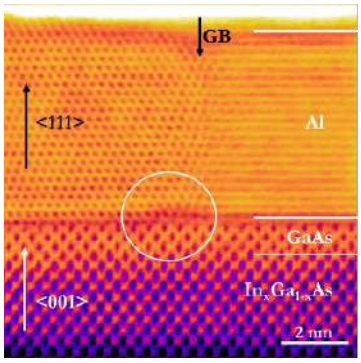


Figure 1: Color added cross-sectional HRSTEM image at the SS interface. Two Al (111) grains (G1,G2) divided by GB creating a distortion at the SS interface. G1 is parallel to the electron beam, and G2 has a small rotation respect to G1.

Rare Earth-Diamond Hybrid Structures for Optical Quantum Technologies

Philippe Goldner
Ionut Gabriel Balasa[1], M.A. Arranz-Martinez[1], P. Perrin[1], M. Ngandeu Mgambou[2], D. Serrano[2], A. Tiranov[2], J. Achard[2], A. Tallaire[1]

[1]*Institut de Recherche de Chimie Paris, Chimie ParisTech, PSL University, CNRS, Paris, France*
[2]*LSPM, CNRS, Université Sorbonne Paris Nord, Villetaneuse, France*

philippe.goldner@chimieparistech.psl,eu

Hybrid materials that associate distinct quantum species may be used to achieve new functionalities. In this work, we combine two systems that are broadly used for quantum applications, the NV^- color center in diamond [1] and rare earth (RE) ions doped in crystals [2].

The hybrid structure we studied consists of an Er^{3+} doped Y_2O_3 thin film deposited by direct liquid injection chemical vapor deposition (CVD) [3] on a diamond substrate in which shallow NV^- were implanted [4].

We investigated the structure of the thin films and the optical properties of the embedded Er^{3+} ions (Fig. 1), and how the spin and optical properties of the NV^- were affected by the thin film deposition. Our results indicate that erbium ions are in a high-quality crystalline environment, while the optical and spin properties of the NV^- centers are preserved after deposition.

These results suggest that the proposed structure is promising for integrating rare-earth ions with NV^- centers at the nanoscale level for developing hybrid solid state quantum systems.

References

[1] D. D. Awschalom, R. Hanson, J. Wrachtrup, and B. B. Zhou, Nat. Photonics, 12 (2018)516

[2] T. Zhong and P. Goldner, Nanophotonics, 8 (2019) 2003

[3] Nao Harada et al., Journal of Applied Physics, 128 (2020) 055304

[4] Midrel Wilfried Ngandeu Ngambou et al, Mater. Quantum. Technol. 2 (2022) 045001

Figures

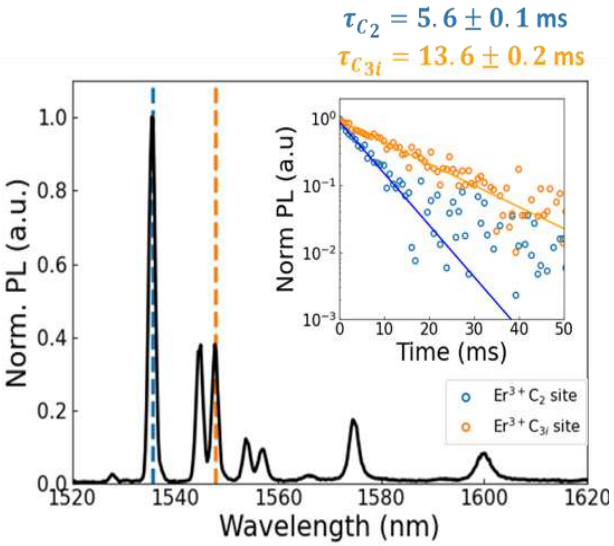


Figure 1: Low temperature telecom band emission in a Er:Y_2O_3 thin film deposited on diamond and fluorescence decay times (inset). Properties are comparable to bulk crystals.

Adiós flatland – Quantum transport in MoS_2 nanotube and nanoribbon quantum dots

Andreas K. Hüttel[1]
R. T. K. Schock[1], S. Obloh[1], K. Schneider[1], J. Neuwald[1], M. Kronseder[1], M. Malok[2], L. Pirker[2,3], M. Remŝkar[2]

[1]*Institute for Exp. and Applied Physics, University of Regensburg, Regensburg, Germany*
[2]*Solid State Physics Department, Institute Jožef Stefan, Ljubljana, Slovenia*
[3]*J. Heyrovský Institute of Physical Chemistry, Czech Academy of Sciences, Prague, Czech Republic*

andreas.huettel@ur.de

Extensive research on planar, 2D TMDCs focuses on their exceptional electronic and optical properties arising from their inherent layer structure. Despite numerous studies on optical behavior, achieving single-level transport in lithographic quantum dots at low temperatures, crucial for quantum electronic devices, faces challenges due to the need for small confinement potentials and disorder at nanoflake edges.
A highly promising solution [1,2] involves using crystalline MoS_2 nanotubes grown via a chemical transport process, for natural electron confinement in two directions. With bismuth as contact material, Schottky barriers can be avoided. Low-temperature measurements confirm nondestructive, transparent contacts and single-level quantum transport at $T < 100$mK [1].
To further reduce disorder, an innovative dry transfer technique with anthracene crystals as a pick-up material [3] is employed; several fabrication variants are discussed.

References

[1] R. T. K. Schock, A. K. Hüttel, *et al.*, Adv. Mat. 35 (2023), 2209333
[2] S. Reinhardt, A. K. Hüttel, *et al.*, pssRRL 13 (2019), 1900251
[3] K. Otsuka *et al.*, Nat. Comm. 12 (2021), 3138

Figures

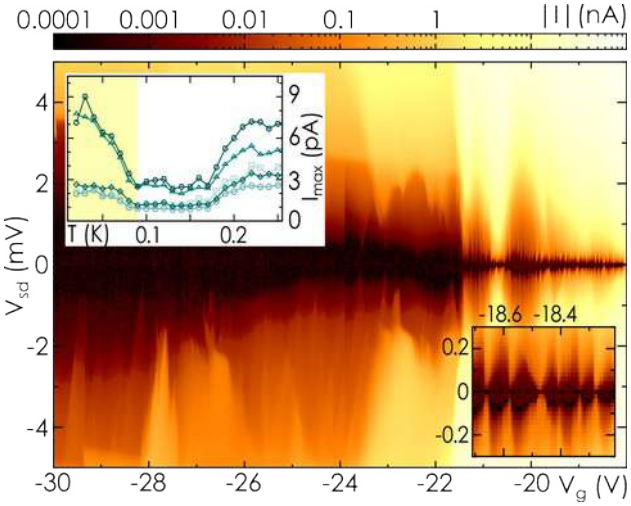


Figure 1: Coulomb "diamonds" of a MoS_2 nanoribbon (nanotube collapsed during growth), with charging energies consistent with the active device region.

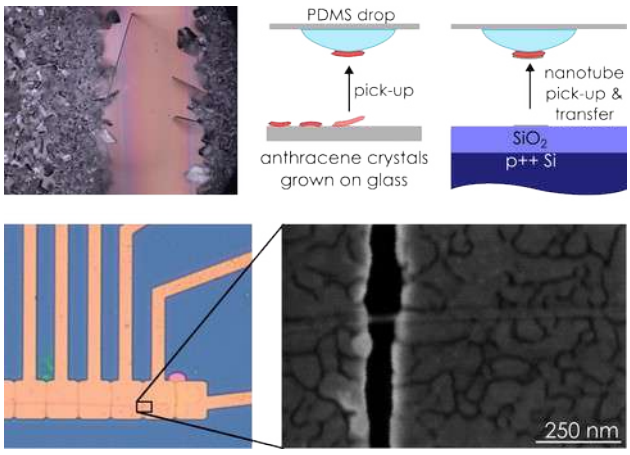


Figure 2: Top: Anthracene crystal based residue-free transfer of MoS_2 nanotubes. Bottom: MoS_2 nanotube device (optical and SEM image).

Role of interface in quantum devices

Manas Mukherjee
Senthil kumar karuppannan, Naga Manikanta Kommanaboina, Adrian Nugraha Utama and Kamma Anil

*NQFF, Institute of Materials Research and Engineering, Technology and Research, A*STAR, 2 Fusionopolis Way, Innovis Building, Singapore 138634*

manas_mukherjee@imre.a-star.edu.sg

The quality factor of niobium thin film structures used in superconducting quantum circuits is constrained by a native surface oxide layer, resulting in two-level system loss. This leads to a higher loss in the microwave resonators as well as two-level losses (TLS) in the qubit. To address the impact of the surface oxide layer on the niobium thin film, several methods are proposed, including surface passivation through another metal capping layer[1], self-assembly of an organic monolayer[2], and surface treatment[3]. Various thin metal capping layers, such as Al, Ta, TiN, and others,[4,5] have been explored, demonstrating enhancements in the quality factor and qubit lifetime compared to uncapped niobium metal film. However, it's noted that these capping layers themselves tend to form a 3-5 nm thick oxide on the surface, introducing surface defects in oxidized metals. Nitrogen plasma treatment of niobium leads to nitrogen doping more than 5 nm into the surface, accompanied by a suppressed oxygen presence, resulting in a fourfold enhancement in performance compared to un-passivated samples. On the other hand, the self-assembly of an organic monolayer prevents oxidation on the surface; however, it may not be as suitable for prolonged exposure in ambient environments or subsequent qubit fabrication processes. In this context, ideal passivation methods or metals should possess the following characteristics: 1) Formation of Thin Self-Limited Oxide Layer: The passivating material should form a very thin <1 nm oxide layer with self-limited oxidation. This effectively shields the underlying superconductive layer from further oxidation. 2) Minimization of Oxide Compositions: The material should form a minimal number of oxide compositions to reduce the occurrence of surface defects associated with oxide vacancies. 3) Chemical Resistance: Capping layers should be chemically and environmentally resistive to ensure that multiple fabrication processes do not adversely affect the surface quality.
To enhance the performance and reliability of superconducting quantum circuits, it is important to find an appropriate passivation method or metal with specific characteristics such that both TLS as well as dielectric losses can be minimized. In this study, we have carefully selected a few hitherto unstudied metals as a capping layer which forms an oxide thickness of ~0.6 nm[6] without affecting the crystal structure and surface resistance of the superconducting niobium thin film. The X-ray diffraction analysis showed a shift in the [110] peaks, indicating uniform compression of the crystal lattice and a reduction in the crystallite size from 20 nm to 18 nm. The atomic force microscopic results showed that the ruthenium capping reduces the exposed grain boundary by approximately 20% and the RMS roughness value changes from 1.05 nm to 0.85 nm with the capping layer. We will present a detailed report on the effect of the capping layer on the superconductivity and the internal quality factor of the niobium resonator.

References

1. Wisbey, D. S. et al., J. Low Temp. Phys. 195, 474–486 (2019).
2. Alghadeer, M. et al., ACS Appl. Mater. Interfaces 15, 2319–2328 (2023).
3. Zheng, K. et al., Appl. Phys. Lett. 120, (2022).
4. Burnett, J. et al., Nat. Commun. 5, 4119 (2014).
5. Mergenthaler, M. et al., npj Quantum Inf. 7, 157 (2021).
6. Coloma Ribera, R. et al., Appl. Phys. Lett. 105, (2014).

Unveiling the interlayer interaction in a 1H/1T TaS_2 van der Waals heterostructure

I.M. Ibarburu, C.G. Ayani, M. Bosnar, F. Calleja, A. Pinar Solé, O. Stetsovych, C. Rebanal, M. Garnica, R. Miranda, M.M. Otrokov, M. Ondracek, P. Jalinek, A. Arnau, A. L. Vázquez de Parga

Dep. Física de la Materia Condensada UAM, & IMDEA Nanociencia Cantoblanco, Madrid 28049, Spain.
DIPC & Dep. de Polímeros y Materiales Avanzados: Física, Química y Tecnología, UPV/EHU, San Sebastián, 20018, Spain
Institute of Physics, Academy of Science of the Czech Republic, Prague 6, CZ 16200, Czech Republic
Instituto Nicolás Cabrera & IFIMAC, UAM, Cantoblanco 28049, Madrid, Spain
Centro de Física de Materiales CSIC/UPV-EHU, 20018 San Sebastián, Spain
IKERBASQUE, Spain

Ivan.martinezi@uam.es

Different transition metal dichalcogenides heterostructures have being studied in recient years due to their diverse electronic properties and the potential of combining them to create new systems that can host correlated ground states. In particular, TaS_2 is well known to exhibit two distinct structural phases: 1H, a metallic phase with a quasi-(3x3) charge density wave (CDW) below 81K, and 1T, a Mott insulator with a Star of David $\sqrt{13}x\sqrt{13}$-R14° CDW below 183K [1]. When a 1T layer is placed on top of a 1H layer, a Kondo lattice is formed within the system [2]. On the other hand, when a 1H layer is placed on top of a 1T layer, a transparency effect is observed in STM measurements through the top layer [3], as depicted in Figure 1. Some early studies suggested that this effect could be attributed to direct tunneling from the tip to the 1T layer [4]. Here, we propose a new explanation based in a weak but measurable electronic coupling between the 1T and 1H layers, which preserve their structural properties and characteristic CDWs.

References

[1] J. A. Wilson, F. J. Di Salvo, S. Mahajan, Adv. Phys. 24, (1975), 117-201
[2] C. G. Ayani, M. Pisarra, I. M. Ibarburu, M. Garnica, R. Miranda, F. Calleja, F. Martin and A. L. Vazquez de Parga, Small (2023) 2303275
[3] R. V. Coleman, B. Giambattista, P. K. Hansma, A. Johnson, W. W. McNairy, and C. G. Slough, Adv. Phys. 37, 6 (1988), 559-644
[4] W. Han, E. R. Hunt, O. Pankratov, and R. F. Frindt, Phys. Rev. B 50, 19, (1994), 14746

Figures

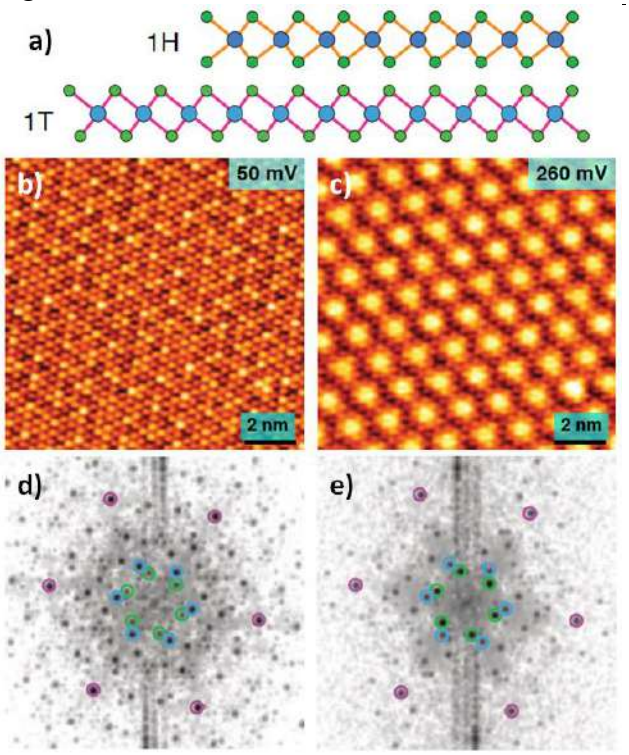


Figure 1: Transparency effect on a 1H/1T-TaS_2 heterostructure. (**a**) Ball model of the system, Ta atoms in blue and S atoms in green. (**b-c**) STM images performed on the same area on the 1H layer at 300pA and two different voltages, showing the underlying 1T CDW through the 1H layer. (**d-e**) FFT of the STM images. Atomic lattice spots are marked in purple, 1H CDW spots in blue and 1T CDW spots in green.

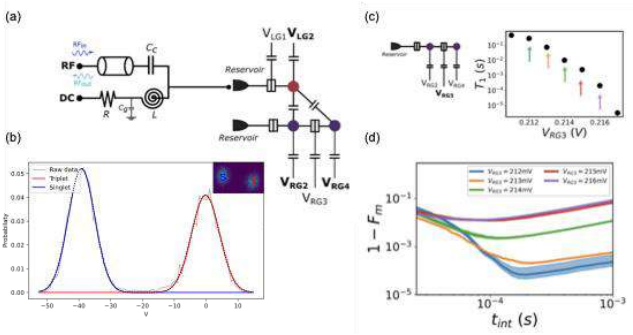
High-fidelity dispersive spin readout in a scalable unit cell of silicon quantum dots

Giovanni A Oakes
Constance Laine, Jacob Chittock-Wood, Sofia M Patomäki, Michael Fogarty, Stefan Kubicek, Ross C. Leon, Fernando Gonzalez-Zalba, John Morton.

Quantum Motion, UK

giovanni@quantummotion.tech

Figures



Planar MOS multi-gate technology is one of the leading approaches for silicon-based quantum computing, especially when coupled with dispersive charge sensors, which offer scalable unit cells by reducing the need for reservoirs. So far, demonstrations of planar MOS quantum dots have been restricted to architectures where sensors are co-linear with the qubit array, limiting scalability. Achieving readout fidelity at the level of control operations has also remained challenging.

In this work, we address both limitations by demonstrating single-shot spin readout above 99.9% in 400 us within a planar MOS quantum dot array fabricated using a 300 mm wafer process. We use a single electron box (SEB) to measure the two-electron spin state of a double quantum dot via Pauli spin blockade. The sensor and qubit dots are placed in parallel channels of a bilinear array, forming a compact and scalable unit cell. The high fidelity is achieved thanks to the tunability of the structure that allows:

(i) Optimisation of the tunnelling rate of the SEB for enhanced signal.
(ii) Tuning of the coupling between the double quantum dots using a J-gate, leading to an enhancement of the singlet-triplet relaxation time from 4 us to 0.5 s.

Overall, this work demonstrates sensing in a compact unit cell with state-of-the-art fidelity, providing a path to scalable high-connectivity bilinear qubit arrays.

Automatic detection of vacancies in WS_2 for Quantum Materials studies using HAADF-STEM Imaging

Ivan Pinto-Huguet[a]
Marc Botifoll[a], Jordi Arbiol[a,b]

a. Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Barcelona, Catalonia, Spain
b. ICREA, Pg. Lluis Companys 23, 08010 Barcelona, Catalonia, Spain

ivan.pinto@icn2.cat

Two-dimensional (2D) materials, such as WS_2, have garnered significant attention for their potential applications in quantum computing and related technologies. These materials exhibit unique electronic and optical properties owing to their atomically thin nature and strong quantum confinement effects. In particular, vacancies, or defects, within these materials play a pivotal role in influencing their quantum behaviour **[1]**.

Vacancies introduce localized electronic states within the bandgap of 2D materials, altering their electronic structure and optical properties. These defect-induced states can serve as quantum emitters, enabling applications in single-photon sources, quantum communication, and quantum information processing **[2]**.

Understanding and controlling vacancies in 2D materials are thus essential for harnessing their full potential in quantum technologies. High-Angle Annular Dark-Field Scanning Transmission Electron Microscopy (HAADF-STEM) emerges as a powerful technique for probing the atomic-scale structure of 2D materials like WS_2, allowing precise characterization of vacancies and their effects on the material's quantum properties **[3].**

In this study, we present an automated method for identifying vacancies in WS2 monolayers. Our approach leverages a convolutional neural network (CNN) for denoising, applied to Fast Fourier Transform (FFT) spectra. The CNN model is trained on a dataset comprising over 5000 simulated spectra **[4, 5]**. By filling in the gaps corresponding to vacancies, this denoising technique facilitates accurate tracking of vacancy locations through image differencing.

Our work underscores the importance of vacancies in 2D materials for quantum applications and highlights the significance of advanced imaging techniques like HAADF-STEM in studying quantum materials at the atomic level. This automated detection method paves the way for further exploration and utilization of vacancies in WS_2 and other 2D materials for quantum technologies.

References

[1] Liu X., Hersam M.C., *Nat Rev Mater*, 4 (2019) 669-684
[2] Parto K., Azzam S.I., Banerjee K. *et al.*, *Nat Commun*, 12 (2021) 3585
[3] Sytze de Graaf and Bart J Kooi, 2D Mater. 9 (2022) 015009
[4] Ziatdinov M., Dyck O., Maksov A. et al., ACS Nano, 11, 12 (2017) 12742–12752
[5] Botifoll M., Pinto-Huguet I., Arbiol J., *Nanoscale Horiz.*, 7 (2022) 1427-1477

Figures

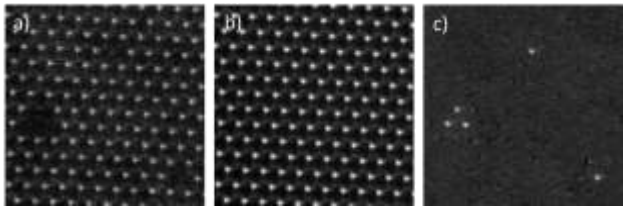


Figure 1: a) HAADF-STEM image of WS_2 material with vacancies. b) Image with vacancies refilled. This image was obtained through FFT denoising using CNN. c) Image showing vacancy positions.

Strain control, imaging and tuning developed for SiGe qubit devices

Tobias Schulli[1],
N. Nawaz[1,2], C. Corley[1], Z. Ismaili[2], M. Rodriguez[2], T. Billo[1], H. Djazouli[1], E. Dollekamp[1], S. Leake[1], M. Jankowski[1], and Y.M. Le Vaillant[2]
[1]*The European Synchrotron, Grenoble, France*
[2]*Nelumbo Digital SAS, 143 rue du Brocey, 38920 Crolles, France*
schulli@esrf.fr

Quantum hardware based on Si and Ge present the advantage of integration and scalability due to compatibility with the mainstream C-MOS semiconductor industrial technology. In addition to the unique crystalline perfection, these materials can be isotopically purified further improving their spin coherence time. The challenge in the indirect semiconductors Si and Ge is to lift the six-fold valley degeneracy in order to isolate proper qubits. This requires quantum well heterostructures with well-defined interface sharpness and most importantly a well-controlled level of homogeneous strain [1].

Biaxial strain of the order of 1 % in 10 nm quantum wells is achieved on mismatch-tuned substrates based on strain-relaxed buffers (SRBs) of $Si_{1-x}Ge_x$ alloys with Ge-content x graded up to the required relaxed lattice of the mismatched seed. However, the intrinsic defect structure of such SRBs leads at their surface to lattice parameter variations reproduced in the overgrown epitaxial layers. The ID01 beamline located at the European Synchrotron offers X-ray nanobeam diffraction imaging, a tool essential to image and study strain in such quantum wells with high spatial and strain resolution [2-4]. Typical images of an SRB and an overgrown qubit device are shown in Fig. 1(a) and (b). As strain directly affects band structure, these lattice parameter variations trigger spatial fluctuations of the conduction band minima and the expected band degeneracy lifting. These defects in the end jeopardize the functionality of the qubit devices.

To avoid such strain fluctuations, we developed a technique to strain a semiconductor membrane by external mechanical means, yielding a spatially homogeneous and controlled deformation. Using an elastomer- semiconductor hybrid structure, we demonstrate straining membranes far beyond the traditional straining by epitaxial methods, in terms of strain amplitude (up to 2 % biaxial in a Si 200 nm membrane), strain homogeneity, and strained film thickness. We estimate this technique to open up a road towards the fabrication of high quality strained structures for Si and Ge based quantum computing.

References

[1] F. A. Zwanenburg *et al.*, Reviews of modern physics, 85 (2013) 961
[2] P. Evans *et al.*, Adv. Mater. 24 (2012) 5217
[3] M.-I. Richard *et al.*, ACS Applied Mater. Interfaces, 7 (2015) 26696
[4] C. Wiciak *et al.*, ACS Appl. Mater. Interfaces, 15 (2023) 3119
[5] T. U. Schulli *et al.*, submitted Materials Today advances 2024,

Figures

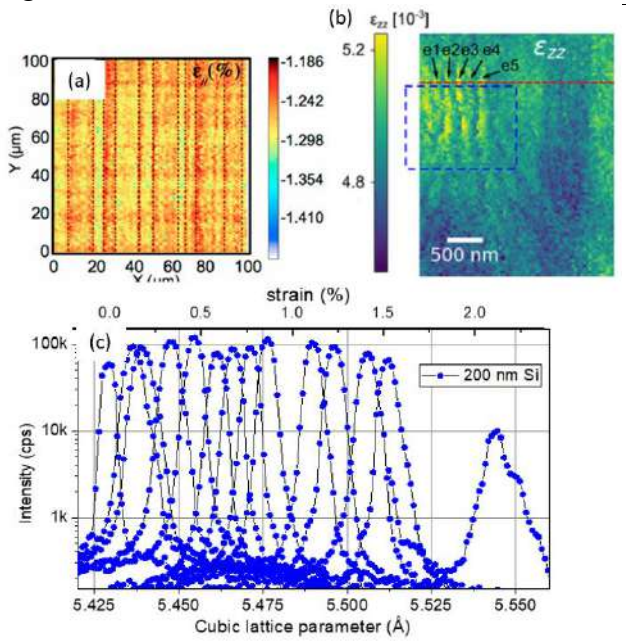


Figure 1: (a) X-ray nano-beam imaged biaxial strain in a SRB based surface (from [3]). **(b)** similar image of strain in and around a qubit device (from [4]). **(c)** biaxial strain tuning in a polymer-Si compound based process (from [5])

Long optical coherence in $Eu_xLa_{1-x}PO_4$ crystals, a new synthetic material for quantum technologies.

Diana Serrano[1]
V. Grand d'Esnon[1,2], S. Delacroix[2], S. Maron[2], T. Gacoin[2], P. Goldner[1].

[1]*IRCP, Institut de Recherche de Chimie Paris, CNRS, Chimie ParisTech, PSL University, 75005 Paris, France.*
[2]*Laboratoire de Physique de la Matière Condensée (PMC), CNRS, École polytechnique – Institut Polytechnique de Paris, 91120 Palaiseau, France.*

diana.serrano@chimieparistech.psl.eu

For several years now, rare-earth-doped crystals have been identified as promising candidates for solid-state quantum memories [1], single photon emitters [2] and scalable quantum computing [3]. In the bulk state, these materials show extremely long optical and spin coherence times, around the millisecond [4] and several hours respectively [5]. They are in addition adapted to multi-mode storage [1]. In addition, recent promising demonstrations of long optical and spin coherence times in oxide nanoparticles doped with rare-earth ions [6,7] have opened the way to new functionalities for these materials [8].

In the present work we introduce a new family of rare-earth crystals in view of their use for quantum technologies applications: the phosphates. We synthesized a series of $Eu_xLa_{1-x}PO_4$ microcrystalline powders with *x* varying from 0.01 to 1 and characterized their structural (**Figure 1**) and optical properties. Optical coherence times (T_2) (**Figure 2**) and spin population lifetimes (T_1) of Eu^{3+} ions were also assessed at cryogenic temperature. Finally, we discuss approaches for obtaining this material at the nanoscale with preserved optical coherence properties.

References

[1] M. Afzelius et al., Phys. Rev. A 79, (2009), 052329.
[2] S. Ourari et al., Nature 620 (2023), 977.
[3] A. Kinos et al., arXiv preprint arXiv:2103.15743 (2021).
[4] T. Böttger et al., Phys. Rev. B 73 (2006), 075101.
[5] M. Zhong et al., Nature 517, (2015).
[6] J. Bartholomew et al., Nano Letters 17 (2017), 778.
[7] D. Serrano et al., Nat. Commun. 9, (2018), 2127.
[8] B. Casabone et al., Nat. Commun. 12 (2021), 3570.

Figures

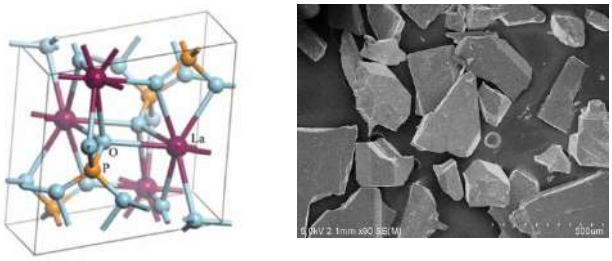


Figure 1: Left – $LaPO_4$ crystal lattice (monoclinic monazite). Right – SEM image of $Eu_{0.05}La_{0.95}PO_4$ single crystals obtained by flux method.

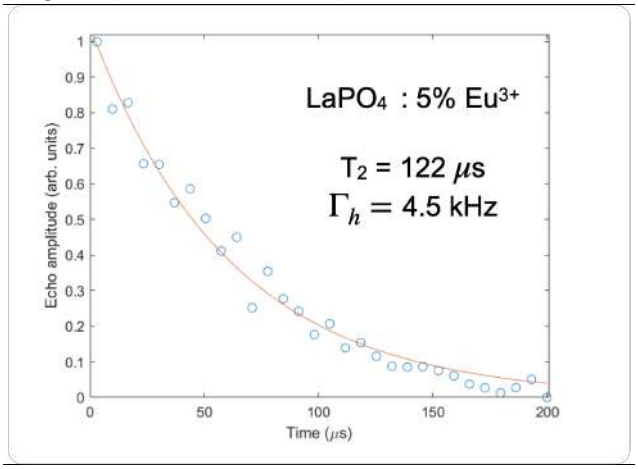


Figure 2: Photon echo decay for the $^5D_0 \leftrightarrow {}^7F_0$ transition of Eu^{3+} at 578.63 nm in $Eu_{0.05}La_{0.95}PO_4$ microcrystals yielding an optical coherence time of 122 μs. *T* = 1.3 K

Single-Atom Control of Arsenic Incorporation in Silicon for Quantum Materials Fabrication

Taylor J. Z. Stock
Oliver Warschkow, Procopios C. Constantinou, David R. Bowler, Steven R. Schofield, Neil J. Curson

University College London, Electronic and Electrical Engineering, Roberts Building, Torrington Place, WC1E 7JE, London, United Kingdom

t.stock@ucl.ac.uk

Abstract

Semiconductor device manufacturing steadily approaches the ultimate limit of miniaturization – single-atom precision. Developing a scalable, atomically precise fabrication technique would afford tremendous scientific and technological opportunities. By providing novel engineered quantum materials and devices, scalable atomically precise fabrication will enable exploration of new areas of condensed matter physics and could facilitate the realization of universal solid-state quantum computers. Scanning tunnelling microscopy hydrogen resist lithography is the only fabrication technique capable of positioning individual dopant atoms at nearly exact lattice sites in silicon and germanium. Traditionally, this technique has used the precursor phosphine to precisely position phosphorus atoms. Using phosphorus-in-silicon, single and few atom donor devices are now routinely demonstrated, providing tantalizing glimpses into future quantum technologies. Recent studies suggest that the phosphine-silicon surface chemistry limits the single-atom fabrication yield. Arsine as a precursor to arsenic patterning offers an alternative and advantageous approach to atomically precise fabrication [1,2]. By using arsenic-in-silicon it is possible to improve the single-atom yield sufficiently to allow repeatable single atom fabrication, thus providing pathways to single-atom precision fabrication scale-up. In this talk we explore the single atom control of arsenic incorporation in silicon that can provide up to 100% yield, and discuss recent progress in fabrication of quantum materials using this approach.

References

[1] T.J.Z. Stock, *et al*., arXiv:2311.05752 (2023)
[2] T.J.Z. Stock, *et al*., ACS Nano 14, (2020) 3316

Figures

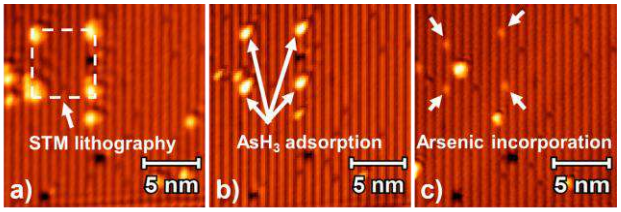


Figure 1: Single-atom arsenic pattering in Si(001) by scanning tunnelling microscopy hydrogen resist lithography: Step-wise fabrication of an artificial 2×2 single-atom arsenic lattice, imaged after: a) STM lithographic patterning of the hydrogen resist, b) room temperature adsorption of AsH_3 through the patterned adsorption windows, and c) thermal annealing for substitutional arsenic incorporation.

Quantum nanostructures of correlated metal oxides

Hongguang Wang
Gennadii Laskin
Varun Harbola
Jochen Mannhart
Peter A. van Aken

Max Planck Institute for Solid State Research, Heisenbergstraße 1, 70569 Stuttgart, Germany

hgwang@fkf.mpg.de

NANOSTRUCTURES of functional materials provide an experimental platform to study novel physical phenomena when the characteristic device size reaches intrinsic length scales, such as the inelastic scattering length or the Fermi wavelength [1]. Nanostructures of mean-field systems, especially semiconductors, with confined electron systems have been studied for decades, leading to widespread technological applications. However, studies of correlated systems, such as complex oxide materials, are mainly presented in 2D, especially at interfaces. Confinement effects in fewer dimensions, i.e., 0D, have been only marginally studied due to the challenges associated with the fabrication of 0D objects from 3D oxide materials with low defect density.

In this study, we present two different approaches (top-down and bottom-up) for fabricating quantum nanostructures of correlated metal oxides. We illustrate the top-down fabrication and exploration of arrays of nanodots of $SrRuO_3$ with dot sizes between 500 and 15 nm (Figure 1). The magnetic properties of $SuRuO_3$ nanodots depend on the size of the nanodots associated with strain and oxygen octahedral rotation, as demonstrated by scanning transmission electron microscopy [2, 3]. In another parallel study, we show that the self-assembly of complex oxide membranes enables the fabrication of faceted nanodots with low defect density (Figure 2) [4]. Our studies highlight the potential for fabricating oxide nanostructures with exotic properties.

References

[1] Gennadii Laskin, Hongguang Wang, Hans Boschker, Wolfgang Braun, Vesna Srot, Peter A. van Aken, and Jochen Mannhart. *Nano Letters,* 19(2019) 1131-1135.

[2] Hongguang Wang, Gennadii Laskin, Weiwei He, Hans Boschker, Min Yi, Jochen Mannhart, and Peter A. van Aken. *Advanced Functional Materials,* 32 (2022) 2108475.

[3] Hongguang Wang, Vesna Srot, Bernhard Fenk, Gennadii Laskin, Jochen Mannhart, and Peter A. van Aken. *Micron,* 140 (2021) 102979.

[4] Varun Harbola, Yu-Jung Wu, Hongguang Wang, Sander Smink, Sarah C. Parks, Peter A. van Aken, and Jochen Mannhart. *Advanced Materials,* 35 (2023) 2210989.

Figures

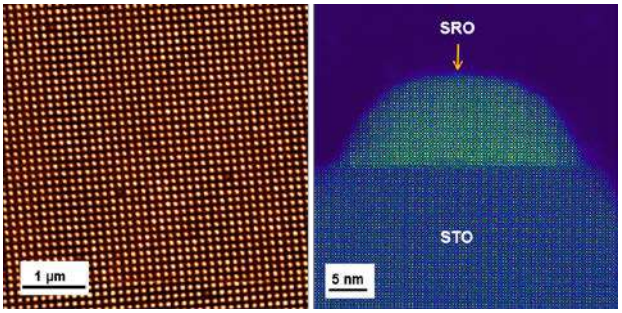


Figure 1: Arrays of nanodots of SrRuO3 with the dot size of 30 nm

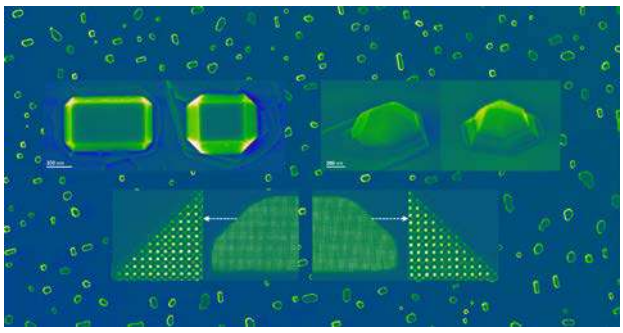


Figure 2: Nanocrystalline structures obtained by self-assembly of oxide membranes

Oblivious Transfer and Bit Commitment Based on Quantum Communication

Pino Caballero-Gil
Daniel Escanez-Exposito

University of La Laguna, 38271 La Laguna, Tenerife, Spain

pcaballe@ull.edu.es

Abstract

In Quantum Key Distribution (QKD), a sender (Alice) and a receiver (Bob) who trust each other want to establish a shared secret key through quantum communication.
Unlike QKD, in two-party cryptographic protocols based on quantum communication, such as quantum oblivious transfer and bit commitment, Alice and Bob are not assumed to trust each other. This implies that the study of these protocols must consider both combinations of honest Alice with malicious Bob, and vice versa.
In Quantum Oblivious Transfer (QOT) Alice transfers with probability 1/2 a secret to Bob in such a way that she does not know whether he succeeded in obtaining the secret (concealing property), using quantum communication [1].
In Quantum Bit Commitment (QBC) Alice selects a binary value and commits it to Bob so that she cannot change her choice after committing it (binding property), while Bob does not know the selected value until Alice reveals it (hiding property), all of this using quantum communication [2].
QOT and QBC have been the subject of research over the last years in which several proposals and results have been presented, based on principles of quantum mechanics such as entanglement, superposition and non-cloning. One of those results is that QBC can be implemented from QOT and vice versa. Unfortunately, other results include different quantum no-go theorems showing that quantum mechanics does not allow implementations of such cryptographic primitives without further assumptions [3].
This work discusses the two main paths being taken to develop practical quantum protocols that minimize the risk of cheating. On the one hand, some developments are based on certain assumptions about the existence of functional primitives (e.g., QBC) [4], or on limitations in the technological potential of the malicious party (e.g., noisy-storage model) [5]. On the other hand, other developments are based on a relaxed definition of security that allows the malicious party to extract, with a given probability, certain information about the input/output of the honest party, leading to weak protocol definitions [6].

References

[1] Bennett, C.H., Brassard, G., Crépeau, C., Skubiszewska, M.H. (1991). Practical quantum oblivious transfer. Annual international cryptology conference, 351-366. Springer.
[2] Brassard, G., Crépeau, C. (1991). Quantum bit commitment and coin tossing protocols. Advances in Cryptology-CRYPTO'90, 49-61. Springer.
[3] Mayers, D. (1997). Unconditionally secure quantum bit commitment is impossible. Physical review letters, 78(17), 3414.
[4] Grilo, A.B., Lin, H., Song, F., Vaikuntanathan, V. (2021). Oblivious transfer is in MiniQCrypt. Annual International Conference on the Theory and Applications of Cryptographic Techniques, 531-561. Springer.
[5] Liu, Y., et al. (2014). Experimental unconditionally secure bit commitment. Physical review letters, 112(1), 010504.
[6] Aharonov, D., et al. (2016). A simpler proof of the existence of quantum weak coin flipping with arbitrarily small bias. SIAM Journal on Computing, 45(3), 633-679.

Parametric longitudinal coupling between a semiconductor charge qubit and a RF resonator

Victor Champain
S. Zihlmann, A. Chessari, B. Bertrand, H. Niebojewski, E. Dumur, X. Jehl, V. Schmitt, B. Brun, C. Winkelmann, Y.M. Niquet, M. Filippone, S. De Franceschi, and R. Maurand

Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG-Pheliqs, Grenoble, France.
Victor.champain@cea.fr

We investigate here a relatively unexplored interaction between a semiconductor charge qubit and a radiofrequency resonator, known as longitudinal coupling [1], which has been recently implemented in the context of superconducting qubits [2]. Such an interaction allows time-multiplexed and quicker measurements of multiple qubits using a single resonator. Furthermore, the longitudinal coupling commutes with the measured qubit observable offering true quantum non-demolition read-out and minimal Purcell decay. Finally, it would allow fast and high-fidelity two-qubit CPHASE gates [3].
We study both dispersive and longitudinal qubit-resonator interactions as a function of the qubit Larmor frequency in the adiabatic regime. We report a conditional parametric displacement of the resonator field (see FIG.1.(a)), and rule out any dispersive contribution (see FIG.1.(b)), demonstrating a purely longitudinal interaction between the qubit and the resonator. Our work paves the way to the longitudinal read-out of spin-qubits in semiconducting hybrid devices [4,5].

References

[1] Didier et al., Phys. Rev. Letters (2015)
[2] Touzard et al., Phys. Rev. Letters (2019)
[3] Schuetz et al., Phys. Rev. B (2019)
[4] Yu et al., Nat. Nano. (2023)
[5] Corrigan et al., Phys. Rev. Appl. (2023)

Figures

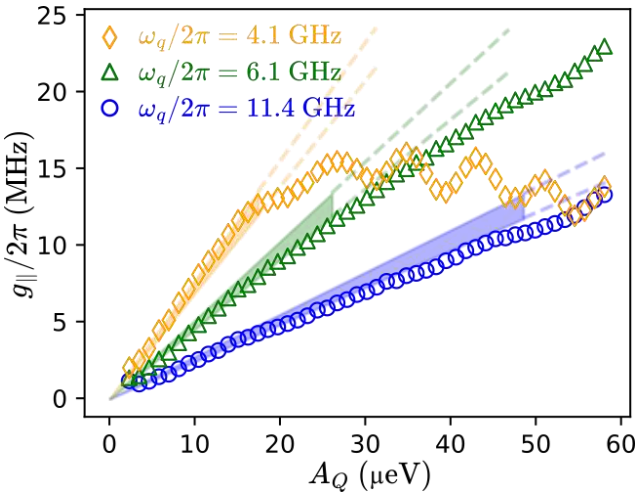
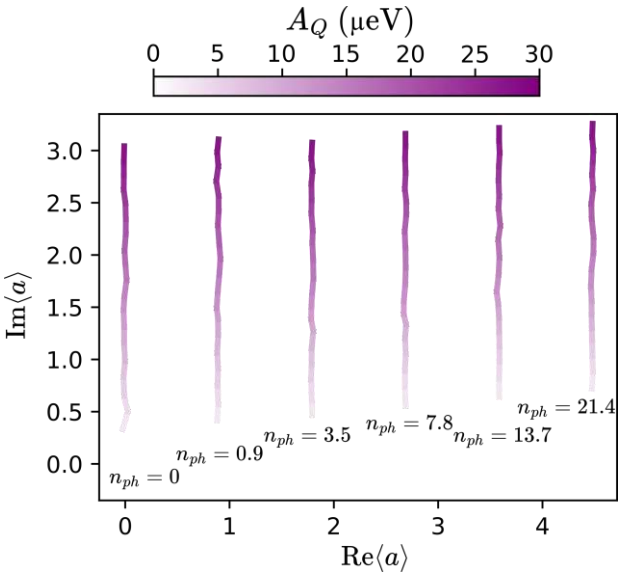


Figure 1: Parametric modulation of the longitudinal coupling with the drive amplitude.



s

Figure 2: Linear displacement of the resonator coherent state with the drive amplitude and independence in the resonator population, ruling out dispersive contribution.

Poor’s man Majorana with superconducting phase control

Samuel D. Escribano
Anders Enevold Dahl, Omri Lesser, Karsten Flensberg, Yuval Oreg

Weizmann Institute of Science, Rehovot, Israel

samuel.diazes@gmail.com

Majorana modes, topologically protected edge states arising in 1D systems, demonstrate non-abelian anyonic properties, rendering them promising candidates as fundamental components for fault-tolerant quantum computers [1]. Despite extensive efforts spanning two decades to generate and manipulate these states in nanowires, their definitive existence remains elusive [2]. Recent proposals have shifted focus towards engineering chains of quantum dots (QDs) to emulate the Kitaev chain [3, 4]. While it is feasible to achieve a rudimentary version of Majorana modes with only two QDs, called Poor’s Majorana modes (PMMs), they often exhibit a limited topological minigap for fined tunned parameters. This is primarily due to the substantial magnetic fields required, which is significantly detrimental for such short chains.

We present a novel approach to engineer a magnetic field-free Kitaev chain utilizing superconducting phase differences. Our strategy involves coupling each QD to three superconductors, see Fig. 1. By tuning the coupling between the two QDs and three (out of six) superconducting phases, we find PMMs without the need for magnetic fields. Through analytical calculations of a minimal model and numerical simulations of a more realistic description, we demonstrate the robustness of our approach, yielding PMMs across a broad parameter range. Notably, these modes exhibit measurable topological minigaps unaffected by magnetic field-induced smearing. Furthermore, our scheme facilitates the emergence of PMM in the strong coupling regime with the superconductors, thereby mitigating certain sources of noise.

References

[1] R. Aguado, La Rivista del Nuovo Cimento, 40 (2017) 523.
[2] E. Prada, P. San-Jose, M. W. A. de Moor, *et al.*, Nature Reviews Physics, 2 (2020) 575.
[3] T. Dvir, G. Wang, N. van Loo, *et al.*, Nature, 614 (2023) 445.
[4] A. Tsintzis, R. Seoane Souto, K. Flensberg, J. Danon, and M. Leijnse, PRX Quantum 5 (2024) 010323.

Figures

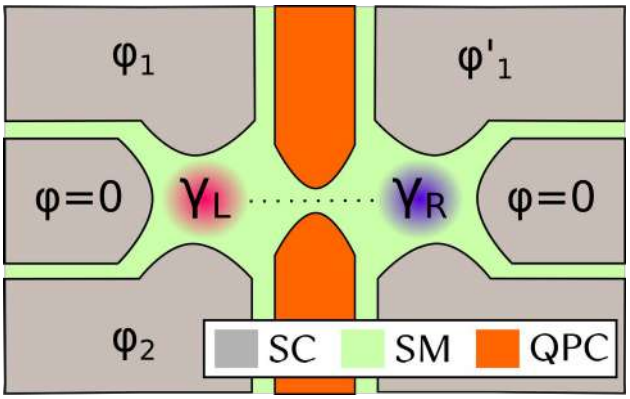


Figure 1: Sketch of the system analyzed in our work: a double quantum dot (QD) electrostatically defined in a semiconductor (SM), represented in red/blue colors. Each QD is coupled to three different superconductors (SCs). By tunning the coupling between the QDs (with the gates in orange) and controlling three out of six superconducting phases, one can obtain Poor’s Majorana modes (PMM) on each QD, the so-called left γ_L and right γ_R Majoranas.

High-fidelity spin shuttling in silicon quantum dots

M. De Smet[1]†
Y. Matsumoto[1†], A.M.J. Zwerver[1], L. Tryputen[2], S.L. de Snoo[1], S.V. Amitonov[2], A. Sammak[2], M. Rimbach-Russ[1], G. Scappucci[1], L.M.K. Vandersypen[1]

[1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands
[2]QuTech and Netherlands Organization for Applied Scientific Research (TNO), Delft, The Netherlands

†These authors contributed equally
m.w.h.desmet@tudelft.nl

Long-range quantum links between spin qubits in quantum dots [1,2] are a key aspect in architectures that scale to the thousands of qubits that are required for practical quantum computation. In this work we create a quantum link by shuttling a single electron spin across a linear array of six tunnel-coupled quantum dots (Fig. 1). An electron can be shuttled through the array in bucket-brigade mode (Fig. 2a) by sequentially pulsing both the electrochemical potential of each quantum dot and the interdot tunnel barriers. Alternatively, sinusoidal voltage signals can be applied to the channel gates to create a traveling wave potential, which we call a conveyor (Fig. 2b). We benchmark both bucket brigade and conveyor-mode shuttling while transporting the electron back and forth through the array. In bucket brigade, the (echoed) spin is shuttled with an average single hop phase flip probability of 0.57% (0.28%), consistent with earlier work on shuttling between two dots in silicon [3,4]. We find that conveyor mode shuttling improves the phase flip probability by a factor of 3.5 for the same shuttling distance. We also introduce a two-tone conveyor concept, which reduces the spin flip probability by another factor of 2. This method achieves a shuttling fidelity of 99% for an effective distance of 10 µm, covered in under 200 ns.

References

[1] J.M. Taylor et al., Nature Physics, 1 (2005) 177–183
[2] L.M.K. Vandersypen et al., npj Quantum Information, 3 (2017) 34
[3] J. Yoneda et al., Nature Communications, 12 (2021) 4114
[4] A. Noiri et al., Nature Communications, 13 (2022) 5740

Figures

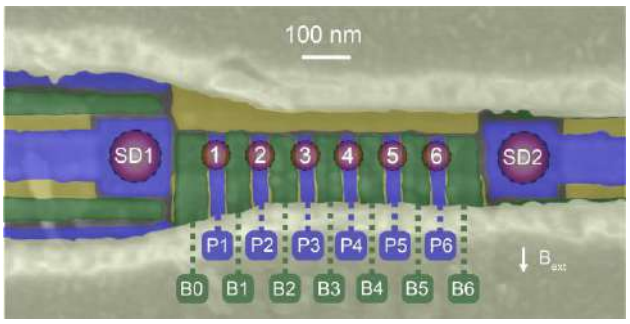


Figure 1: False-colored scanning electron microscope image of a nominally identical device to the one used. The colors indicate different metallization layers on top of an isotopically enriched ^{28}Si/SiGe heterostructure, forming a linear array of six quantum dots (indicated by numbered circles). Two sensing dots (SD) are placed at both ends of the array.

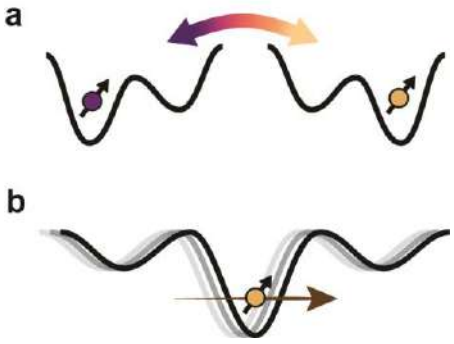


Figure 2: Schematic representation of (a) bucket-brigade mode and (b) conveyor-mode shuttling. In bucket-brigade mode, the electron tunnels from site to site in an array of static quantum dots. In conveyor-mode, the electron is transported smoothly using a traveling potential wave.

Digital Quantum Simulation of Quantum Many-Body Dynamics on NISQ Devices

Benedikt Fauseweh

TU Dortmund University, Department of Physics, Otto-Hahn-Str 4, 44227 Dortmund, Germany

German Aerospace Center (DLR), Institute for Software Technology, Linder Höhe, 51147 Köln, Germany

benedikt.fauseweh@tu-dortmund.de

In this talk I address the complex issue of utilizing Noisy Intermediate-Scale Quantum (NISQ) devices for simulating quantum many-body dynamics. Recent attempts to demonstrate quantum utility in this domain have been met with skepticism, as advanced tensor network methods quickly refuted these claims. The field faces a significant challenge: simulations requiring low entanglement are well within the grasp of tensor network approaches, but those needing deeper circuit depths encounter the 'universal attractor' of noise, leading to the loss of quantum coherence. In this context I will discuss some of our recent results using Trotterized time evolution [1], demonstrating the key problem and how far we can come with error mitigation. Then I will focus on two methods to tackle these issues in non-equilibrium systems like Floquet Hamiltonians. We have developed variational algorithms for approximating Floquet eigenstates [2] and a quantum-classical feedback scheme to stabilize discrete time crystals on NISQ devices, considering the impact of noise [3]. These approaches aim to navigate the delicate balance between entanglement, circuit depth, and noise in NISQ devices.

References

[1] B. Fauseweh and J.-X. Zhu, "Digital Quantum Simulation of Non-Equilibrium Quantum Many-Body Systems," *Quantum Inf. Process.*, **20**, 138, 2021

[2] B. Fauseweh and J.-X. Zhu, "Quantum computing Floquet energy spectra," *Quantum* **7**, 1063, 2023

[3] G. Camacho, B.Fauseweh, "Prolonging a discrete time crystal by quantum-classical feedback", arXiv:2309.02151, 2023

Figures

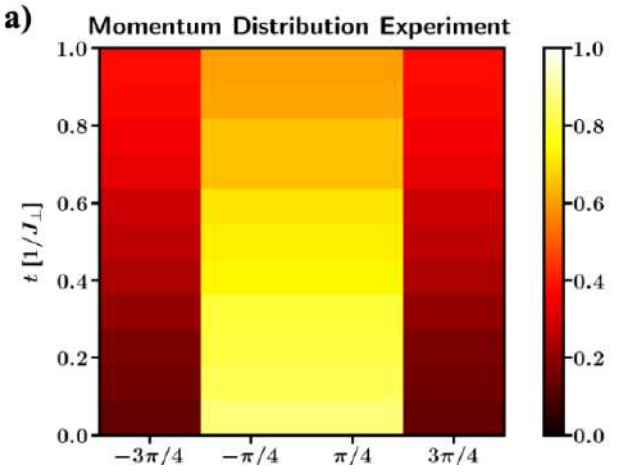


Figure 1: Simulation of a quantum quench in a fermionic system. Investigation into the thermalization of complex quantum matter through quantum simulation.

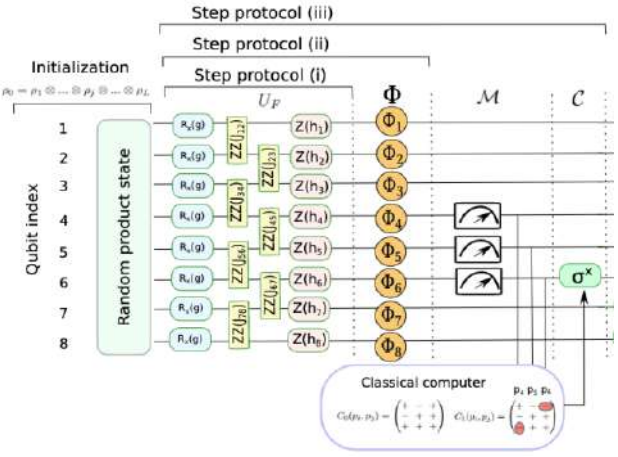


Figure 2: Quantum-Classical feedback scheme to stabilize a many-body localized discrete time crystal on a NISQ device.

Theory of Superconducting Diode effect in Multiterminal Josephson junctions

Jorge H. Correa
Michał P. Nowak

AGH University of Krakow, Academic Centre for Materials and Nanotechnology,
al. A. Mickiewicza 30, 30-059 Krakow, Poland

jorge@agh.edu.pl

We theoretically study the superconducting diode effect (SDE) in a three-terminal Josephson junction (Figure 1). The diode effect in superconducting systems is typically related to the presence of a difference in the critical currents for currents flowing in the opposite direction. We show that in multi-terminal systems this effect occurs naturally without the need of the presence of any spin interactions and is a result of the presence of a relative shift between the Andreev bound states (ABSs) carrying the supercurrent (Figure 2). The origin of this phenomenon is related to the local breaking of time reversal and inversion symmetries, resulting from the coupling of the third terminal with a phase different from 0, mod(π).

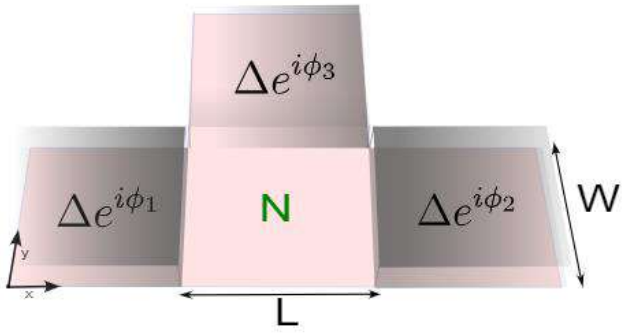


Figure 1: Planar Josephson junction. The pink region corresponds to the normal part and the gray superconducting segments are the superconducting leads.

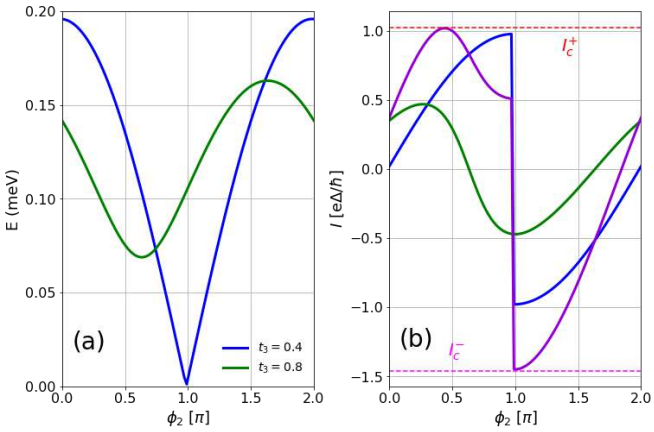


Figure 2: Energy spectrum (a) and supercurrent (b) in three-terminal Josephson junction hosting two ABSs characterized by different coupling strength to the superconducting terminals. The violet curve in (b) shows the non-reciprocal current carried by the two ABSs. The phase on the third superconducting terminal is $\varphi_3 = 1.5\pi$.

References

[1] Jorge H. Correa, Michal P. Nowak, arXiv:2401.16262, (2024).
[2] M. Gupta, et.al, Nature communications, 14 (2023), 3078
[3] Matsuo, Sadashige, et.al, Nature physics, 19 (2023), 1636–1641.
[4] Margarita Davydova, et.al, Science Advances, 8, eabo0309 (2022), 23.
[5] Kun Jiang and Jianping Hu, Nature physics, 18 (2022), 1145-1.

Gate-controlled metallic superconductors and superconducting diodes

Daniel Margineda
NEST, Istituto Nanoscienzce-CNR and Scuola Normale Superiore, Pisa, Italy. Present address: CIC nanoGUNE BRTA, Donostia, Spain.

d.margineda@nanogune.eu

The constant demand for faster and more efficient electronics encourages the development of solutions beyond Moore-era of CMOS technologies on which power consumption and thermal management has become a reason of major concern. To address the problem of the increasing power demand of modern computers, hybrid architectures combining CMOS devices with low-energy dissipation devices made of superconductor materials have been proposed. However, several issues need to be addressed for a realistic implementation. In this talk I will discuss the current progress of two emerging fields in superconducting electronics: gate controlled supercurrent (GCS) in metallic superconductors [1] and the superconduct-ting diode effect (SDE) [2].
The suppression of superconducting correlations due to a gate voltage in metallic platforms offer a promising alternative to Josephson junctions-based technologies with superior performance in terms of (i) scalability, (ii) interfacing with CMOS circuits, and (iii) stability against magnetic performance [3].
On the other side, SDE refers to the asymmetric switching of the critical current required to turn a superconductor into the normal state depending on the current bias polarity. Breaking both inversion and time-reversal is the foundational aspect to enable the diode effect. In our latest works, we demonstrate the potential of conventional Niobium-based nanobridges as tunable superconducting diodes.
in a regime without magnetic screening [4].
Despite the intense efforts in designing highly efficient supercurrent diodes, most of the proposals relies on magnetic fields, magnetic materials, or vortices as time-reversal symmetry breakers [5]. We propose a new paradigm for nonreciprocal superconducting transport in a completely magnetic field-free fashion that does not rely on time-reversal symmetry breakers [6]. We demonstrate nearly ideal rectification of the supercurrent in a gate-controlled reciprocal weak link by employing a back-action supercurrent mechanism. The proof-of-principle not only provides new functionalities to GCS devices, but it also represent a general pathway to design supercurrent diodes independently of the specific mechanism that yields the supercurrent suppression.

[1] de Simoni, G. *et al*. Nat. Nanotechnol. 13,802 (2018)
[2] Ando, F. *et al*. Nature 584,373 (2020)
[3] Lupo, FV. *et al*. IEEE Trans. Appl. Supercond. 34, 3 (2024)
[4] Margineda, D. *et al*. Comms. Phys. 6,343(2023)
[5] Nadeem, M. et al. Nat. Rev. Phys. 5, 558 (2023)
[6] Margineda, D. et al. arXiv:2311.14503 (2024)

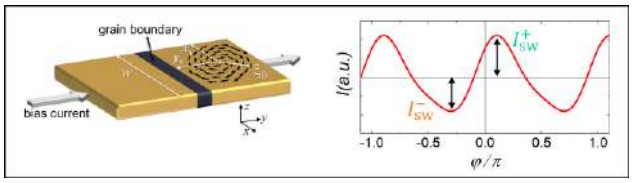


Figure 1: Model of sign-tunable diode effect in superconducting nanobridge. [4]

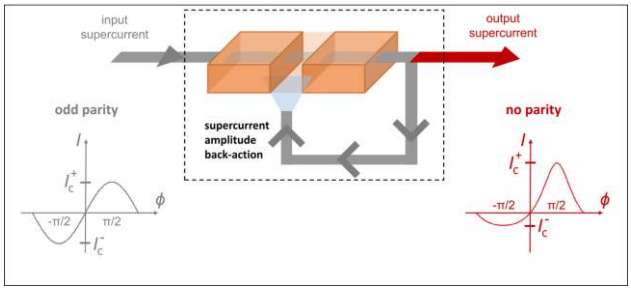


Figure 2: Principle of supercurrent diode effect by supercurrent amplitude back-action. [6]

Thermally driven quantum refrigerator autonomously resets superconducting qubit

Aamir Ali[1]
Paul Jamet Suria[1], José Antonio Marín Guzmán[2], Claudia Castillo-Moreno[1], Jeffrey M. Epstein[2,3], Nicole Yunger Halpern[2,3], and Simone Gasparinetti[1]

1. Department of Microtechnology and Nanoscience, Chalmers University of Technology, 41296, Gothenburg, Sweden
2. Joint Center for Quantum Information and Computer Science, NIST and University of Maryland, College Park, MD 20742, USA
3. Institute for Physical Science and Technology, University of Maryland, College Park, MD 20742, USA

aamir.ali@chalmers.se
nicoleyh@umd.edu
simoneg@chalmers.se

Abstract

The first thermal machines steered the industrial revolution, but their quantum analogs have yet to prove useful. Here, we demonstrate a useful quantum absorption refrigerator formed from superconducting circuits. We use it to reset a transmon qubit to a temperature lower than that achievable with any one available bath. The process is driven by a thermal gradient and is autonomous -- requires no external control. The refrigerator exploits an engineered three-body interaction between the target qubit and two auxiliary qudits coupled to thermal environments. The environments consist of microwave waveguides populated with synthesized thermal photons. The target qubit, if initially fully excited, reaches a steady-state excited-level population of $5\times10^{-4} \pm 5\times10^{-4}$ (an effective temperature of 23.5 mK) in about 1.6 μs. Our results epitomize how quantum thermal machines can be leveraged for quantum information-processing tasks. They also initiate a path toward experimental studies of quantum thermodynamics with superconducting circuits coupled to propagating thermal microwave fields.

References

[1] Preprint: https://arxiv.org/abs/2305.16710

Figures

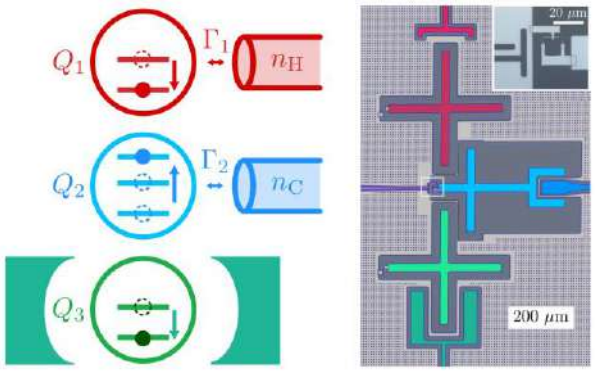


Figure 1: Scheme and implementation of a quantum absorption refrigerator.

Single-particle emission from the Andreev's level

Mykhailo Moskalets[1]
Pablo Burset[2], Benjamin Roussel[3], Christian Flindt[3]

[1] *Instituto de Física Interdisciplinar y Sistemas Complejos IFISC (CSIC-UIB), E-07122 Palma, Spain; on leave from the Department of Metal and Semiconductor Physics, NTU "Kharkiv Polytechnic Institute", Kharkiv, Ukraine (e-mail: mykhailo.Moskalets@khpi.edu.ua)*
[2] *Department of Theoretical Condensed Matter Physics, Condensed Matter Physics Center (IFIMAC) and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, 28049 Madrid, Spain*
[3] *Department of Applied Physics, Aalto University, 00076 Aalto, Finland*

moskalets@ifisc.uib-csic.es

Abstract

Recently, high-speed quantum-coherent electron sources injecting one- to few-particle excitations into the Fermi Sea have been experimentally realized.[1]-[3] The main obstacle to using these excitations as flying qubits [4] for quantum-information processing purposes is decoherence due to the long-range Coulomb interaction [5]. An obvious way to get around this difficulty is to employ electrically neutral excitations, for instance electron-hole pairs from the composite source.[6] Here we discuss how such excitations can be generated on-demand using the same injection principles as in existing electron sources. Namely, with the help of a voltage pulse of a certain shape applied to the Fermi Sea, or using a driven quantum dot with superconducting correlations. In the former case a two-particle state (per spin) is excited, an electron-hole pair. While in the latter case a single-particle state with a variable charge is excited, an electron-hole superposition (EHS). Using a time-resolved electric current, in Fig.1 we show how the EHS composition varies with magnetic field from symmetric (electrically neutral) to asymmetric (charged). As shown in Fig.2, heat carried by EHS is proportional to charge, not noise, as in the case of the electron-hole pair state.

References

[1] M.D. Blumenthal et al., Nat Phys., 3 (2007) 343
[2] G. Fève et al., Science, 316 (2007) 1169
[3] J. Dubois et al., Nature, 502 (2013) 659
[4] H. Edlbauer et al., EPJ Quantum Technol. 9 (2022) 21
[5] V. Freulon et al., Nat Comm., 6 (2015) 6854
[6] M. Moskalets et al., Eur. Phys. J. Special Topics 229 (2020) 647

Figures

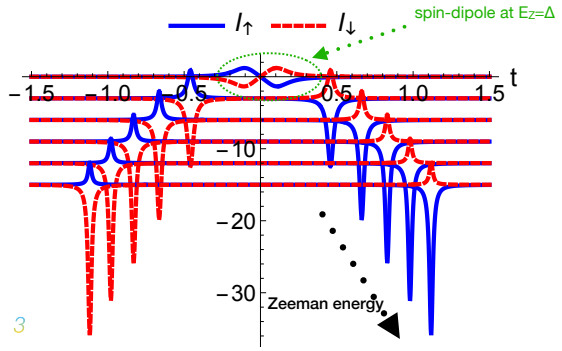


Figure 1: A time- and spin-resolved electric current injected into a normal lead from the Andreev's level, driven by a gate potential linear in time, U ~ t. Graphs at different Zeeman energies, E_Z/Δ= 1;1.1;1.2;1.3;1.4; and 1.5, are shifted for clarity. Δ is the superconducting gap

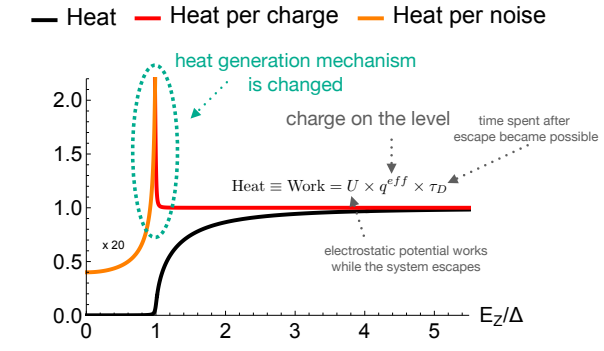


Figure 2: Electrical and thermal quantities are smooth functions of Zeeman energy. In contrast, their ratios clearly demonstrate a phase transition at $E_Z=\Delta$, from the phase when the Andreev's level crosses the Fermi energy and changes its population as the gate potential U(t) is varied, to the phase when the population does not change with varying U(t).

Qblox Quantum Control Stacks: Accelerating Experiments, Reducing Error, and Enabling Large-Scale Quantum Computing

Tahereh Niknejad
Rohit Navarathna, Edgar Reehuis, Damaz de Jong, Marijn Tiggelman, Daniel Weigand, Edmundo Ferreira, Calin Sindile, Jordy Gloudemans, Wouter Vlothuizen, Jules van Oven, Christiaan Cornelis Bultink,

Qblox BV, Delft, the Netherlands

tniknejad@qblox.com

Abstract:

NISQ applications require improvements in gate fidelities, scalability, and overcoming experimental overheads. Qblox's Cluster system is designed to support these efforts by providing fully integrated, time-efficient, and ultralow-noise control stacks covering frequency range of DC to 18.5 GHz, making it suitable for various qubit types.

The Cluster control stacks incorporate Q1 advanced sequence processors capable of sequencing pulses and their parameters in real-time, and on-the-fly analysis of the readout signals. Orders of magnitude speed-up is achieved by avoiding software-controlled loops and fast scalable feedback operation.

RFSoC-based qubit control and readout modules generate RF signals directly on-chip, using double super-heterodyne approach, eliminating the need for mixer calibration. They are designed for scaling up control and readout systems with higher channel density, extended analog bandwidth up to 1.6 GHz, and multiplexing capability of up to 12 frequencies.

Additionally, a dedicated time-tagging module with digital I/O streamlines readout of single photon detectors for both time tagging and photon counting.

To minimise errors at the individual qubit level, the Qblox Cluster integrates real-time pre-distortion within the signal chain. This actively corrects pulse imperfections imposed by travelling through cables and cryogenic systems enabling repeatable and high-fidelity control pulses.

Finally, Qblox's fast scalable feedback distributes measurement outcomes with all-to-all connectivity to allow active-reset operations and error mitigation algorithms. This massively scalable approach brings qubit control and readout to a new level on the route to NISQ applications and further to fault-tolerant quantum computing.

For controlling the instrument, Qblox offers open-source Python-based software packages. The high-level software package, Quantify, simplifies complex quantum programming with libraries of pre-defined pulse schemes tailored to different qubit platforms.

For users requiring even greater control, the system allows programming the Q1 sequencer directly using assembly language for complex user-defined pulse sequences allowing unparalleled control. Additionally, Qblox integrates a Qiskit compiler enabling seamless execution of Qiskit experiments directly on the Qblox Cluster.

In this talk we will dive deep into the Qblox solution, from its hardware and software architecture to real-world applications.

Quantum computing with qubits embedded in trapped-ion qudits

Anastasiia S. Nikolaeva[1,2]
Ilia V. Zalivako[2,1], Alexander S. Borisenko[2,1], Evgeniy O. Kiktenko[1], Ilya A. Semerikov[2,1], Aleksey K. Fedorov[1,2], Nikolay N. Kolachevsky[2,1]

[1]*Russian Quantum Center, Skolkovo, Moscow 121205, Russia*
[2]*P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow 119991, Russia*

anastasiia.nikolaeva21@gmail.com

Due to the progress in developing quantum computing hardware platforms, more and more attention is being paid to quantum computing with d-level quantum systems, qudits [1-4]. Since most physical systems typically used as quantum information carriers have more than two levels, the idea of using the increased computational space to perform quantum algorithms is being actively studied. Moreover, prototypes of qudit-based quantum processors with photons, superconducting circuits, and trapped ions have already been presented [1,4].

In our work [2], we focus our attention on trapped-ion-based qudits as an efficient experimental control of such systems with up to 8 levels with high enough gate fidelities has been shown, and experimental results for systems with even higher level numbers have been presented. In particular, we develop methods for compiling qubit algorithms to the set of native gates for trapped-ion qudits of various experimentally relevant dimensionalities (d=3,...,8). For qutrits (d=3), we show how the third level simplifies multi-qubit gate decompositions. For ququarts (d=4), we explain how to obtain a universal gate set for embedded in ququarts' space qubit pairs. Further, we extend this approach to 5,6 and 7-level qudits and demonstrate how each additional level of a qudit (compared to the first 4 levels) helps to reduce the circuit width and depth in multiqubit gate decompositions. Finally, we discuss how to construct a universal set of gates with triples of qubits embedded in quocts (d=8).

The main feature of the developed methods is the use of qudit extensions of the Mølmer-Sørensen gate as a basic two-particle operation. It makes our results directly applicable to existing prototypes of qudit-based trapped-ion processors and allows one to implement qubit algorithms with qudit-based trapped-ion hardware.

The research is supported by RSF grant No. 19-71-10091.

References

[1] I.V. Zalivako, A.S. Nikolaeva, et. al., Towards multiqudit quantum processor based on a $^{171}Yb^{+}$ ion string: Realizing basic quantum algorithms, arXiv:2402.03121
[2] A.S. Nikolaeva, E.O. Kiktenko, A.K. Fedorov, Universal quantum computing with qubits embedded in trapped-ion qudits, arXiv:2302.02966 (accepted in Phys. Rev. A)
[3] E.O. Kiktenko, A.S. Nikolaeva, A.K. Fedorov, Realization of quantum algorithms with qudits, arXiv:2311.12003
[4] M. Ringbauer, et al. A universal qudit quantum processor with trapped ions. Nature Physics, 18(9), 1053-1057 (2022)

Integrating tensor networks with quantum computing for simulations of strongly correlated materials

Yannic Rath[1]
François Jamet[1], Connor Lenihan[1], Lachlan P. Lindoy[1], Abhishek Agarwal[1], Enrico Fontana[1,2], Baptiste Anselme Martin[3,4], Ivan Rungger[1]

[1]*National Physical Laboratory, Teddington, TW11 0LW, United Kingdom*
[2]*University of Strathclyde, Glasgow G1 1XH, United Kingdom*
[3]*TotalEnergies, Tour Coupole - 2 place Jean Millier 92078 Paris la Défense, France*
[4]*Universite Paris-Saclay, CNRS, Laboratoire de Physique des Solides, 91405, Orsay, France*

yannic.rath@npl.co.uk

The accurate numerical simulation of materials from first principles inherently relies on an efficient description of the electronic correlation underpinning many observable properties. Especially in regimes of strong correlation, dynamical mean-field theory (DMFT) has emerged as one of the main workhorses for the accurate extraction of system properties that cannot be captured efficiently by higher level theories. However, the scalability of this approach often remains limited due to inabilities of classical techniques to capture the emergence of strong entanglement within the underlying many-body problems. In this talk, we discuss novel routes towards overcoming such barriers by integrating quantum algorithms into the DMFT pipeline which aid the computation of dynamical properties such as Green's functions. We outline a hybrid quantum-classical approach [1] aiming to bring together the strengths of classical tensor network approaches and quantum algorithms to enable scalable simulations of strongly correlated materials.
Within our hybrid scheme, schematically depicted in Fig. 1, we leverage the representational power of tensor networks as a classical description of the Hamiltonian's ground state, which typically exhibits low to medium degrees of entanglement. We then extract the dynamical properties required for DMFT simulations by applying a quantum algorithm to perform a real-time evolution of the state [2] naturally increasing the entanglement and limiting the applicability of classical wavefunction methods.
In addition to the suitability of the tensor network to represent targeted Fermionic ground state, the success of the hybrid approach particularly hinges on the ability to prepare Fermionic tensor network states as shallow quantum circuits. In this talk, we show how general-purpose compilation approaches [3] can be adapted to reach necessary fidelities for the preparation of Anderson impurity model ground states. This paves the way for scaling the hybrid approach to practically relevant scenarios and eventually enable simulations that are out of reach of classical techniques.

References

[1] F. Jamet, et. al., arXiv:2304.06587
[2] F. Jamet, et. al., arXiv:2205.00094
[3] M. S. Rudolph, et. al., Quantum Sci. Technol. 9 015012 (2024)

Figures

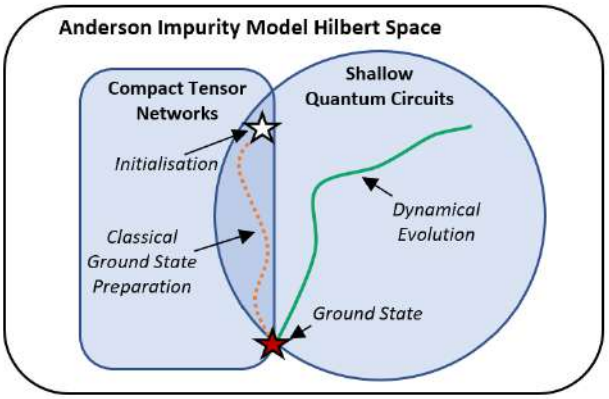


Figure 1: Schematic overview hybrid approach to compute dynamical quantities for Anderson impurity models.

Exploring noisy quantum Kibble-Zurek physics with superconducting transmon qubits

Brendan Rhyno
Swarnadeep Majumder, Oles Shtanko, Smitha Vishveshwara, Khadijeh Najafi

University of Illinois at Urbana-Champaign, Urbana, IL, USA

brhyno2@illinois.edu

In this talk, we discuss using superconducting transmon qubit-based IBM quantum hardware to explore the quantum Kibble-Zurek (QKZ) mechanism. In particular, we focus on the well-studied transverse-field Ising (TFI) model as one quenches the Hamiltonian across its quantum critical point. Theoretically, we investigate how standard QKZ predictions are modified for the TFI model in the presence of noise by focusing on an idealized model of decoherence using continuous quantum non-demolition measurements. From this we show how the strength of noise directly effects universal critical exponents. We conclude by discussing our efforts to observe such physics in IBM quantum hardware.

Figures

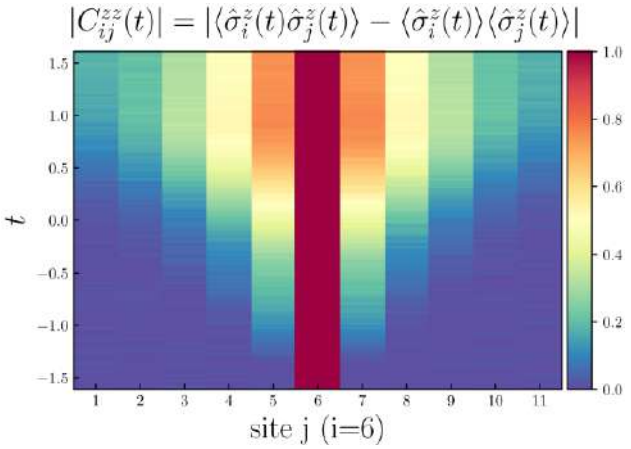


Figure 1: Qiskit simulation of the connected two-point correlation function plotted as a function of space and time as one quenches a small number of qubits across the transverse-field Ising model's quantum critical point.

References

[1] W.-T. Kuo, D. Arovas, S. Vishveshwara, and Y.-Z. You, SciPost Phys. 11, 084 (2021).

Storage and retrieval of quantum operations – an experimental test

Robert Stárek[1]
N. Horová[1], M. Mičuda[1], J. Fiurášek[1], A. Bisio[2], M. Sedlák[3]

[1] *Department of Optics, Faculty of Science, Palacký University, 17. Listopadu 1192/12, 77900 Olomouc, Czechia*
[2] *Dipartimento di Fisica, Universit`a di Pavia, via Bassi 6, 27100 Pavia, Italy*
[3] *RCQI, Institute of Physics, Slovak Academy of Sciences, Dúbravská cesta 9, 84511 Bratislava, Slovakia*
starek@optics.upol.cz

The fundamental requirement for quantum information science is the ability to encode, transfer, process, decode, and store quantum information. An interesting application of quantum state storage is the storage of unknown unitary operations [1]. Here, we analyze and experimentally test a protocol in which we leverage partial prior knowledge about the to-be-stored unitary.

Fig. 1(a) depicts the situation. The stored unitary operation is unknown, but we know it can be either U_0 or U_1, both a priori known and equally probable. We imprint the operation into an auxiliary quantum state $|a\rangle$ and obtain state $|s\rangle$, which can be stored. To retrieve the operation, we let $|s\rangle$ couple with the target state $|\psi\rangle$ and perform quantum state discrimination on the auxiliary system. When the discrimination succeeds, the stored operation is perfectly retrieved and applied to the target state.

We analyze the probability of correct retrieval as a function of the closeness of two operations to be stored. Then, we show that the success probability can be increased by repeatedly applying the stored operation to the auxiliary system. We show that the quantum operation performing the protocol is a solution to the positive-semidefinite program. If we additionally allow imperfect retrieval, we go beyond this protocol and can trade the effective fidelity for success probability.

Finally, we present an experimental retrieval of an unknown phase-shifting operation, either $+\alpha$ or $-\alpha$ phase shift, using linear quantum optics [2]. The storage quality is assessed using quantum tomography of states and processes [3], and the results are compared to the reference case of the measure-and-prepare strategy.

References

[1] M. Sedlák, A. Bisio, M. Ziman, Phys. Rev. Lett. 122, 170502 (2019).
[2] E. Knill, R. Laflamme, G. Milburn, Nature 409, 46–52 (2001).
[3] Z. Hradil, J. Řeháček, J. Fiurášek, M. Ježek, 3 - Maximum-Likelihood Methods in Quantum Mechanics. In: *Quantum State Estimation*. Lecture Notes in Physics, vol 649.

Figures

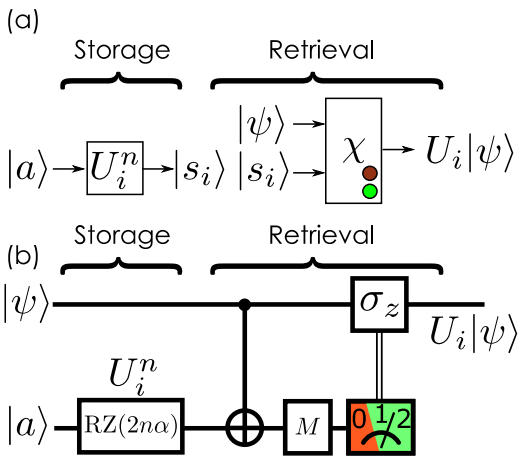


Figure 1: (a) One of two possible operations (U_0 or U_1) is imprinted into an auxiliary state. Then the operation is probabilistically retrieved and applied on a target state.
(b) Experimental implementation – stored operation is phase shift, retrieval is achieved with CNOT gate, POVM measurement performing quantum state discrimination, and feed-forward.

A scalable local addressing system for optically addressable qubits using integrated photonics

Ramon Szmuk[1]

Noel Wan[2], Mengdi Zhao[2], Henry Thoreen[2], Robert DeAngelo[2], Anshuman Singh[2], Frédéric Peyskens[2], Nathan Gemelke[2], Daniel Dominguez[3], Andrew Leenheer[3], Matt Eichenfield[3,4], Dirk Englund[5], Yoav Romach[1], Yonatan Cohen[1]

[1]*Quantum Machines Inc., Tel Aviv, Israel*
[2]*QuEra Computing Inc., Boston, MA United States*
[3]*Sandia National Laboratories, Albuquerque, NM, United States*
[4]*University of Arizona, Tucson, AZ, United States*
[5]*Massachusetts Institute of Technology, Cambridge, MA, United States*

ramon@quantum-machines.co

Abstract

Among the leading approaches to scalable quantum computers are systems made of optically addressable qubits, such as neutral atoms, trapped ions and solid-state emitters. In these platforms, quantum information is typically manipulated using optical fields, so that scaling to large systems demands a high channel-count, high-speed, and precise optical modulators at low incremental cost. Existing solutions are not practical beyond a few tens of channels, limiting the number of independent degrees of freedom in the quantum computer. Here we present a Photonic Control Unit (PCU) that enables scaling of the number of local addressing beams using integrated photonics. Using the PCU, we experimentally demonstrate high-speed, high-extinction modulation and multi-channel operation, supporting the visible to near-infrared wavelength range, therefore meeting the precision, power, and wavelength requirements of quantum computing applications. We outline the route to achieving hundreds to thousands of channels for scalable optical control of qubits.

Interconnect Properties of Spin Qubit Devices

L. Tryputen[1]
T. J. J. Willigers[1], H. Amin[2], S. Karwal[1], S. V. Amitonov[1], A. Sammak[1], Ö. Gül[1], E. Tsapanou-Katranara[1], L. Mazzarella[1], H.G.J. Eenink[1], Y. Vos[1], R. N. M. Wasserman[1], R. Hanfoug[1], N. Samkharadze[1], G. Scappucci[2], M. Veldhorst[2], L. M. K. Vandersypen[2], D. J. Michalak[1]

[1]*QuTech and Netherlands Organisation for Applied Scientific Research (TNO), Delft, Netherlands*

[2]*QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft, Netherlands*

larysa.tryputen@tno.nl

Significant progress in the control of single electrons in semiconductor quantum computing devices has been recently shown [1, 2]. However in order to scale such systems to larger qubit counts the improved control of materials properties will be critical. In this work we show room temperature characterization of multi-layered test structures fabricated on the same chip as spin qubit devices [3]. We observe that on-chip palladium interconnects have higher sheet resistances than palladium as deposited. Such additional resistance could be responsible for qubit "heating" during cryogenic device operation [5]. We also show the voltage- and frequency-dependent dielectric properties for the amorphous alumina (Al_2O_3) material used as the interlayer dielectric and gate oxide in our spin qubit devices (Fig. 2). Such dispersive behaviour may contribute to charge noise and/or device drift. Finally, we also discuss our recent developments in the magnetic material of the nanomagnets used for qubit addressability.

References

[1] Philips et al., Nature, 609 (2022) 919.
[2] Xue et al., Nature, 601 (2022) 343.
[3] Verberk et al., Proc. SPIE 12472, 37th European Mask and Lithography Conference, 1247207 (2022) 1.
[4] de Vries et al., Thin Solid Films, 167 (1988) 25.
[5] Undseth et al., Physical Review X,13 (2023) 041015.

Figures

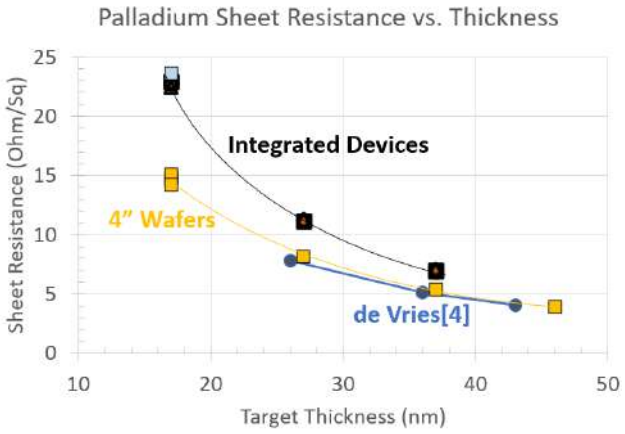


Figure 1: The sheet resistance values of test structures integrated during fabrication of qubit device runs (black and blue squares) are larger than the values of as-deposited palladium test wafers (yellow squares), which are similar to those reported in de Vries [4].

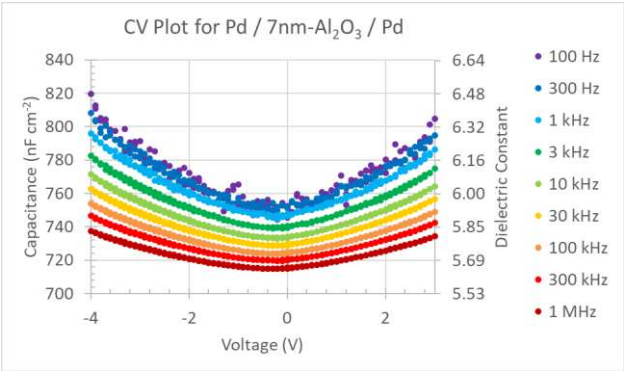


Figure 2: Frequency and voltage dependence of capacitance data for a 7 nm amorphous Al_2O_3 film between palladium electrodes.

Operating semiconductor quantum processors with hopping spins

Chien-An Wang[1]
Valentin John[1], Hanifa Tidjani[1], Cécile X. Yu[1], Alexander Ivlev[1], Corentin Déprez[1], Floor van Riggelen-Doelman[1], Benjamin D. Woods[2], Nico W. Hendrickx[1], Will I. L. Lawrie[1], Lucas E. A. Stehouwer[1], Stefan Oosterhout[3], Amir Sammak[3], Mark Friesen[2], Giordano Scappucci[1], Sander L. de Snoo[1], Maximilian Rimbach-Russ[1], Francesco Borsoi[1+], and Menno Veldhorst[1+]

[1]*QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands*
[2]*Department of Physics, University of Wisconsin-Madison, Madison, USA*
[3]*QuTech and Netherlands Organisation for Applied Scientific Research (TNO), Delft, The Netherlands*

m.veldhorst@tudelft.nl

Qubits that can be efficiently controlled are pivotal in the development of scalable quantum hardware. Resonant control is commonly embraced to execute high-fidelity quantum gates but demands integration of high-frequency oscillating signals and results in qubit crosstalk and heating. Establishing quantum control based on discrete signals could therefore result in a paradigm shift. This may be accomplished with single-spin semiconductor qubits, if one can engineer hopping spins between quantum dots with site-dependent spin quantization axis. Here, we introduce hopping-based universal quantum logic and obtain single-qubit gate fidelities of 99.97%, coherent shuttling fidelities of 99.992%, and two-qubit gates fidelities of 99.3%, corresponding to error rates that have been predicted to allow for quantum error correction. We demonstrate that hopping spins also constitute an elegant tuning method by statistically mapping the coherence of a 10-quantum dot system. These results motivate dense quantum dot arrays with sparse occupation for efficient and high-connectivity qubit registers.

Figures

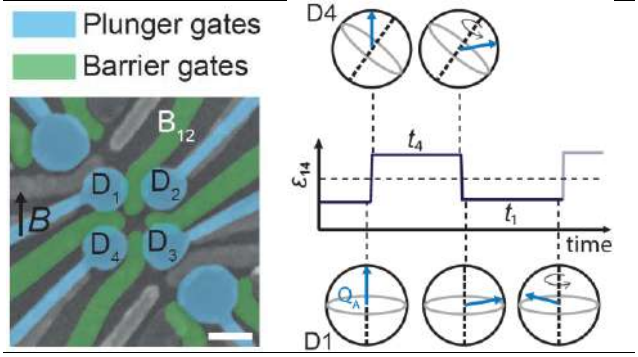


Figure 1: (left) SEM image of the germanium quantum dot array device. (right) Schematic illustration of the coherent quantum control by hopping a single spin.

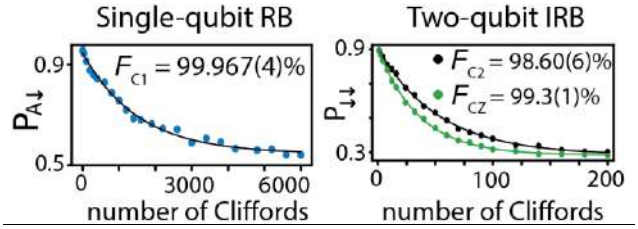


Figure 2: Randomized benchmarking of (left) hopping-based single-qubit gate, and (right) two-qubit adiabatic CZ gate.

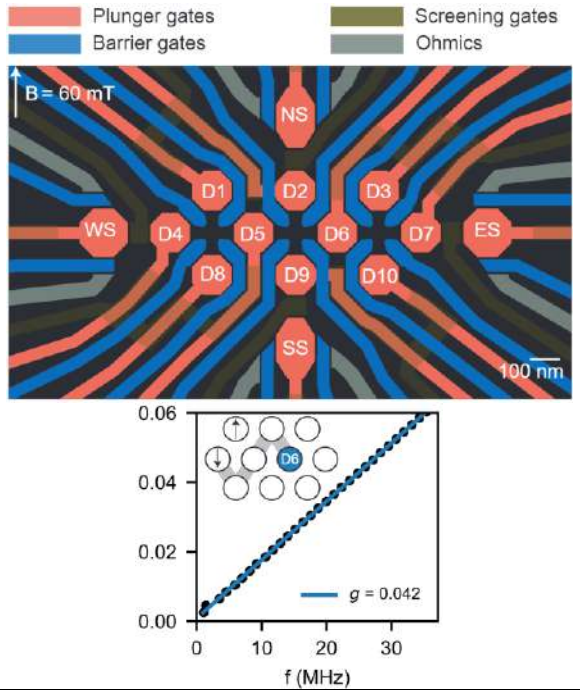


Figure 3: (top) Layout of the 10 quantum dot array. (bottom) Shuttling operations in the 10-dot device for measuring g-factor.

Noise-aware variational eigensolvers: A dissipative approach for lattice gauge theories

Jesús Cobos Jiménez
David F. Locher
Alejandro Bermudez
Markus Müller
Enrique Rico

Department of Physical Chemistry, University of the Basque Country, UPV/EHU, Box 644, 48080 Bilbao, Spain

jesus.cobos@ehu.eus

Abstract

We propose a novel variational ansatz for the ground-state preparation of the Z2 lattice gauge theory (LGT) in quantum simulators. It combines dissipative and unitary operations in a completely deterministic scheme with a circuit depth that does not scale with the size of the considered lattice. We find that, with very few variational parameters, the ansatz can achieve >99% precision in energy in both the confined and deconfined phases of the Z2 LGT. We benchmark our proposal against the unitary Hamiltonian variational ansatz and find a clear advantage of our scheme, especially when focusing on the nature of the confinement-deconfinement transition of the Z2 LGT. After performing a finite-size scaling analysis, we show that our dissipative variational ansatz can predict critical exponents with reasonable accuracies even for reduced qubit numbers and circuit depths. Furthermore, we investigate the performance of this variational eigensolver subject to circuit-level noise, determining variational error thresholds that fix the error rate p_ℓ below which $p<p_\ell$ it would be beneficial to increase the number of layers $\ell \mapsto \ell' > \ell$. In light of these quantities and for typical gate errors p in current quantum processors, we provide a detailed assessment of the prospects of our scheme to explore the Z2 LGT on near-term devices.

References

[1] J. Cobos, D. F. Locher, A. Bermudez, M. Müller, E. Rico. arXiv:2308.03618 (2023)

Dynamical Gauge Fields with Bosonic Codes in Nonlinear Resonators

Javier del Pino[1,2]
Oded Zilberberg[2]

[1]*Institute for Theoretical Physics, ETH Zürich.*
[2]*Department of Physics, University of Konstanz.*

javier.del-pino@uni-konstanz.de

Dynamical gauge theories are crucial for understanding particle interactions mediated by gauge bosons. However, they are challenging to simulate using classical methods. The idea of a quantum simulator has led to research efforts to use low-energy, engineered quantum devices to replicate high-energy physics phenomena [1]. A promising approach in quantum computation is to introduce quantum error correction, which involves extending the original Hilbert space and endowing it with local symmetries that define the code space. However, qubit-based QEC is challenging due to vast physical resource overheads and scalability issues. Bosonic codes offer a solution that exploits multi-particle redundancy in bosons.

In this talk, I will showcase the potential of bosonic codes in simulating dynamical gauge fields. Our approach involves encoding both matter and dynamical gauge fields in a network of resonators that are coupled through three-wave mixing nonlinearity. By operating the gauge resonators as Schrödinger Cat states, we establish a mapping to a Z2 dynamical lattice gauge theory. Our research explores the optimal conditions that enable the system to maintain the required gauge symmetries. Our results demonstrate the potential of realizing high-energy models using bosonic codes.

References

[1]. E. Altman et al. Quantum Simulators: Architectures and Opportunities (2021). PRX Quantum 2, 017003

[2] del Pino, J. & Zilberberg, O. : Dynamical Gauge Fields with Bosonic Codes (2023). Phys. Rev. Lett. **130**(17), 171901

Figures

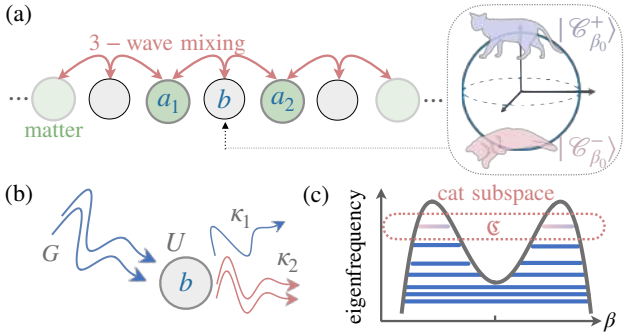


Figure 1: (a) A chain of resonators labeled as matter (type a) and gauge (type b) modes are coupled through three-wave mixing. This setup can mimic a 1+1D lattice gauge theory (LGT) when gauge resonators adopt cat states with specific parity and amplitude. (b) The link site is represented by a Kerr parametric resonator experiencing a (parametric) two photon drive. (c) Drive and nonlinearity create cat states as ground states in a dynamic potential shaped by the parametric drive and the Kerr nonlinearity.

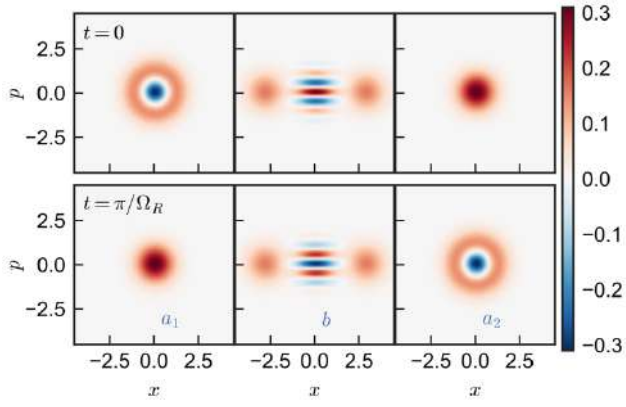


Figure 2: Quasiprobability distributions at bosonic sites reveal the Z2 matter-gauge dynamics, manifesting as exchange between Fock states (matter) and cat states (encoded gauge field states).

Digital simulation of non-Abelian anyons with superconducting qubits

Presenting Author: Dong-Ling Deng

Tsinghua University, Beijing, China

dldeng@tsinghua.edu.cn

Abstract

Non-Abelian anyons are exotic quasiparticle excitations hosted by certain topological phases of matter. They are the building blocks of topological quantum computing. In this talk, I will report an experimental quantum digital simulation of projective non-Abelian anyons and their braiding statistics with up to 68 programmable superconducting qubits arranged on a two-dimensional lattice. By implementing the ground states of the toric-code model with twists through quantum circuits, we demonstrate that twists exchange electric and magnetic charges and behave as a particular type of non-Abelian anyons, i.e., the Ising anyons. In particular, we show experimentally that these twists follow the fusion rules and non-Abelian braiding statistics of the Ising type, and can be explored to encode topological logical qubits. Furthermore, we demonstrate how to implement both single- and two-qubit logic gates through applying a sequence of elementary Pauli gates on the underlying physical qubits.

Figures

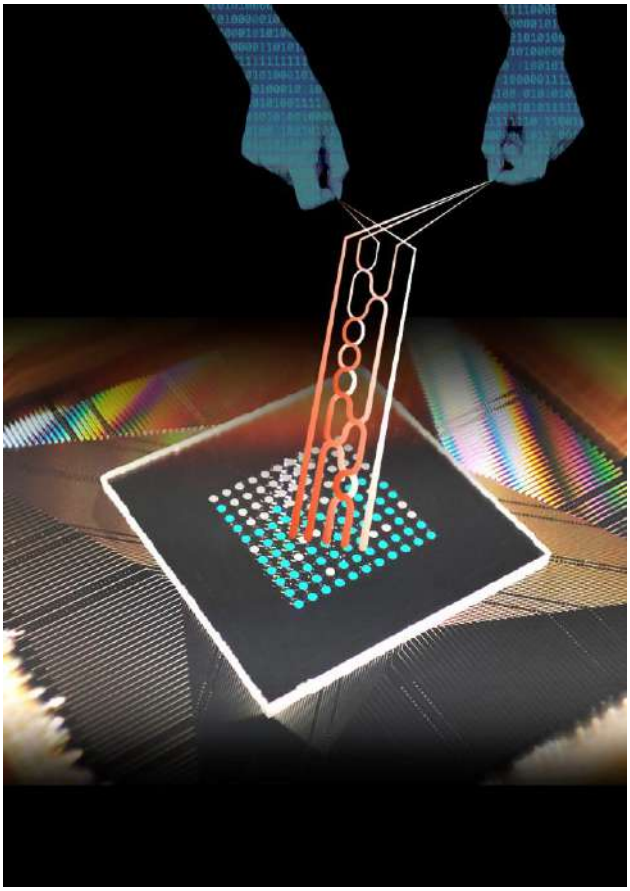


Figure 1: A schematic illustration of digital simulations of non-Abelian anyons.

References

[1] Xu *et al.*, Chin. Phys. Lett. 40, 060301 (2023).

A quantum materials simulator based on Coulomb-confined quantum dots

Rebekka Garreis
M. B. Donnelly, Y. Chung, S. Plugge, D. Pye, M. Kiczynski, M. M. Munia, S. Sutherland, B. Voisin, L. Kranz, C. Moehle, C. R. Myers, R. Rahman, J. G. Keizer, S. K. Gorman and M. Y. Simmons

Silicon Quantum Computing Pty. University of New South Wales, Sydney 2052, Australia

r.garreis@unsw.edu.au

One of the significant promises of quantum technology is the ability to simulate complex materials for applications such as novel electronics and improved electrodes for batteries. Analogue quantum simulators based on semiconductor quantum dots have already started to investigate these types of problems with the realisation of one-dimensional correlated phases [1-3], ferromagnetism [4], and resonating valence bond states [5]. However, all these quantum simulators have been well within the reach of classical simulation techniques due to the small number of sites and particles. Here, we show that atomically precise Coulomb-confined quantum dots allow for the controllable simulation of two-dimensional quantum materials. As illustrated in figure 1, we use the sub-nanometre precision of these quantum simulators to simulate a metal-to-insulator transition (MIT) of interacting electrons on a square extended Fermi-Hubbard lattice of 15,000 sites -- well beyond the limit of classical simulations. The collective behaviour of the lattice is measured using temperature dependent transport measurements where we see the opening of an energy gap driven by electron-electron interactions (a Mott insulator). These analogue devices provide a promising route for quantum simulation of interacting electrons on arbitrary two-dimensional lattices such as quantum spin liquids, topological quantum matter, and unconventional superconductivity.

References

[1] T. Hensgens, T. Fujita, L. Janssen, et al., Nature, 548 (2017)
[2] C. J. van Diepen, T.-K. Hsiao, U. Mukhopadhyay, et al., Phys. Rev. X, 4, 041025 (2021)
[3] M. Kiczynski, S. K. Gorman, H. Geng, et al., Nature, 606 (2022)
[4] J. P. Dehollain, U. Mukhopadhyzy, V. P. Michal, et al., Nature, 579 (2020)
[5] C.-A. Wang, C. Déprez, H. Tidjani, et al., npj Quantum Information, 9, 58 (2023)

Figures

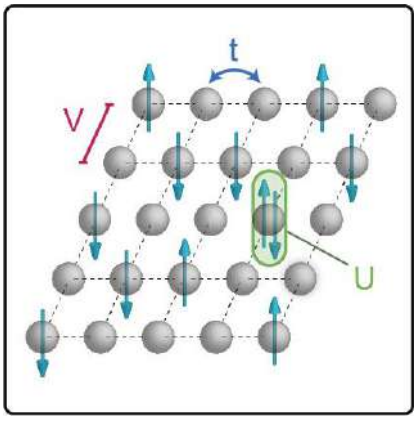


Figure 1: Schematic of the extended Fermi-Hubbard model on a 2D square lattice. The sites (grey) hold up to 2 electrons (blue arrows) with electron hopping terms t, and on-site (inter-site) electron-electron interaction U (V).

Universal control of a bosonic mode via drive-activated native cubic interaction

Simone Gasparinetti
Axel M. Eriksson, Théo Sépulcre, Mikael Kervinen, Timo Hillmann, Marina Kudra, Simon Dupouy, Yong Lu, Maryam Khanahmadi, Jiaying Yang, Claudia Castillo Moreno

Department of Microtechnology and Nanoscience, Chalmers University of Technology, 412 96 Gothenburg, Sweden

simoneg@chalmers.se

Abstract

Bosonic modes, thanks to their large Hilbert space, offer a hardware-efficient alternative for quantum information processing. However, to operate linear bosonic modes, some nonlinearity is still required, which is typically realized by an ancilla qubit. We present a bosonic mode consisting of a superconducting nonlinear asymmetric inductive element (SNAIL)-terminated planar resonator, which is controlled by microwave-activated nonlinearities in the SNAIL element. The Kerr nonlinearity is canceled by tuning the flux through the SNAIL to realize a close to linear mode when the system is idling. The off-resonant strong third order nonlinearity can be activated by applying a flux pulse at three times the frequency of the bosonic mode. Hence, the resulting tri-squeezing interaction promotes the more easily accessible Gaussian interactions to a universal gate set. By combining these interactions, we experimentally demonstrate Wigner-negative states such as the cubic phase state. Furthermore, the operation of these native squeezing and tri-squeezing interactions can be combined with standard ancilla qubit control and thereby boost the control capabilities.

References

[1] Eriksson, A. M. et al. Universal control of a bosonic mode via drive-activated native cubic interactions, arXiv:2308.15320, to appear in Nat. Commun.
[2] Frattini, N. E. et al. 3-wave mixing Josephson dipole element. Appl. Phys. Lett. 110, 222603 (2017)

Figures

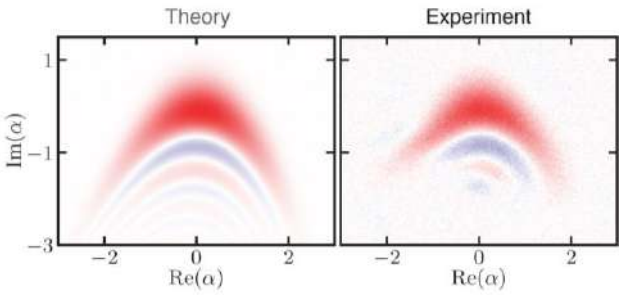


Figure 1: Wigner function of the experimentally generated cubic phase state (right) and corresponding theory prediction (left). Adapted from Ref. [1]

Cold atoms with flat bands – from synthetic bilayers to flat band Bose-Einstein condensates

Tobias Grass

DIPC – Donostia International Physics Center, Manuel Lardizabal 4, 20018 Donostia, Spain

Tobias.Grass@dipc.org

Different systems with (nearly) dispersionfree energy bands have appeared in the past years, from magic angle twisted bilayer graphene to optical lattices with exotic lattice geometries, such as the Lieb lattice or the Kagome lattice. Flat bands provide a fascinating arena for strongly correlated manybody phenomena, since their physics is automatically dominated by interactions.
This talk is centered around different aspects of flat bands in cold atomic setups. First, I will discuss strategies to produce synthetic bilayer systems [1], and I will show how the superconducting phase of attractive fermions can be enhanced by twisting the bilayer [2]. Second, I will discuss Bose-Einstein condensation in flat bands [3]. In this context, an intriguing question arises: Will bosons in flat bands actually condense, and if yes, where? We have analyzed flat band condensates numerically and via a mean-field description. Our results do not only confirm that condensation in the flat band of a Kagome lattice is possible, but also that the condensate may even carry topological properties induced by interactions.

References

[1] T. Grass, R. W. Chhajlany, L. Tarruell, V. Pellegrini, and M. Lewenstein: *Proximity effects in cold atom artificial graphene*, 2D Mater. **4**, 015039 (2017)

[2] T. Salamon, B. Irsigler, D. Rakshit, M. Lewenstein, T. Grass, R. Chhajlany: *Flat-band-induced superconductivity in synthetic bilayer optical lattices*, Phys. Rev B **106** 174503 (2022)

[3] Z. Jalali-Mola, T. Grass, V. Kasper, M. Lewenstein, U. Bhattacharya: *Topological Bogoliubov quasiparticles from Bose-Einstein condensate in a flat band system*, Phys. Rev. Lett. **131**, 226601 (2023)

Figures

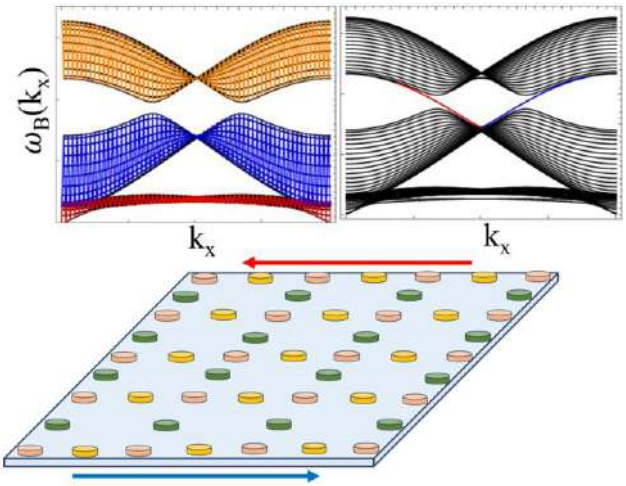


Figure 1: The topological condensate of bosons in a Kagome lattice (with pi flux) is characterized by a gap opening in the bulk spectrum and the appearance of edge states.

Towards quantum simulation of spin wave modes in quantum dot arrays

Tzu-Kan Hsiao[1,2]
Tien-Ho Chang[1], Chia-Hao Wei[1], Kim Chye Cheng[1], Jian-Chang Zeng[1], Fu-Yuan Gu[1], Yin-Chuan Lai[1], Jun-Yang Yuan[1], and Chi-Wei Lee[1]

[1]*Department of Physics, National Tsing Hua University, Hsinchu 300044, Taiwan*
[2]*Center for Quantum Science and Technology, National Tsing Hua University, Hsinchu 300044, Taiwan*

tkhsiao@phys.nthu.edu.tw

Electrostatically-defined quantum dot arrays are a natural and versatile platform for quantum simulations of Fermi-Hubbard and Heisenberg physics [1]. In particular, the development of control and readout techniques has facilitated simulations of quantum magnetism such as Nagaoka ferromagnetism [2], Heisenberg antiferromagnetic spin chains [3], and resonating valence bond states [4]. Nevertheless, these experiments mainly focus on measuring local spin correlations instead of long-range spin correlation, which can provide more insights.

Here we propose an experiment to study quantized spin wave (magnon) modes, which play an important role in spintronics and quantum information processing [5]. Their long-range spin order makes the spin waves a good candidate for observing long-range spin correlations. We will describe experimental methods for preparing and probing the quantized spin wave modes in accessible quantum dot simulators. The long-range spin order can be confirmed by measuring the spin correlation as a function of distance. Finally, we will report our progress in device fabrication and measurement setup for this project.

References

[1] Barthelemy, P., et al. Annalen der Physik 525 (2013), 808
[2] Dehollain, J. P., et al. Nature 579 (2020), 528
[3] van Diepen, C. J., et al. Phys. Rev. X 11 (2021), 041025
[4] Wang, C.-A., et al. npj Quantum information, 9 (2023), 58
[5] Lachance-Quirion, D., et al. Science 367 (2020), 425

Figures

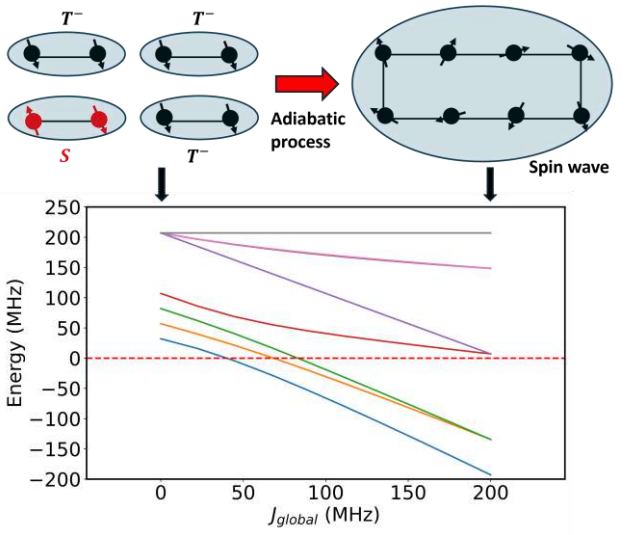


Figure 1: Top: As the system Hamiltonian is engineered from four decouple dimers to a ring, the eigenstates evolve from singlet-triplet product to spin wave states. Bottom: Energy spectrum of a subspace with seven down spins and one up spin.

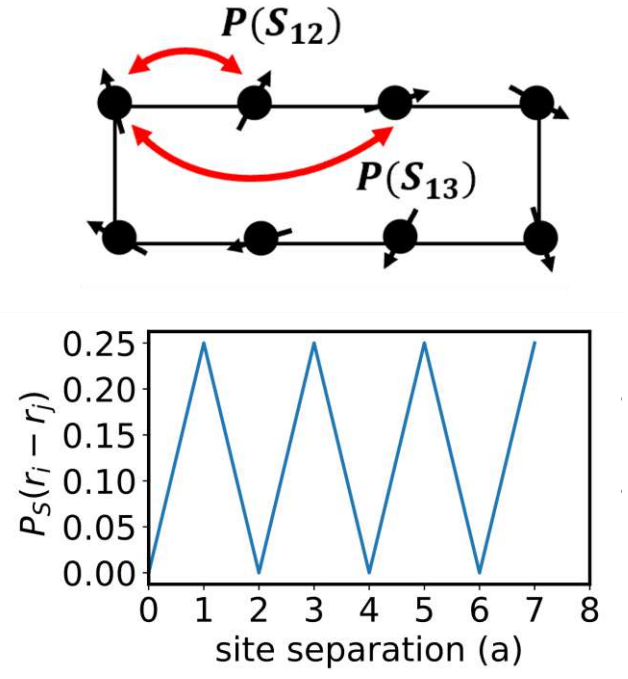


Figure 2: Top: Pauli-spin-blockade readout for spins in a spin wave state. Bottom: singlet projection probability as a function of site separation for the lowest spin wave state. The result shows the long-range spin correlation in the spin waves.

Optimal quantum circuits for the quantum simulation of quantum matter

Joris Kattemölle
University of Konstanz, D-78457, Konstanz, Germany
joris.kattemoelle@uni-konstanz.de

Optimal-depth quantum circuits are crucial for pushing the boundaries of current noisy intermediate-scale quantum technology, where noise effects in the output become stronger with the depth of the quantum circuit. When constructing (the cycles of) the quantum circuits for the quantum simulation of quantum matter by Trotterization, typically, a two-qubit quantum gate must be added for each edge of a lattice graph, with qubits on its vertices. Since each qubit can participate in at most one quantum gate at a time, associating colors with layers of quantum gates, a depth-optimal cycle is described by a minimal edge coloring of the lattice graph. We develop and implement a classical algorithm that efficiently finds minimal edge colorings of lattice graphs and thereby depth-optimal circuits for the quantum simulation of quantum matter [1,2]. Once a solution is found that solution can be repeated indefinitely by translational symmetry. We demonstrate the algorithm by minimal edge coloring a plethora of relevant lattice graphs, including the meshes of all k-uniform tilings of the plane for k less than 7, while utilizing modest computational resources.

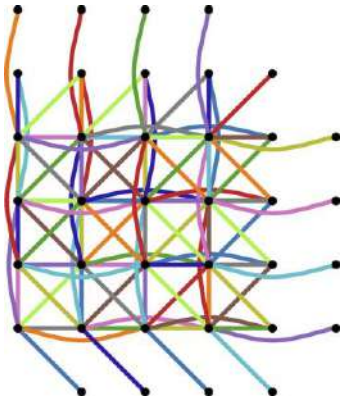


Figure 1: Optimal circuit for the quantum simulation of the Heisenberg model on the square lattice, with nearest, next-nearest and next-next-nearest neighbor interactions. Every color represents a layer in the quantum circuit. The solution can be repeated indefinitely in the vertical and horizontal directions without two edges of the same color meeting at a vertex, or, when interpreted as a circuit, without gate collisions.

References

[1] https://github.com/kattemolle/ecolpy
[2] Joris Kattemölle, Edge coloring lattice graphs. To appear on the arxiv this week.

Observation of vortices in dipolar quantum gases

Manfred J. Mark,
Clemens Ulm, Eva Casotti, Lauritz Klaus, Claudia Politi1, Elena Poli, Andrea Litvinov, Thomas Bland, Andrea Di Carli, Francesca Ferlaino

University of Innsbruck, Technikerstr. 25, Innsbruck, Austria

Manfred.Mark@uibk.ac.at

Due to anisotropic long-range interactions, degenerate ultra-cold dipolar gases of Erbium and Dysprosium exhibit supersolidity [1,2], an exotic phase of matter both density-modulated and phase coherent. It is theorized that these supersolids maintain their phase coherence due to a superfluid background. While density modulation can be directly observed and phase coherence emerges from self-interference, the superfluid nature of the system in terms of irrotational flow has yet to be shown unambiguously. Quantized vortices, a defining feature of superfluidity, is an unequivocal probe of irrotational flow which can be used to prove the existence of the superfluid background in the supersolid phase. Here we study, both experimentally and theoretically, the creation of vortices in both the unmodulated BEC phase [3] and the modulated supersolid phase of Dy-164 [4].

References

[1] Long-lived and transient supersolid behaviors in dipolar quantum gases, L. Chomaz et al., Phys. Rev. X, 9, 021012 (2019)
[2] Two-dimensional supersolidity in a dipolar quantum gas, M. A. Norcia et al., Nature 596, 357-361 (2021)
[3] Observation of vortices and vortex stripes in a dipolar condensate, L. Klaus et al., Nature Physics 18, 1453–1458 (2022)
[4] Manuscript in preparation

Figures

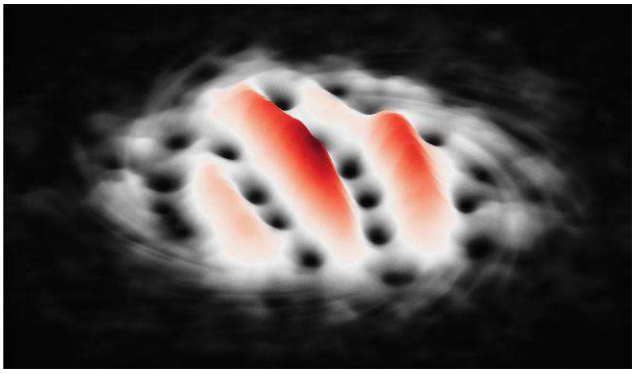


Figure 1: Simulation of a rotating dipolar quantum gas featuring quantized vortices [3]

Experimental Reconstruction of Local Integrals of Motion for Quantum Many-Body Dynamics

Oles Shtanko[1], Derek Wang[2], Haimeng Zhang[2], Nikhil Harle[3], Alireza Seif[2], Ramis Movassagh[4] and Zlatko Minev[2]

[1]IBM Quantum, IBM Research – Almaden, San Jose CA, US
[2]IBM Quantum, IBM T.J. Watson Research Center, Yorktown Heights, US
[3]Department of Physics, Yale University, New Haven CT, US
[4]IBM Quantum, MIT-IBM Watson AI Lab, Cambridge MA, US

oles.shtanko@ibm.com

arXiv:2307.07552

Abstract

When studying complex quantum systems on a classical computer, researchers typically rely on finding exact eigenvalues and eigenvectors that correspond to the system's energy levels and eigenstates. Despite the potential of quantum computers to outperform classical ones, they currently lack a comparable framework. In this talk, I will show that in some cases the structure of quantum systems can be studied on quantum hardware using local conservation laws.

Conservation laws are fundamental to physical description because they constrain the behavior of a system. While most systems have a limited number of observable laws, others, such as strongly disordered systems exhibiting many-body localization [1], can be completely described by a large set of them. Mathematically, these laws are expressed by many conserving operators, commonly referred to as local integrals of motion (LIOMs) [2,3]. Finding a complete set of LIOMs for a large localized quantum system provides its complete description, comparable to eigenstates.

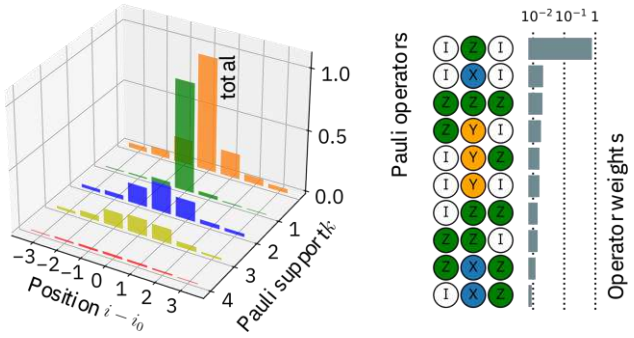


Figure 1. Average structure of the detected LIOMs. Left: Spatial structure with contributions from 1-local (green), 2-local (blue), 3-local (yellow), 4-local (red), and all (orange) Pauli operators. Right: Distribution over Pauli operators.

Using our method, we faithfully reconstruct a complete set of LIOMs for 1D and 2D disordered interacting systems, with the cost independent of system size. The results, on up to 124 qubits, depth 60, error-mitigated quantum circuits, focus on the paradigmatic setting of Floquet systems, which exhibit disorder-induced ergodicity breaking. In regions where ergodicity is violated, we efficiently reconstruct complete sets of LIOMs. From the LIOMs, we extract signature system properties, such as site-dependent localization lengths. In ergodic regions, we show the absence of LIOMs by hallmark signatures. In 1D, we validate the experiments against classical numerics and find good agreement.

Our work demonstrates a new path for studying many-body quantum systems using quantum hardware, and provides new insights into the many-body localized regime of a two-dimensional system of qubits.

References

[1] Abanin et al. Rev. Mod. Phys. 91, 021001 (2019)
[2] Serbyn et al., Phys. Rev. Lett. 111, 127201 (2013)
[3] Huse et al, Phys. Rev. B 90, 174202 (2014)

Quantum simulation of strong field phenomena and curved spaces in deformed optical lattices

Nikodem Szpak

Faculty of Physics and CENIDE, University of Duisburg-Essen, Duisburg, Germany

nikodem.szpak@uni-due.de

Low energy excitations in specially designed optical lattice systems can behave like relativistic particles. Inhomogeneous perturbations of these lattices can give rise to effective coupling to artificial electromagnetic fields and curvature. We give a review of interesting strong field phenomena, like *spontaneous pair creation* or *graviational lensing*, still not accessible in direct experiments, which can be simulated with cold atoms in finite size optical lattices.

References

[1] N. Szpak and R. Schützhold, Phys. Rev. A 84, 050101
[2] N. Szpak and R. Schützhold, New J. Phys. 14, 035001
[3] L. Klar, N. Szpak, and R. Schützhold, arXiv:1901.09880
[4] N. Szpak, arXiv:1410.1567

Figures

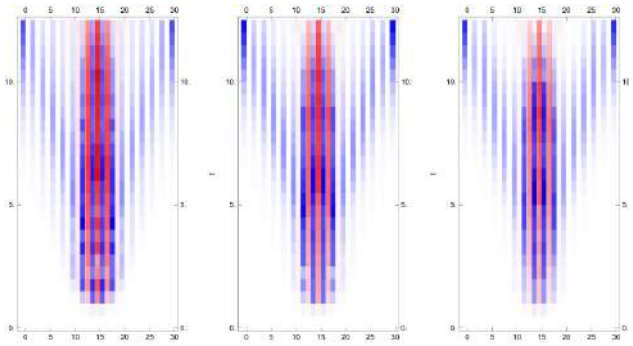


Figure 2: Simulation of *spontaneous pair creation* in lattice from Fig. 3 with attractive, none and repulsive interaction.

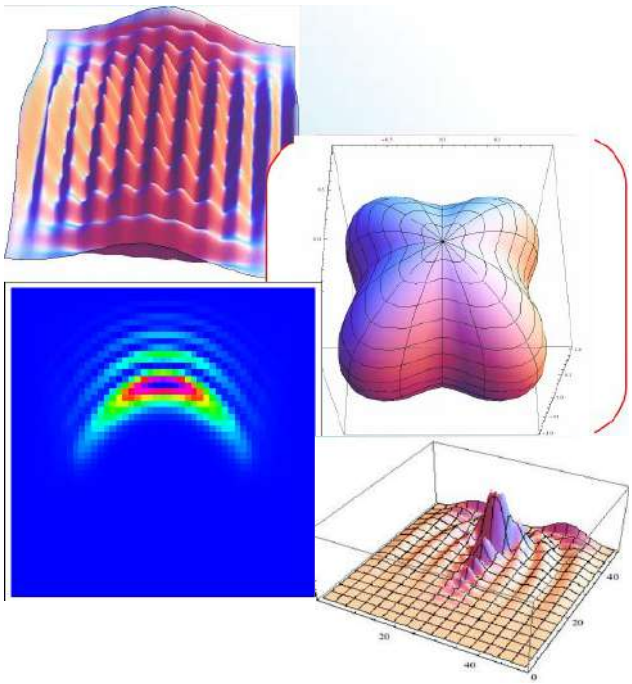


Figure 1: Finite size effects in a deformed optical 2D lattice (left top), interpreted in terms of a continuous analogue curved space (right top) lead to a *gravitational lensing* of propagating plane wave excitations (bottom left, right).

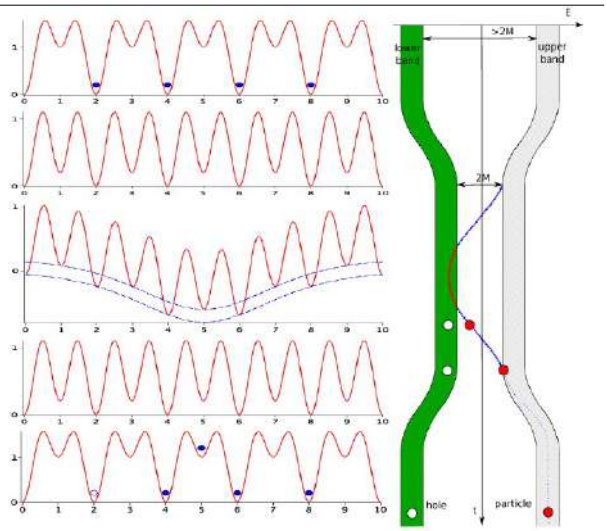


Figure 3: Modulated 1D optical lattice can simulate *spontaneous pair creation* via the dynamical Schwinger effect.

Simplifying the simulation of local Hamiltonian dynamics

Ayaka Usui[1]
Anna Sanpera[1,2]
María García Díaz[3]

Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain[1]
ICREA, 08010, Barcelona, Spain[2]
Universidad Politécnica de Madrid, 28006, Madrid, Spain[3]

ayaka.usui@uab.cat

Local Hamiltonians H_k describe non-trivial k-body interactions in quantum many-body systems. Here, we address the dynamical simulatability of a k-local Hamiltonian by a simpler one $H_{k'}$ with k'<k under the realistic constraint that both Hamiltonians act on the same Hilbert space [1]. When it comes to exact simulation, we build upon known methods to derive examples of H_k and $H_{k'}$ that simulate the same physics. Next, we address the most realistic case of approximate simulation. There, we upper-bound the error up to which a Hamiltonian can simulate another one, regardless of their internal structure, and prove, by means of an example, that the accuracy of a (k' = 2)-local Hamiltonian to simulate H_k with k > 2 is likely to increase with k. Finally, we propose a numerical method to search for the k'-local Hamiltonian that simulates, with the highest possible precision, the short time dynamics of a given Hk Hamiltonian.

References

[1] A. Usui, A. Sanpera, M. García Díaz, arXiv:2310.07054.

Kondo Impurity in an attractive Hubbard Bath

Zhi-Yuan Wei

Zhi-Yuan Wei[1], Eugene Demler[2], Ignacio Cirac[1], Tao Shi[3]

1 Max Planck Institute for Quantum Optics, Garching, Germany
2 ETH Zürich, Zürich, Switzerland
3 Institute of Theoretical Physics, Chinese Academy of Science, Beijing, China
Contact: zhiyuan.wei@mpq.mpg.de

Abstract

In this work, we theoretically study the ground-state properties and out-of-equilibrium dynamics when a Kondo impurity couples with 1D and 2D attractive Hubbard bath. First, we find the ground state exhibits a singlet-doublet phase transition, and observe the competition between the Kondo correlation and the superconducting (SC) order. In particular, the SC gap on the two sides of the 1D chain exhibits a π phase shift when the Kondo singlet forms. Then we study the relaxation dynamics of the impurity coupled to a 2D bath and observe a fast buildup of Kondo correlation near the impurity, with a spin-wave emitted into the bath. The presence of the SC gap leads to an exponential decay of the spin-wave amplitude. Finally, we study the transport between two 1D chains connected by the impurity. By adding a bias voltage, we observe the Josephson effect in the weak-link regime and the ballistic charge transport when the Kondo singlet forms. The charge transport further dramatically influences the bath and the impurity state, leading to rich behaviors such as the dynamical breaking of the Kondo singlet.

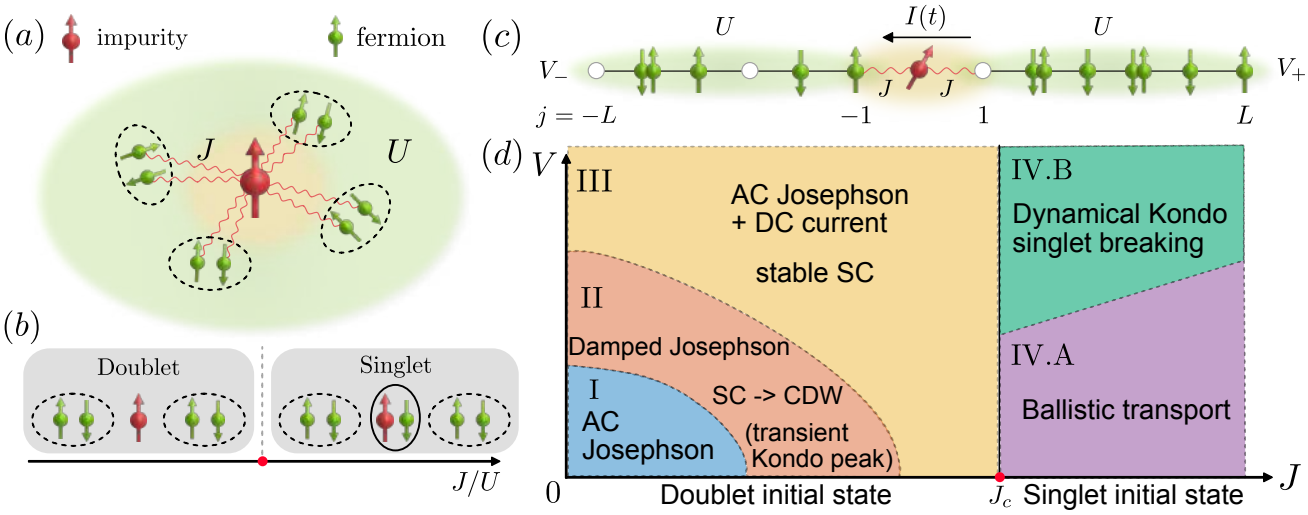


Figure: Ground-state and non-equilibrium physics of a Kondo impurity coupled to attractive Hubbard bath(s). (a) We consider a fermionic bath with attractive Hubbard interaction of strength U, such that the fermions with opposite spins can form Cooper pairs in the bath (denoted by the dashed ovals). A Kondo impurity is coupled to the bath via a spin-exchange interaction of strength J. (b) When $U \gg J$, the fermions tend to form Cooper pairs in the bath, with the impurity being close to a free spin, thus the system is in a doublet phase with total spin 1/2. When $U \ll J$, the Kondo impurity and one electron in the bath together form a Kondo singlet, thus the system is in the singlet phase with total spin 0. By tuning J and U, a first-order phase transition (denoted by the red dot) happens between the doublet and the singlet phase. (c) Consider two chains of Fermions with attractive Hubbard interaction connected by the Kondo impurity. By adding external bias voltages $V_{\pm} = \pm V/2$, we study the charge transport in this setup, such as the behavior of the charge current $I(t)$. (d) The transport properties of the setup in (c) shows five qualitatively different regimes (I,II,III,IV.A,IV.B).

Quantum simulation of 1D-fermionic systems with Ising Hamiltonians

Matthias Werner
Artur Garcia-Saez, Marta P. Estarellas

Qilimanjaro Quantum Tech., Carrer dels Comtes de Bell-Lloc, 161, 08014 Barcelona, Spain

matthias.werner@qilimanjaro.tech

In recent years, programmable, analogue quantum simulators have become capable of simulating quantum critical phenomena in many-body systems, including dynamical phase transitions. However, many of these quantum simulations are focussed on Ising-type Hamiltonians with transverse fields, as these are native to quantum hardware platforms like superconducting flux qubits or neutral atoms. The simulation of 1D-systems of spinless fermions, or quantum spin chains, poses a challenge to these platforms due to the lack of non-stoquastic couplings.
We propose a method to simulate the time-evolution of certain spinless fermionic systems in 1D using simple Ising-type Hamiltonians with local transverse fields. Our method is based on domain-wall encoding [1], which is implemented via strong (anti-)ferromagnetic couplings $|J|$. We show that in the limit of strong $|J|$, the domain-walls behave like fermions in 1D. This approach makes the simulation of certain fermionic many-body systems accessible to contemporary analogue quantum hardware that natively implements Ising-type Hamiltonians with transverse fields.
As a proof-of-concept, we perform numerical simulations of various fermionic systems, such as the Aubry-Andre model, using domain-wall evolution and accurately reproduce various properties, such as phase diagrams and dynamical phase transitions.

References

[1] Nicholas Chancellor. Domain wall encoding of discrete variables for quantum annealing and QAOA. Quantum Sci. Technol. 4 045004 (2019)

Figures

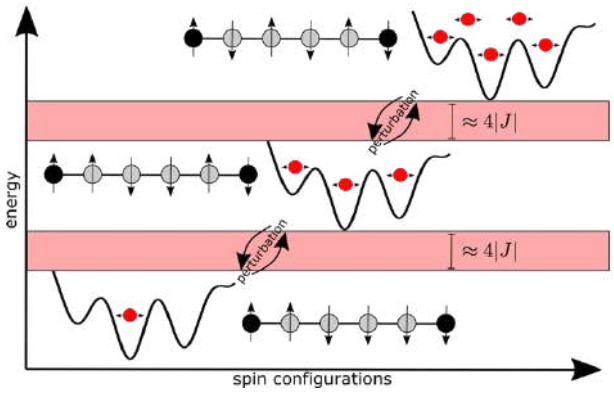


Figure 1: Illustration of the energy landscape of the domain-wall Hamiltonian. For sufficiently large $|J|$, the subspaces corresponding to different numbers of domain walls are separated by energy gaps of approx. $4|J|$ (red shaded areas). In each subspace, the domain-wall Hamiltonian is effectively a 1D-fermionic system, up to some perturbation due to off-diagonal matrix elements that vanish for large $|J|$.

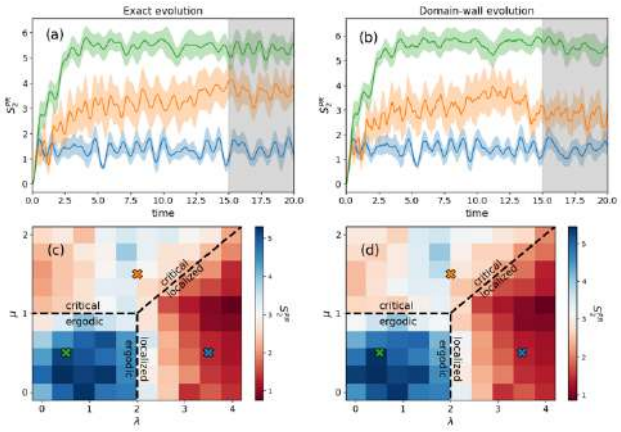


Figure 2: Time-evolution of the participation entropy S_2^{PR} (a, b) and MBL-phase diagram (c, d) of the Aubry-Andre model. The left plots (a,c) show the true quantities, while on the right (b,d) we see the approximation by domain-wall evolution. The blue, green and orange crosses in (c,d) correspond to the respective curves in (a,b)

Neutral Atoms with Rydberg Interactions for Many-Body Physics and Quantum Simulations

Presenting Author: Yijia Zhou

Shanghai Qi Zhi Institute, Floor 41 AI Tower, 701 Yun Jin Road, 200232 Shanghai, China

zhouyijia@sqz.ac.cn

Abstract

Neutral atoms have emerged as a promising platform for quantum computing and quantum simulation. A key advantage lies in the ability to induce controllable long-range interactions by exciting the atoms to Rydberg states. In this talk, I will present our theoretical research focusing on the pivotal role of Rydberg interactions in a variety of atomic systems, enabling the study of exotic many-body physics and quantum simulations. For bosonic atoms in optical lattices [1], we show that Rydberg-dressing can lead to the emergence of density wave and supersolid states. The profile of these interactions can be characterized by examining the structure of density correlations and studying quench dynamics. In the case of degenerate Fermi gases [2], we show that Rydberg-dressed interactions can induce anisotropic Fermi surface deformation and Cooper pairs that reflect the characteristics of the target Rydberg state. Moreover, we recently proposed to investigate many-body effects in Rydberg atom arrays, where the exchange interactions of Rydberg atoms can be harnessed to tune the dynamics and phase transitions. These findings pave the way for further exploration of quantum simulation and computation using neutral Rydberg atoms.

References

[1] Y. Zhou, Y. Li, R. Nath, and W. Li, Phys. Rev. A 101, 013427 (2020).

[2] Y. Zhou, R. Nath, H. Wu, I. Lesanovsky, and W. Li, Phys. Rev. A 104, L061302 (2021).

Neural Network simulations of quantum long range models

David Zueco
Instituto de Nanociencia y Materiales de Aragón CSIC-Unizar, Zaragoza (Spain)
dzueco@gmail.com

Quantum Many-Body Problems range from those that are tractable with techniques such as Matrix Product States (MPS) for non-critical 1D systems [1], Dynamical Mean Field Theory (DMFT) for impurity models [2], Quantum Monte Carlo [3], and physically inspired ansätze (like the Bethe ansatz and perturbation theories), to those that are computationally challenging, such as 2D materials on different lattice topologies [4]. Beyond these, quantum simulations offer hope. In recent years, however, Neural Network ansätze are being investigated to overcome the limitations of these numerical methods. In this talk, I will compare different NN architectures such as Restricted Boltzmann Machines (RBMs) [6], feed-forward neural networks, and Transformers [5] for solving spin long-range models, both in weak and strong interaction regimes, for uniform models like the transverse Ising model or models with all-to-all couplings and quenched disorder in the couplings and longitudinal field, such as the Quantum Sherrington-Kirkpatrick Model.

We will discuss the physics of the different NN ansätze, show the phase diagram [See figure 1], the critical exponents, and the physics of the models, as well as the computational complexity of the neural networks in comparison to other numerical methods. The idea of the talk is to demonstrate that AI-inspired techniques can be useful for quantum many-body problems and can complement the efforts in quantum simulators.

References

[1] R. Orus, Annals of Physics 349 117-158 (2014).
[2] A. Georges *et al*., Rev. Mod. Phys. 68, 13–125 (1996).
[3] F. Becca and S. Sorella, *Quantum Monte Carlo Approaches for Correlated Systems* (Cambridge University Press, 2017).
[4] Y. Alexeev et al., arXiv:2312.09733 (2023)
[5] L L Viteritti, et al., Phys. Rev. Lett. 130, 236401 (2023)
[6] G. Carleo and M. Troyer, Science 355, 602 (2017)
[7] G. Sun Phys. Rev. A 96, 043621 (2017)

Figures

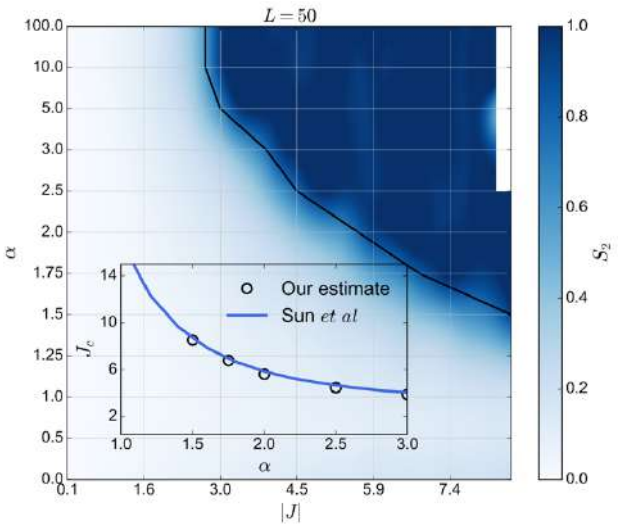


Figure 1: Phase diagram for the antiferromagnetic quantum Ising model with long-range interactions (i.e., the spin-spin interaction decreases as J/|i-j|), plotted as a function of J and . This serves as an example of preliminary calculations performed with 50 spins, utilizing the transformer as a variational ansatz. The phase boundary aligns with those obtained from the Density Matrix Renormalization Group (DMRG) calculations, which are more computationally intensive [7].

Probing spin fractionalization with absolute magnetometry ESR-STM

Y. del Castillo [1,2]
J. Fernández-Rossier [1]

[1]*Internationa Iberian Nanotechnology Laboratory, Av. Mestre José Veiga, 4715-330 Braga, Portugal.*
[2]*Centro de Física, Universidade do Minho, 4710-057 Braga, Portugal.*

yelkodelcastillo@gmail.com

One dimensional chains of antiferromagnetically coupled spins have gathered significant attention due to their distinct properties, particularly the realization of symmetry protected topological phases. These phases manifest as a gap in the bulk excitation spectrum and the emergence of effective degrees of freedom with fractional spin values at the edges of the chain [1,2]. Recent progress in on surface nanographene Haldane spin chains, studied by means of scanning tunneling inelastic spectroscopy, has provided indirect evidence of fractionalization via the observation of Kondo peaks at the chain edges [3].

In this work, we propose a new approach to study these fractional degrees of freedom using scanning tunneling microscopy electron-spin resonance (STM-ESR)[4] by mapping the stray field generated by the S_z= ±1 states of the low energy manifold in the Haldane spin chain [5]. We use machine learning techniques to invert the Biot-Savart equation and obtain the expectation value of the local spin operators. This provides a direct measurement of two emergent properties: the fractional magnetic moment and the localization length ξ.

References

[1] F. D. M. Haldane, Physics Letters A 93, 464 (1983).
[2] F. D. M. Haldane, Phys. Rev. Lett. 50, 1153 (1983).
[3] Mishra, S., Catarina, G., Wu, F. et al. Nature 598, (2021), [287–292].
[4] Choi, T., Lutz, C. P., & Heinrich, A. J., Current Applied Physics, 17(11), (2017) [1513-1517].
[5] del Castillo, Y., Fernández-Rossier, J. arXiv preprint arXiv:2311.15720, (2023).

Figures

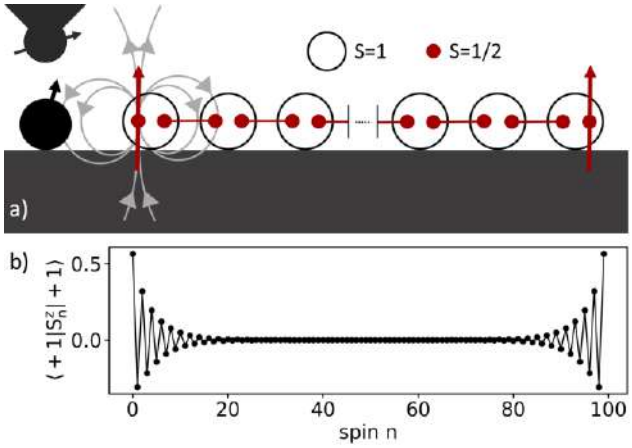


Figure 1: a) Scheme of the proposed experiment to measure fractionalization by means of ESR-STM. A Haldane chain is built on a kondo-free surface. The system is described as if there were two S = 1/2 objects at the edge. An ESR active atom (sensor atom) is placed near the chain to infer the magnetic moments of such chain from its stray field. b) Spin density of the S_z = +1 triplet state for β = 0.09.

Investigating Phase Transitions in Van Der Waals Magnets using a Quantum Sensor

Debarghya Dutta
Clément Pellet-Mary, Patrick Siegwolf, Märta Tschudin, Patrick Maletinsky

Department of Physics, University of Basel, Basel, Switzerland

debarghya.dutta@unibas.ch

Abstract

The advent of two-dimensional magnetic van der Waals(vdW) heterostructures has expanded the boundaries of nano-magnetism and led to novel ideas for information transfer in the field of spintronics[1]. By probing the intrinsic layer-dependent magnetic phases, it is possible to gain fundamental understanding of spin structure and dynamics[2]. We aim to study these exotic magnetic phase transitions using a local, non-invasive scanning magnetometry technique. Our sensor consists of a single nitrogen-vacancy (NV) center in diamond that is attached to an AFM cantilever to enable scanning measurements at cryogenic temperatures[3].

We are particularly interested in studying the magnetic phases of CrSBr, a layered 2D vdW anti-ferromagnet with intralayer ferromagnetic (FM) and interlayer anti-ferromagnetic (AFM) coupling[4]. We quantitatively characterize the FM to AFM phase transition in bilayer CrSBr by directly imaging the FM-AFM phase boundary as it propagates through the sample[5]. Strikingly, we observe the formation of characteristic "cusp-like" features in the FM-AFM phase wall which leads to the creation and propagation of AFM-AFM domain walls. Furthermore, we correlate the interplay between the phase walls and neighboring connected CrSBr multilayers to ultimately decipher the spin configuration of the underlying layers.

References

[1] Chumak, A., Vasyuchka, V., Serga, A. et al. Magnon spintronics. Nature Phys 11, 453–461 (2015)
[2] Gibertini, M., Koperski, M., Morpurgo, A.F. et al. Nat. Nanotechnol. 14, 408–419 (2019)
[3] L. Thiel et al. *Science* **364**, 973-976 (2019)
[4] S.A. López-Paz et al., Nat. Commun. 13, 4745 (2022)
[5] Tschudin, Märta A., et al. "Nanoscale magnetism and magnetic phase transitions in atomically thin CrSBr." arXiv preprint arXiv:2312.09279 (2023)

Figures

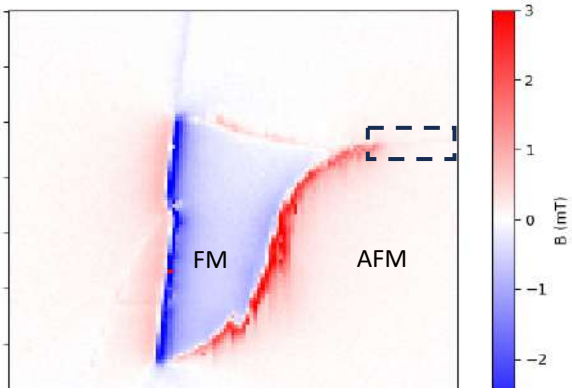


Figure 1: Imaging the FM to AFM phase transition in bilayer CrSBr at 5.2K using scanning NV-magnetometry reveals the presence of a "cusp-like" deformation of the phase boundary. The cusp merges into a line of non-zero stray magnetic field (boxed) traversing across the AFM region, which we associate to an AFM-AFM domain wall.

Optically detected electronic spin resonance of single emitters in hexagonal boron nitride under an angle-resolved magnetic field at room temperature

Simone Eizagirre Barker[1]
Carmem M Gilardoni[1], Oliver FJ Powell[1,2], Xiaoxi Deng[1], Stephanie A Fraser[1], Catherine Curtin[1], Dillon Lewis[1], Andrew Ramsey[1,2], Igor Aharonovich[3], Hoe Hark Tan[4], Hannah L Stern[1,5], Mete Atatüre[1]

[1]*Cavendish Laboratory, University of Cambridge, UK*
[2]*Hitachi Cambridge Laboratory, UK*
[3]*ARC Centre of Excellence for Transformative Meta-Optical Systems, Department of Electronic Materials Engineering, Australian National University, Canberra, Australia*
[4]*ARC Centre of Excellence for Transformative Meta-Optical Systems, School of Mathematical and Physical Sciences, University of Technology Sydney, Australia*
[5]*Photon Science Institute, University of Manchester, UK*

se410@cam.ac.uk

Single-photon emitters in 2D hexagonal boron nitride (hBN) have emerged as a promising platform for room-temperature quantum optical technologies[1-3]. Recently, we reported coherent control of single electronic spins in hBN, identifying a spin-triplet ground state with large zero-field splitting and coherence times of up to microseconds under ambient conditions [4]. In this contribution, we build on this work and investigate the symmetry properties of these emitters using photoluminescence (PL) and optically detected magnetic resonance (ODMR) spectroscopy with angle-resolved magnetic fields. We combine these measurements with polarisation-dependent PL to study the relationship between the emission transition dipole and defect spin axis direction. In some cases, we find that continuous wave ODMR contrast of emitters is over 65%. Our results provide insight on the rich spin dynamics underpinning this novel solid-state qubit platform and further reveal the potential of van der Waals materials for quantum information and sensing, where their reduced dimensionality opens routes to new nanoscale devices and sensors.

References

[1] TT Tran, K Bray, MJ Ford, M Toth, I Aharonovich, *Nat. Nanotechnol*. **11** 37-41 (2016)
[2] W Liu, et al., *Mater. Quantum. Technol.* **2** 032002 (2022)
[3] HL Stern, Q Gu, J Jarman, SE Barker, N Mendelson, D Chugh, S Schott, HH Tan, H Sirringhaus, I Aharonovich, M Atatüre, *Nat. Comm.* 13, 618 (2022)
[4] HL Stern, CM Gilardoni, Q Gu, SE Barker, O Powell, X Deng, L Follet, C Li, A Ramsay, HH Tan, I Aharonovich, M Atatüre, *arXiv:2306.13025* (2023)

Figures

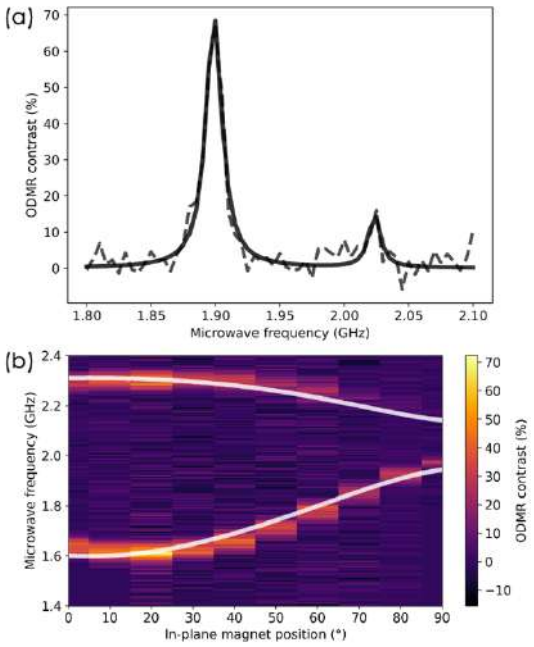


Figure 1: (a) ODMR spectrum of a single emitter at zero field. (b) ODMR spectra under an applied in-plane magnetic field. The white line represents a fit to an *S=1* ground state with zero-field splitting parameters extracted from (a).

Time-frequency quantum metrology

Nicolas Fabre

Télécom Paris, Institut Polytechnique de Paris, 91120 Palaiseau France

nicolas.fabre@telecom-paris.fr

Abstract

Hong-Ou-Mandel interferometry takes advantage of the quantum nature of two-photon interference to increase the resolution of precision measurements of time delays. Relying on few-photon probe states, this approach is applicable also in cases of extremely sensible samples and it achieves attosecond-scale resolution, which is relevant to cell biology and two-dimensional materials. Here, we theoretically analyze how the precision of Hong-Ou-Mandel interferometers can be significantly improved by engineering the spectral distribution of two-photon probe states. In particular, we assess the metrological power of different classes of biphoton states with non-Gaussian time-frequency spectral distributions, considering the estimation of both time and frequency shifts. We find that grid states, characterized by a periodic structure of peaks in the chronocyclic Wigner function, can outperform standard biphoton states in sensing applications.
After discussing the spectral engineering of photon pairs, we will discuss the use of more general quantum states possessing a higher number of photons for estimating time shifts using the presented intrinsic multimode quantum metrology approach. We will show that the particle-number and time-frequency degree of freedom are intertwined for quantifying the ultimate precision achievable by quantum means. Increasing the number of photons of a large entangled EPR probe state actually increases the noise coming from the frequency continuous variable hence deteriorating the precision over the estimation of a time shift.

References

1. N. Fabre and S. Felicetti, Parameter Estimation of Time and Frequency Shifts with Generalized Hong-Ou-Mandel Interferometry, Phys. Rev. A **104**, 022208 (2021).
2. Eloi Descamps, Nicolas Fabre, Arne Keller, and Pérola Milman, Phys. Rev. Lett. **131**, 030801 (2023)

Figures

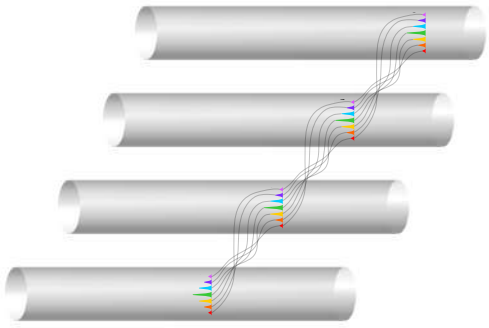


Figure 1: n-photon frequency entangled state in different spatial mode as a probe for estimating small temporal parameter.

Teleportation of a genuine single-rail vacuum/one-photon qubit generated via a quantum dot source

Beatrice Polacchi, **Francesco Hoch**, Giovanni Rodari, Stefano Savo, Gonzalo Carvacho, Nicolò Spagnolo, Taira Giordani, and Fabio Sciarrino

Dipartimento di Fisica - Sapienza Università di Roma, P.le Aldo Moro 5, I-00185 Roma, Italy

Francesco.hoch@uniroma1.it

Quantum state teleportation represents a pivotal result of the quantum information theory and one of the essential protocols for the creation of quantum networks.
In the literature there are several photonic implementations of the protocol for different degree of freedoms [1-2], however until now there are no implementation in the single mode vacuum/one-photon encoding.

Previous attempts to use this particular encoding led to the implementation of the entanglement swapping protocol [3] since maximally entangled states in such an encoding can be generated through the use of a beam splitter. In contrast, the teleportation protocol results more challenging since the difficulty of creating generic single mode vacuum/one-photon state.

In this work [4], we present the genuine implementation of a quantum teleportation protocol in single-rail vacuum/one-photon coding using a quantum dot-based single photon source coherently controlled in a micro-cavity. Indeed, it has recently been experimentally demonstrated how this type of source allows the creation of superposition states of vacuum and single photons [5].
Furthermore, with the same apparatus we demonstrate the implementation of an entanglement swapping protocol using the time-bin encoding.

Our results disclose new applications and potentialities for the single-rail vacuum/one-photon encoding in the quantum information and quantum communications.

References

[1] Bouwmeester, D., Pan, JW., Mattle, K. *et al.* Experimental quantum teleportation. *Nature* **390**, 575–579 (1997).
[2] Marcus Reindl *et al.* All-photonic quantum teleportation using on-demand solid-state quantum emitters.*Sci. Adv.***4**,eaau1255(2018)
[3] Egilberto Lombardi, Fabio Sciarrino, Sandu Popescu, and Francesco De Martini. Phys. Rev. Lett. **88**, 070402 – Published 30 January 2002
[4] Beatrice Polacchi, Francesco Hoch, Giovanni Rodari, Stefano Savo, Gonzalo Carvacho, Nicolò Spagnolo, Taira Giordani, Fabio Sciarrino arXiv:2310.20521
[5] Loredo, J.C., Antón, C., Reznychenko, B. *et al.* Generation of non-classical light in a photon-number superposition. *Nat. Photonics* **13**, 803–808 (2019).

Figures

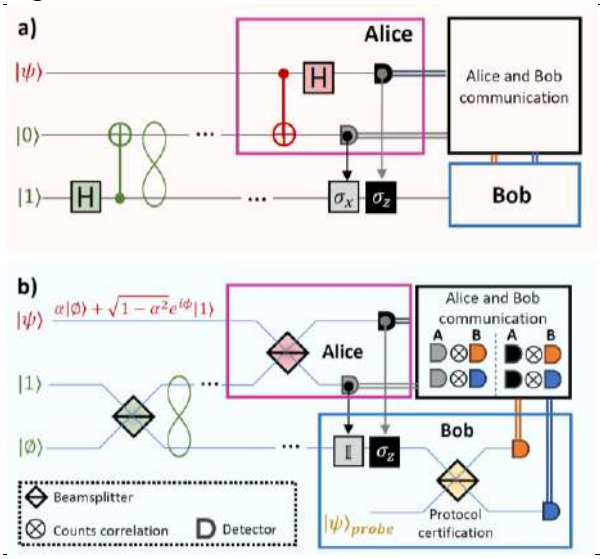


Figure 1: Conceptual scheme of the protocol [4]

Electronic structure and decoherence of the VB center in hexagonal boron nitride for sensing in low dimensions

Viktor Ivády[1,2,3]
András Tárkányi,[1,2] Zsolt Benedek,[1,2,3] Gergely Barcza[2,4]

[1]*Eötvös Loránd University, Budapest, Hungary*
[2]*MTA–ELTE Lendület "Momentum" NewQubit Research Group, Budapest, Hungary*
[3]*Linköping University, Linköping, Sweden*
[4]*Wigner Research Centre for Physics, H-1525, Budapest, Hungary*

ivady.viktor@ttk.elte.hu

Point defects quantum bits in wide-bandgap semiconductors with controllable electron and nuclear spin states provide a versatile toolbox for developing applications in the fields of quantum sensing, quantum information processing, and quantum computation. Recently, two-dimensional semiconductors have gained considerable attention for hosting quantum states. The negatively charged boron vacancy center (VB center) [1] is among the first point defect qubits in hexagonal boron nitride (hBN), whose spin could be initialized, coherently manipulated, and read out.[2] The possibility of exfoliation of hBN and the creation of vacancy centers close to the surface have opened new horizons for quantum sensing low dimensions.[3]
My talk outlines the physics of the VB center in hBN, see Fig. 1, and discusses recent advances in light of quantum sensing. In particular, I will discuss the electronic structure and optical spin polarization mechanism of the VB center and identify key ingredients of the quantum noise of hBN quantum sensors.[1,4,5] I will show that by shifting from low magnetic fields to higher magnetic fields, the decoherence mechanisms of the VB center involve different flavors of hyperfine coupling and many-body physics. I will discuss optimal magnetic field ranges and possible coherence-protecting strategies. These findings collectively advance our understanding of the VB center in hBN and its potential applications in quantum technologies.

References

[1] V. Ivády *et al.*, npj Computational Materials 6, (2020) 41.
[2] A. Gottscholl *et al.*, Nature Materials 19, (2020) 540.
[3] A. J. Healey *et al.*, Nature Physic 19, (2023) 87.
[4] A. Haykal et al, Nature Communications 13 (2022), 4347.
[5] W Liu et al., Nature Communications 13 (2022), 5713.

Figures

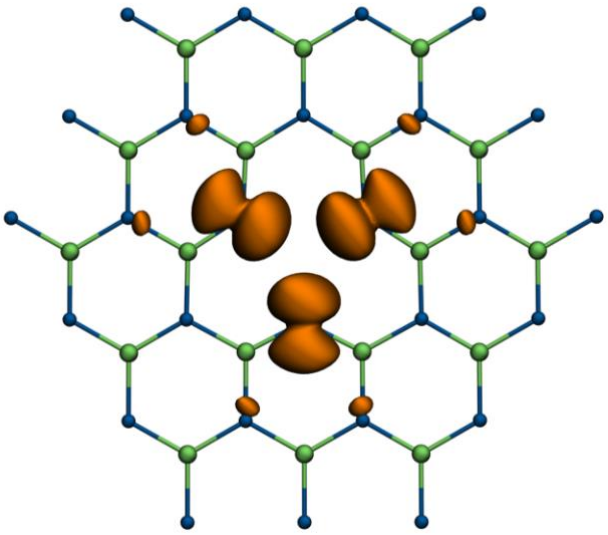


Figure 1: Structure and spin density of the negatively charged boron vacancy center in hexagonal boron nitride.

High-kinetic inductance coupled cavity arrays for analog quantum simulation

Vincent Jouanny
S. Frasca, V.J. Weibel, L. Peyruchat, M. Scigliuzzo, F. Oppliger, F. De Palma, D. Sbroggio, G. Beaulieu, O. Zilberberg and P. Scarlino

HQC, Institute of Physics, EPFL, Switzerland
LPQM, Institute of Physics, EPFL, Switzerland
Department of Physics, University of Konstanz, Konstanz, Germany

Vincent.jouanny@epfl.ch

In the field of analog quantum simulation, coupled cavity arrays (CCAs) have emerged as promising platforms for creating quantum baths of varying complexity, crucial for emulating complex many-body Hamiltonians [1, 2]. However, enhancing the reliability and compactness of these systems is of fundamental interest for their practical utility. Addressing this challenge, our work introduces a novel compact (50x75 μm^2), versatile, and low-disorder (σ/f = 0.21 %) CCA platform based on high-kinetic inductance NbN thin films (Figure 1). Additionally, we present a new approach to study and extract disorder in CCAs by leveraging symmetry-protected topological SSH modes (Figure 2). The adaptability of our platform in controlling the mode density presents exciting prospects for the study of quantum impurity models and atom-photon bound states physics [3,4].

References

[1] Georgescu et al, Review of Modern Physics, 1 (2014) 153-185.
[2] Zhang et al, Science, 6629 (2023) 278-283
[3] Messinger et al, Physical Review A, 3 (2019) 032325
[4] Scigliuzzo et al, Physical Review X, 3 (2022) 031036

Figures

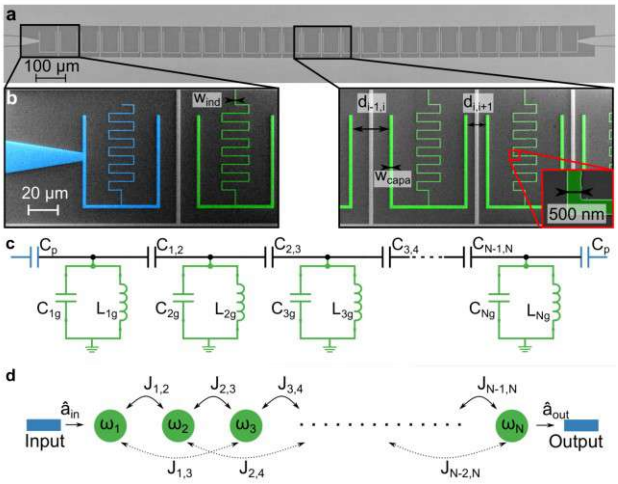


Figure 1: High kinetic inductance metamaterial. **a.** Optical micrograph of the metamaterial. **b.** Scanning electron micrograph of the metamaterial. **c.** Lumped-element model **d.** Coupled cavity model of the metamaterial.

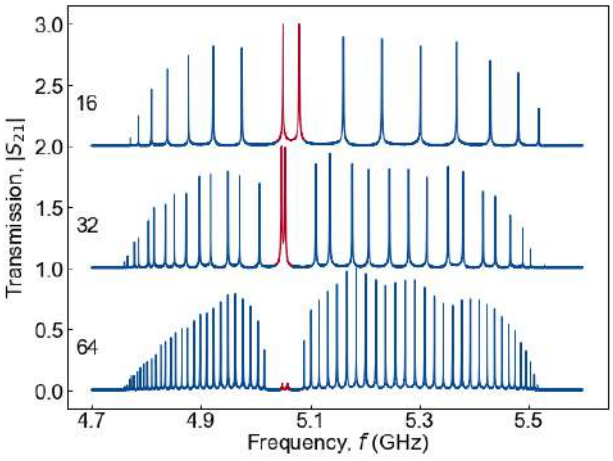


Figure 2: Measured spectrum of CCAs with increasing number of cavities in the SSH configuration. With the bulk modes in blue and edge modes in red.

Engineering Photon Sources With Interacting Quantum Emitters

Adrián Juan Delgado[1]
R. Esteban[1,2], A. Nodar[1,2], J. B. Trebbia[3,4], B. Lounis[3,4] and J. Aizpurua[2,5,6]
[1]*Materials Physics Center, CSIC-UPV/EHU, E-20018 Donostia-San Sebastián, Spain.*
[2]*Donostia International Physics Center DIPC, E-20018 Donostia-San Sebastián, Spain.*
[3]*Université de Bordeaux, LP2N, F-33405 Talence, France.*
[4]*Institut d'Optique & CNRS, LP2N, F-33405 Talence, France.*
[5]*Ikerbasque, Basque Foundation for Science, E-48013 Bilbao, Spain.*
[6]*Departament of Electricity and Electronics, University of the Basque Country (UPV/EHU), E-48940, Spain.*
adrian.juan@ehu.eus

Quantum emitters, such as quantum dots and organic molecules, have an extremely narrow emission line at cryogenic temperatures and emit single photons when they are isolated [1]. Additionally, the interaction between quantum emitters leads to the formation of superradiant and subradiant states [2]. Superradiant states are characterized by a better coupling to light than an isolated emitter, which might be used to design faster photon sources. In contrast, subradiant states couple worse to light and have a larger lifetime, with possible applications in quantum information storage.

To better characterize the possibilities that these cooperative effects introduce to manipulate quantum properties of light for quantum technologies, we perform a detailed theoretical analysis of the intensity correlation of the photons emitted from two interacting emitters.

First, we study the color-blind intensity correlation $g^{(2)}(0)$, which measures the correlation between all the photons emitted from the system. We find that $g^{(2)}(0)$ can be tailored from strong antibunching, when the laser is tuned resonantly tuned to the superradiant state $|\Lambda_-\rangle$ (blue line in Fig. 1a), to strong bunching, when the laser is tuned to the two-photon resonance (red line), which allows for a large control of the quantum properties of the emitted photons. Interestingly, $g^{(2)}(0)$ shows a complex behaviour when the laser is tuned to the subradiant state $|\Lambda_+\rangle$ (green line in Fig. 1a), with the possibility of emitting both bunched and antibunched light depending on the laser intensity.

Moreover, we also analyse the frequency-resolved intensity correlation (FRIC) $g^{(2)}(\omega_1, \omega_2; 0)$, which measures the correlation between pairs of photons of specific frequencies. The dependence of $g^{(2)}(\omega_1, \omega_2; 0)$ on ω_1 and ω_2 is frequently analysed using 2D maps, as the one depicted in Fig. 1b. These maps are very promising characterization tools that unveil complex emission processes, such as two-photon emission transitions through virtual states [3]. In summary, we demonstrate that the statistics of light emitted from interacting emitters can be widely tailored and its characterization can unveil complex emission processes in this system.

References

[1] B. Lounis and M. Orrit, Reports on Progress in Physics, 68 (2005), 1129.
[2] J. B. Trebbia et al., Nature Communications, 13 (2022), 1.
[3] A. Gonzalez-Tudela et al., New Journal of Physics, 15 (2013), 033036.

Figures

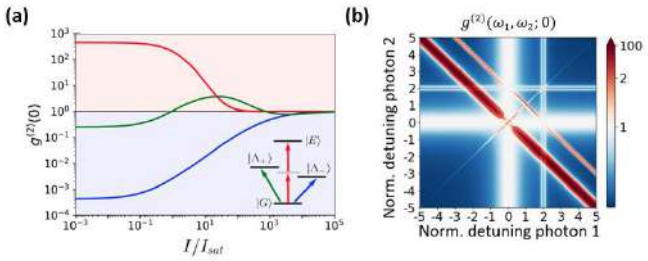


Figure 1: (a) $g^{(2)}(0)$ vs. laser intensity I, for the different laser detunings depicted in the inset. **(b)** FRIC map when the laser is tuned resonantly to the subradiant state $|\Lambda_-\rangle$ and the laser intensity is fixed at 50 times the saturation intensity I_{sat} of the single emitter.

Non-Hermitian physics without gain or loss: the skin effect of reflected waves

Viktor Könye
Selma Franca, Fabian Hassler, Jeroen van den Brink, and Cosma Fulga

University of Amsterdam, Amsterdam, Netherlands

v.konye@uva.nl

Physically, one tends to think of non-Hermitian systems in terms of gain and loss: the decay or amplification of a mode is given by the imaginary part of its energy. Here, we introduce an alternative avenue to the realm of non-Hermitian physics [1], which involves neither gain nor loss. Instead, complex eigenvalues emerge from the amplitudes and phase-differences of waves backscattered from the boundary of insulators. We show that for any strong topological insulator in a Wigner-Dyson class, the reflected waves are characterized by a reflection matrix exhibiting the non-Hermitian skin effect. This leads to an unconventional Goos-Hanchen effect: due to non-Hermitian topology, waves undergo a lateral shift upon reflection, even at normal incidence (Fig. 1). Going beyond systems with gain and loss vastly expands the set of experimental platforms that can access non-Hermitian physics and show signatures associated to non-Hermitian topology [2][3].

References

[1] Selma Franca, Viktor Könye, Fabian Hassler, Jeroen van den Brink, and Cosma Fulga, Phys. Rev. Lett. 129, 086601, (2022)

[2] Ochkan, K., Chaturvedi, R., Könye, V. *et al.* Non-Hermitian topology in a multi-terminal quantum Hall device. *Nat. Phys.* (2024)

[3] Viktor Könye, Kyrylo Ochkan, Anastasiia Chyzhykova, Jan Carl Budich, Jeroen van den Brink, Ion Cosma Fulga, Joseph Dufouleur, arXiv:2308.11367 (2023)

Figures

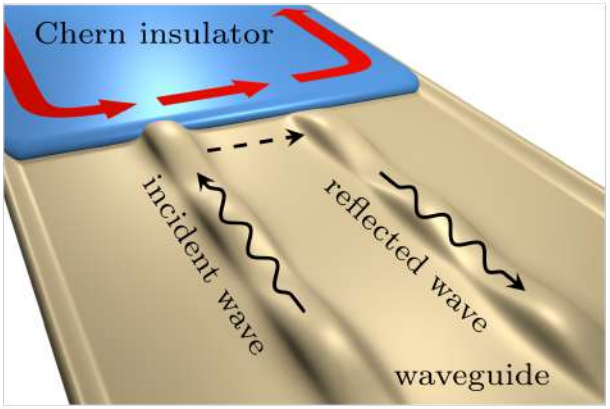


Figure 1: Schematic figure for the non-reciprocal Goos-Hanchen effect

Quantum coherence-assisted sensing with parallel quantum dots

Stephanie Matern[1,2]
Katarzyna Macieszczak[3], Simon Wozny[2], Martin Leijnse[2]

[1]*Pitaevskii BEC Center, CNR-INO and Dipartimento di Fisica, Università di Trento, Trento, Italy*
[2]*NanoLund and Solid State Physics, Lund University, Box 118, 22100 Lund, Sweden*
[3]*Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom*

stephanie.matern@ino.cnr.it

The interplay between quantum interference effects and non-equilibrium dynamics in quantum devices offers a promising avenue for applications. In this talk, we investigate the interplay between these phenomena and their potential for quantum sensing applications, focusing on a specific system consisting of two quantum dots (QD) in a parallel configuration coupled to a source and drain.
The parallel QD system is known to exhibit a sensitive response in its stationary particle current to external perturbations much smaller than the system-lead coupling and the temperature [1], which is a direct consequence of an underlying parity-like symmetry. Under equilibrium conditions this symmetry gives rise to two degenerate ground states, leading to the emergence of two stationary states in nonequilibrium. On an intuitive level the two states correspond to a bright and dark state due to the interference of the electron traveling through the two possible paths of the parallel QD system.
The underlying symmetry also impact the system's transient behavior and the parallel QDs exhibit metastability. The system's metastability manifests in long-lived, slowly decaying states and are described by classical dynamics between two metastable phases. The competition of those two metastable phases explains the sensitive behavior of the stationary current towards small perturbations.
Our goal is to harness this sensitive response for charge sensing which is not limited by temperature. Analyzing the sensitivity in terms of the particle current signal-to-noise ratio we find that the parallel QDs outperform an analogous single QD setup for a wide range of parameters [2].

References

[1] Z.-Z. Li and M. Leijnse, Phys. Rev. B 99, 125406 (2019)
[2] S. Matern, K. Macieszczak, S. Wozny, and M. Leijnse, Phy. Rev. B 107, 125424 (2023)

Measurement of central charge from local measurements

Sona Najafi (IBM Quantum)
Swarndeep Majumdar, Nazli Ugur Koyluoglu, Mirko Amico, Sarah Mostame, Ewout van den Berg, Mohammad Ali Rajabpour, Zlatko Minev
MIT-IBM Warson Lan,314 Main St, Cambridge, MA, USA
knajafi@ibm.com

Abstract

In this work, we utilize Shannon-Renyi entropy of local Pauli observables of one-dimensional quantum spin chains at a critical point and extract the central charge from the scaling behavior of its sub-leading term for two distinct universality classes, namely, transverse field Ising(TFI) chain with Z_2 symmetry, XXZ chain with U(1) symmetry. To this end, we first utilize simulated variational quantum eigen-solver (VQE) to prepare the ground state of the critical spin chains. We run our experiments on IBM quantum processors and leveraging the unique topology we measure the central charge both for open and periodic boundary conditions. The latter aids in reducing the finite size effect, even when the system size is L=12. Finally, equipped with advanced error mitigation schemes such as probabilistic error cancellation, we extract an estimate of the central charge for TFI and XXZ chains with an accuracy reaching 7% in the periodic boundary condition set up.

References

Swarndeep Majumdar, Nazli Ugur Koyluoglu, Mirk Amico, Sarah Mostame, Ewout van den Berg, Mohammad Ali Rajabpour, Zlatko Minev, Khadijeh Sona Najafi, Measuring central charge in a superconducting quantum processor, in preparation

Figures

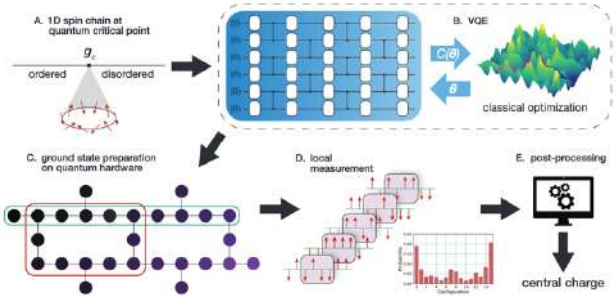


Figure 1: Schematic of measurement of central charge from local measurements in IBM quantum processors

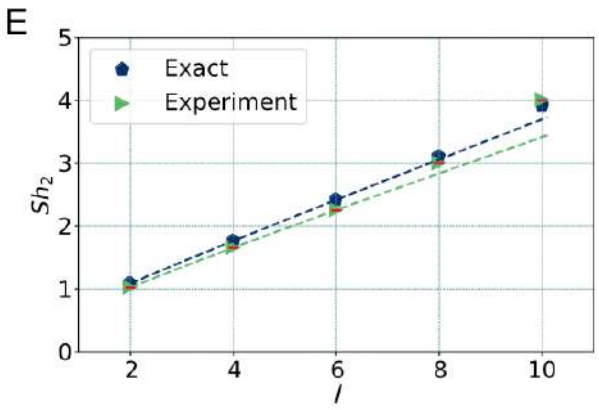


Figure 2: Second Renyi entanglement entropy of transverse field. Using the probabilistic error cancelation, we prepare state with fidelity of 96 percent leading to accurate values of central charge.

Quantum dynamics of Dissipative Kerr solitons

Kilian Seibold[1,2]
R. Rota[1], F. Minganti[1], and V. Savona[1]

[1] *Institute of Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015, Lausanne, Switzerland*
[2] *Department of Physics, University of Konstanz, 78464 Konstanz, Germany*
seibold.kilian@gmail.com

Dissipative Kerr solitons arising from parametric gain in ring microresonators are usually described and understood within a classical mean-field framework. In this work, I develop a quantum-mechanical model of dissipative Kerr solitons in terms of the Lindblad master equation formalism and study the model via the truncated Wigner method. In my talk, using the theory of open quantum systems, I will show that the solitons experience a finite coherence time due to quantum fluctuations originating from losses. The Liouvillian spectrum of the system is characterized by a set of eigenvalues with finite imaginary part and vanishing real part in the limit of vanishing quantum fluctuations. This arrangement emerges asymptotically in the limit of large input power, and the Liouvillian gap vanishes as a power law of the total photon occupation in the microring modes. This shows that DKSs are a specific manifestation of a dissipative time crystal. Establishing the link between DKSs and dissipative time crystals is an important step in the study and characterization of spontaneous time-translational symmetry breaking in quantum systems out of equilibrium. While being a theoretical work per se, special consideration will be given to the experimental implementations of the system under investigation.

References

[1] K. Seibold et al, Phys. Rev. A 105.053530 (2022).
[2] K. Seibold et al, Phys. Rev. A 101.033839 (2020)

Figures

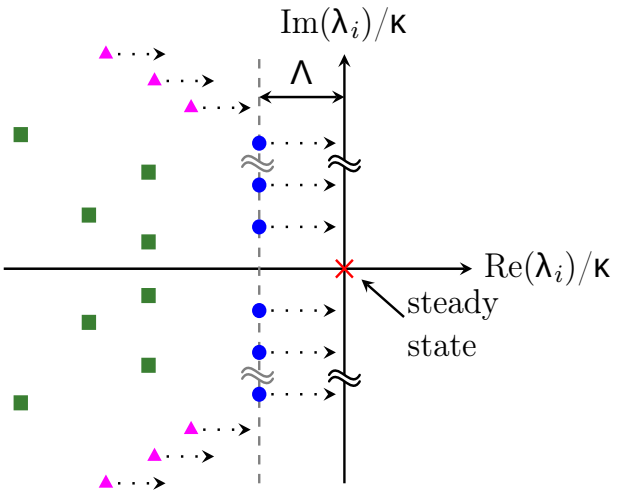


Figure 1: Schematic representation of the spectrum of the Liouvillian.

Charge sensing using a single-electron double-box in a silicon quantum dot array

K. Ulas[1,2]
T. Ferrus[1], F. von Horstig[2,3], H. Niebojewski[4], M. F. Gonzalez-Zalba[3], C. G. Smith[1], F. Martins[1]

1. Hitachi Cambridge Laboratory, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom
2. University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom
3. Quantum Motion, 9 Sterling Way, London N7 9HJ, United Kingdom
4. Laboratoire d'électronique des technologies de l'information (CEA-Leti), Minatec Campus, Grenoble F-38054, France

ku230@cam.ac.uk

With progress made in the scalability of semiconductor-based spin qubits, the development of highly integrated architectures has become essential [1]. Although CMOS technology provides advantages for integration and scaling [2] mostly due to advances in manufacturing processes, the use of structures like single electron tunnelling devices limits de facto the latter because of the presence of contacts and the requirement for extra control gates. The use of dispersive charge sensing in single electron boxes (SEB) [3] has significantly improved device footprints while maintaining a high-fidelity readout. However, the presence of a reservoir still limits its use in high density architectures in practice.

With the view of better scalability and higher qubit density, we have investigated a compact single electron double box (SEDB) integrated into a Si-CMOS array and performed high quality readout without the need of any reservoir.

The device itself is based on a multi-gate CMOS architecture with independent tuneable control and exchange gates [4]. Readout is implemented by a double resonant circuit with superconducting inductors [5].

By comparing a double-box to a single-box in the same Si-CMOS system, the charge readout capabilities of the double-box are assessed. This compact, reservoir-less charge sensor offers a promising approach for spin readout in a large and dense qubit architecture.

References

[1] M. Veldhorst, et al., Nat. Commun. 8, 1766 (2017); J. M. Boter et al., Phys. Rev. Appl. 18, 024053 (2022); R. Maurand et al., Nat. Commun. 7, 13575 (2016).
[2] A. M. J. Zwerver et al., Nat. Electron. 5, 184 (2022)
[3] G. A. Oakes, et al. Phys Rev X 13.1 011023 (2023)
[4] T. Bédécarrats et al., IEEE International Electron Devices Meeting, 1-4 (2021)
[5] F. von Horstig, et al., arXiv:2304.13442 (2023)

Figures

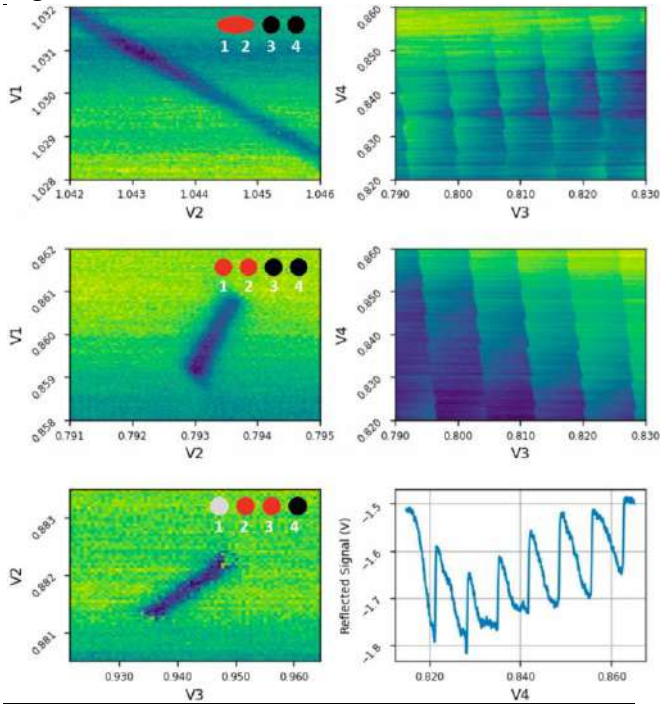


Figure: Comparison between the SEB and SEDB readouts in the configurations indicated in the inset (detector in red, sensing in black, unused in white). The left panels show the dispersive signal whereas the right panels display the charge sensing. The 'Vi' are voltages applied to the dots 'i'.

Weak-measurement protection in quantum simulations of lattice gauge theories

Matteo Michele Wauters
Edoardo Ballini, Philipp Hauke

Pitaevskii BEC center, University of Trento, via sommarive 5, 38123 Trento, Italy

matteo.wauters@unitn.it

Abstract

Lattice gauge theories (LGT) are promising yet challenging candidates for quantum simulation protocols, because of their highly constrained dynamics and complex interactions. A fundamental issue in any experimental proposal is the mitigation of errors breaking the local gauge symmetries, thus leading to unphysical results. However, weak continuous measurements of the symmetry generators drive a transition to a regime where the quantum Zeno effect protects gauge invariance [1]. We extend this approach in the context of digital quantum simulations by measuring ancillary qubits coupled to the system [2] and show that it can be applied also to nonabelian LGTs implemented on qudit platforms [3-5]. Our findings provide valuable tools for error-mitigation and error-correction schemes in quantum simulations of strongly interacting and highly constrained quantum systems.

References

[1] K. Stannigel et al. , Phys. Rev. Lett., 112 (2014) 120406
[2] M. Wauters, E. Ballini, P. Hauke, in preparation
[3] E. Zohar, M. Burrello, Phys. Rev. D, 91 (2015) 054506
[4] M. Ringbauer et al., Nature Physics Lett., 18 (2022) 1053-1057
[5] T. Zache, D. González-Cuadra, P. Zoller, Quantum, 7 (2023) 1140

Figures

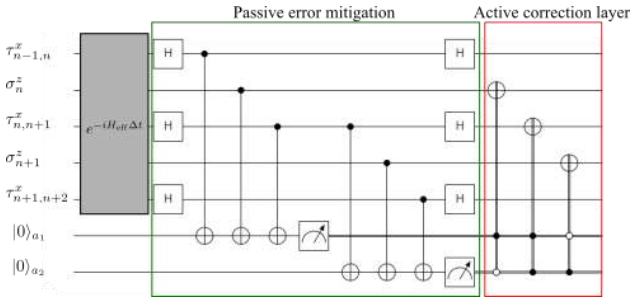


Figure 1: Measurement of two neighboring local symmetry operators by coupling to ancillary qubits. A feedback correction layer can be added to correct incoherent spin-flip errors.

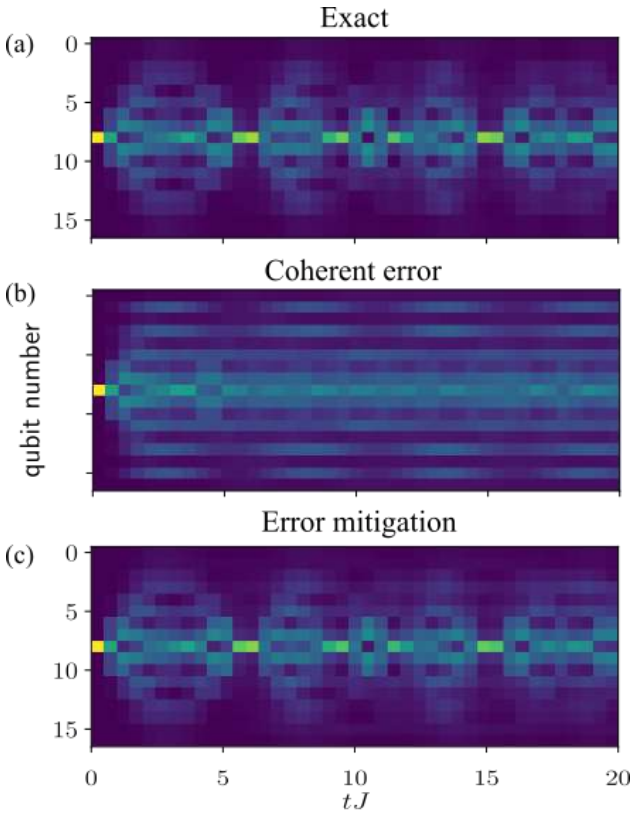


Figure 2: comparison between the exact dynamics (a), with coherent errors (b), and measurement-induced error mitigation (c).

Magnetism meets Topology:
Electronic structure of the candidate FM-TI $Mn_{1+x}Sb_{2-x}Te_4$ by ARPES

Sergio Barquero Pierantoni
S.Mukherjee, F.Kooij, S.Smit, K.Shirkoohi, K.Kochetkova, F.Tazim, I.Aguilera, A.Isaeva, M.Golden

University of Amsterdam, Science Park 904 1098XH, Amsterdam, The Netherlands
s.barqueropierantoni2@uva.nl

Abstract

The observation of the quantum anomalous Hall (QAHE) effect in Cr- & V-doped thin topological insulators (TI's) [1] gave access to dissipationless edge states without the need for an external magnetic field, in principle paving the way for developing low-power consumption topological quantum electronic and spintronic devices. This striking effect is fundamentally caused by the opening of an inverted gap in the topological surface states of the TI, given by the out of plane magnetization of the magnetic dopants (see **Figure 1**). Unfortunately, the disorder from the magnetic dopants confined these states to ultralow temperatures (few mK) hindering any possible applications.

Intrinsically magnetic topological insulators have been proven to be an excellent platform to combine magnetism and topology at high temperatures, allowing the observation of the QAHE [2] and further magnetic topological phases at record-high temperatures [3]. Recently, Angle Resolved Photoemission Spectroscopy (ARPES) measurements of MBE-grown films of Mn-rich $Mn_1Sb_2Te_4$[4] were argued to support it being a ferromagnetic topological insulator with – as yet - the highest Curie temperature T_C=45K.

In this talk, I present our latest ARPES data from Mn-rich $Mn_{1+x}Sb_{2-x}Te_4$ single crystals with T_C as high as 70K (**Figure 2**). I will discuss the pro's and con's of using single crystals in the chase for a ferromagnetic topological insulator with very high transition (Curie) temperature, and introduce surface decoration with alkali metals and the use of circular dichroism in ARPES as powerful methods beyond conventional ARPES to sharpen the determination of the topology of these materials.

References

[1] Chang et al, Science, 340 (2013) 6129
[2] Haiming et al, Nat Physics,17 (2021) 36
[3] Otrokov et al, Nature, 575 (2019) 416
[4] Wimmer et al, Adv Materials, 33 (2021) 2102935

Figures

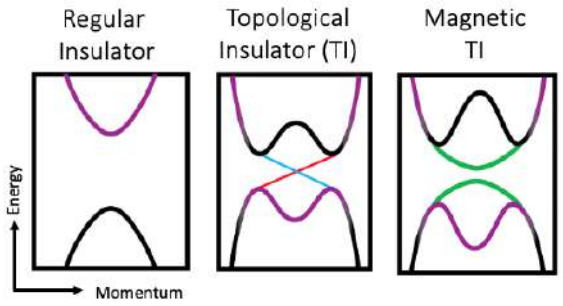


Figure 1: Opening of a magnetic gap within the topological surface states.

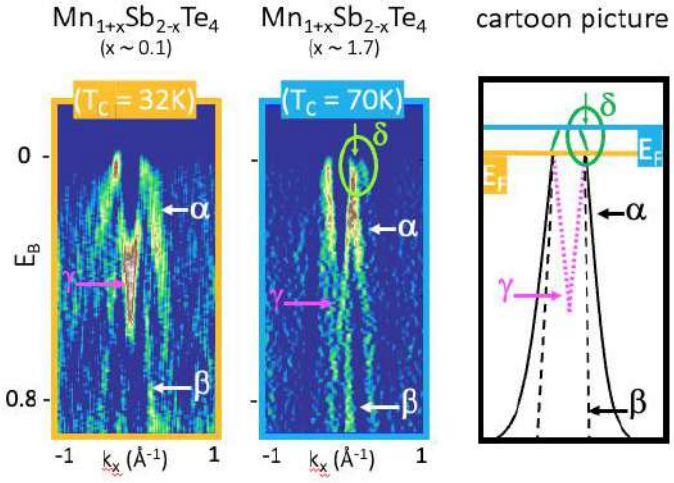


Figure 2: Our ARPES data in $Mn_{1+x}Sb_{2-x}Te_4$ single crystals & current picture of the system.

Topology-driven spin-orbit torques in Weyl Semimetal/Ferromagnet Heterostructures

Amilcar Bedoya-Pinto[1,2]
A.K. Pandeya[2], D. Liu[2] and S.S.P. Parkin[2]
[1]*Institute of Molecular Science (ICMol),University of Valencia, Spain*
[2]*NISE-Department, Max-Planck Insitute of Microstructure Physics, Halle, Germany*
Amilcar.Bedoya@uv.es

Weyl Semimetals (WSMs), materials with three-dimensional topologically protected electronic states, show highly interesting physical properties including surface Fermi-arcs, the chiral magneto-transport anomaly and extremely high electron mobilities. One promising application field of WSMs is spin-orbitronics, as the Fermi-surface is expected to play an important role in the spin-to-charge conversion efficiency, according to theoretical investigations [1,2].

In this work, we report the growth of epitaxial, single-crystalline NbP and TaP Weyl Semimetal thin films [3] by means of molecular beam epitaxy, and their successful integration in spin-torque devices. We have assessed the structural quality of the films (Fig.1a) featuring an atomically flat surface, essential for the observation of topological bands by photoemission (Fig. 1b). Furthermore, we rely on the preparation of high-quality in-situ TaP/NiFe interfaces to investigate the spin-orbit torques produced by the topological WSM by means of spin-torque ferromagnetic resonance (ST-FMR). The TaP/NiFe/MgO devices show signatures of large spin-orbit torques induced by the Weyl Semimetal: (i) a very strong symmetric component of the voltage lineshape across the resonance related to damping-like torques (Fig.1c) (ii) a clear scaling of the resonance linewidth by applying an external DC bias through the bilayer (Fig. 1d). **The connection between Fermi-surface topology and spin-to-charge conversion** is addressed by performing angle-resolved photoemission on the TaP surfaces prior to the *in-situ deposition* of the magnetic layers, and probing the spin-torque efficiency along the high-symmetry directions of the WSM. A drastic enhancement of the spin-orbit torque efficiency is observed when the current is driven along Γ-X and Γ-Y direction, where the topological surface states are located.

References

[1] Sun, Y, et.al. Strong Intrinsic Spin Hall Effect in the TaAs Family of Weyl Semimetals. Phys. Rev. Lett. 117, 146403 (2016)
[2] Johannson, A. et.al. Edelstein effect in Weyl semimetals. Phys. Rev. B 97, 085417 (2018)
[3] Bedoya-Pinto, A. et.al. Realization of NbP and TaP Weyl Semimetal Thin Films, ACS Nano, 14, 4, 4405 (2020)

Figures

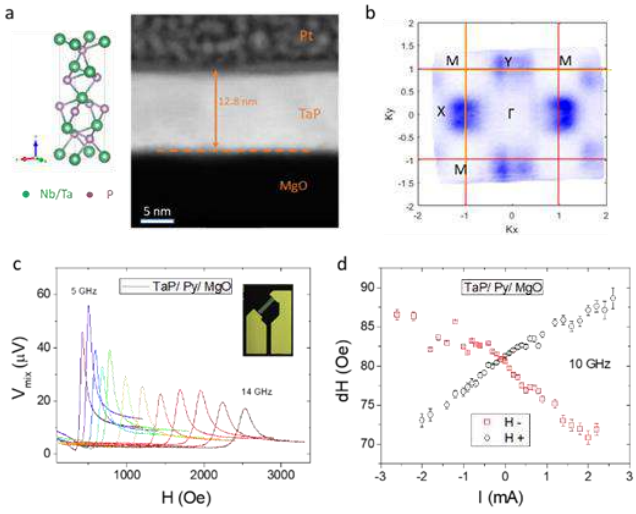


Figure 1: (a)Transmission electron microscopy image of a TaP thin film, showing ordered epitaxial lattice planes and an atomically flat surface. The crystal structure is drawn for clarity. (b) Angle-resolved photoemission measurements of the TaP thin films, showing four-fold symmetric electronic pockets at the Fermi-energy. (c) Frequency-dependent ST-FMR of a TaP/Py/MgO device, evidencing a strong symmetric lineshape component indicative of damping-like spin-orbit torques. Inset: Optical image of ST-FMR device. (d) Linewidth dependence of the ST-FMR signal, showing a consistent scaling with applied DC bias. The slope is proportional to the magnitude of the induced spin-orbit torques per charge unit.

Tunnelling spectroscopy and Josephson coupling through EuS/Al interfaces.

Sara Catalano
David Caldevilla, Max Ilyn, Elia Strambini, F. Sebastian Bergeret, Celia Rogero

Materials Physics Center, Paseo Manuel Lardizabal 5, 20018 Donostia, Spain

sara.catalano@ehu.eus

Abstract

The magnetic proximity effect (MPE) between a ferromagnet (F) and a superconductor (S) mediates the emergence of spin-triplet correlations in the superconducting condensate, inducing a spin-dependent splitting of its density of states (DOS) [1,2]. Thus, F/S interfaces allow for studying the properties of unconventional superconducting systems, which have already demonstrated important quantum technology applications such as the pi-shifted Josephson effect [3].
In this work, we study such F/S interfaces in superconducting tunnel junctions (STJs) in which in which a thin film of the ferromagnetic insulator (FI) EuS is evaporated on top of one of the Al superconducting electrodes. Th STJs are defined by the evaporation through shadow masks of EuS/Al/AlOx/Al heterostructures. In the mK temperature regime, the current-voltage characteristics of the junctions reveal a spin-dependent DOS, from which the strength of the magnetic exchange field in the system can be estimated (*Fig. 1*).
Moreover, the junctions exhibit the Josephson effect, which is studied as a function of the magnetic configuration of the EuS film. We show that the Josephson current is strongly suppressed by a uniform magnetization of the EuS film, while the order parameter of the systems does not seem to be affected as much from the DOS analysis. We also show that the Josephson effect can be recovered by applying a magnetic field close to the coercive field of the EuS film.
We discuss the introduction of our EuS/Al based weak links in a DC-SQUID design, in which the current-phase relation of the system and its dependence on the EuS magnetic state can be revealed.
Our results shed light on the role of F/S interfaces in engineering Josephson effect-based devices and suggest the use of EuS/Al interfaces to mimic an external magnetic field in quantum transport experiments [4,5].

References

[1] R. Meservey and P.M. Tedrow ,Physics Report, 238, 4 (1994) 173-243
[2] F. S. Bergeret, A. F. Volkov and K. B. Efetov, Rev. of Mod. Phys., 77 (2005) 1321-1372
[3] E. C. Gingrich et al., Nat. Phys., 12 (2016) 564-567
[4] A. Hijano et al., Phys. Rev. Res., 3, 2 (2021) 023131
[5] Z. Geng et al., Supercond. Sci. Technol., 36 (2023) 123001

Figures

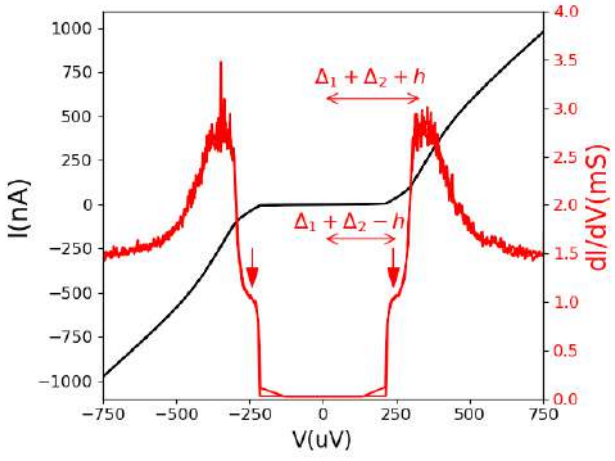


Figure 1: Current-Voltage characteristic of a EuS/Al/AlOx/Al STJ and corresponding dI/dV, revealing the DOS of the condensate.

Observation of magnon dynamics in a quantum dot ladder

Pablo Cova Fariña[1]
Daniel Jirovec[1], Xin Zhang[1], Elizaveta Morozova[1], Stefan Oosterhout[2], Tzu-Kan Hsiao[1], Amir Sammak[2], Giordano Scappucci[1], Menno Veldhorst[1], Lieven Vandersypen[1]

[1]*QuTech and Kavli Institute of Nanoscience, TU Delft*
[2]*QuTech and TNO*
P.CovaFarina@tudelft.nl

Abstract

Analog quantum simulators promise to shed light on current problems in natural sciences before digital, fault tolerant quantum computers reach quantum practicality. In recent years, semiconductor gate-defined quantum dot arrays have emerged as a promising platform for both digital and analog efforts. In the past, these systems have been used to simulate a plethora of physical phenomena [1-5], thanks to the in-situ tunability of tunnel couplings and onsite interactions, as well as the direct mapping of their Hamiltonian to an extended Fermi-Hubbard or Heisenberg model, depending on the parameter regime.

In this work, we use an array of quantum dots in a Ge/SiGe quantum well to simulate the dynamics of single spin excitations or magnons, based on our previous efforts characterizing charge and two-spin states in similar devices [5,6]. For this purpose, we control exchange interactions between neighbouring sites throughout the array, individually tunable over several orders of magnitude. Using transitions with a controlled degree of adiabaticity and exchange-based gates, we demonstrate initialization and readout of several spin states. This ultimately allows us to initialize single magnons in desired locations in the array and pinpoint their position as they propagate over time. We observe their evolution for different exchange coupling configurations and topologies, and compare the results to simulations based on the Heisenberg model. Furthermore, we exploit the rich physics of holes in germanium to explore the impact of disorder to the magnon dynamics. Owing to their strong intrinsic spin-orbit interaction, spins in germanium exhibit site-dependent g-tensors, which act as a source of single-site disorder. We observe how moderately high ratios of disorder to interactions disrupt the ideal dynamics of single magnons and ultimately lead to localization. The obtained results are promising in the context of simulating many-body localization and other disorder-based solid-state phenomena.

References

[1] Hensgens et al., Nature (2017) **548**, 70–73
[2] Dehollain, Mukhopadhyay et al., Nature (2020) **579**, 528–533
[3] van Diepen, Hsiao et al., PRX (2021) **11**, 041025
[4] Wang et al., npj Q info (2023) **9**, 58
[5] Hsiao, Cova Fariña et al., arXiv:2307.02401 (2023)
[6] Zhang, Morozova et al., arXiv:2312.16101 (2023)

Figures

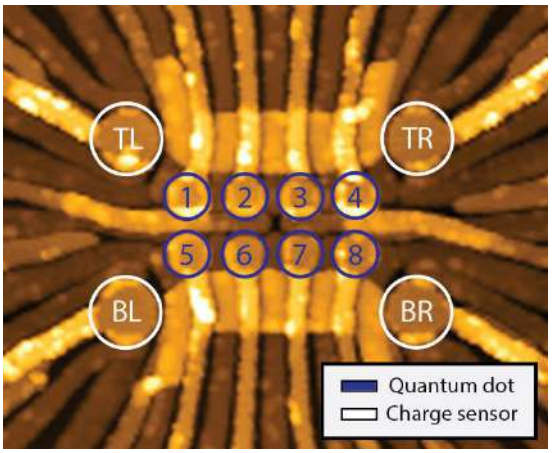


Figure 1: AFM image of a 2x4 germanium quantum dot ladder with four sensing dots, nominally identical to the one used for this experiment.

Real-space evidence for 2D-XY ordering in a van der Waals ferromagnet

Ryuji Fujita[1]
Jheng-Cyuan Lin[1], Andrew F. May[2], Alevtina Smekhova[3], Florian Kronast[3], Gerrit van der Laan[4], Thorsten Hesjedal[1]

[1] Clarendon Laboratory, Parks Rd. Oxford, Oxfordshire, OX1 3PU, UK **[2]** Oak Ridge National Laboratory, 1 Bethel Valley Rd. 37830, TN, USA **[3]** Helmholtz-Zentrum Berlin, BESSY II. Albert-Einstein-Straße 15, 12489 Berlin, Germany **[4]** Diamond Light Source, Harwell Science and Innovation Campus, Fermi Ave., Didcot OX11 0DE, Oxfordshire, UK

ryuji.fujita@physics.ox.ac.uk

Abstract

Two-dimensional (2D) materials often host emergent physical phenomena in the atomically thin limit. Here, we spatially resolve the magnetization in four-layer (4L) Fe_5GeTe_2, a van der Waals ferromagnet [1], utilizing X-ray photoemission electron microscopy (XPEEM) [2]. Generally, the magnetization is found to be determined by an easy-plane anisotropy. Within 90° domain walls, a quasi-ordered phase (QOP), consisting of a continuous rotation of the in-plane magnetization of approximately 180°, is observed across length scales up to nearly one micron (Figure 1). These quasi-ordered phases also host a vortex and antivortex [3, 4] (Figure 1), which are pinned to the boundaries with the surrounding domain wall. These experimental findings will be presented in the broader context of magnetic textures, topological phase transitions in 2D materials and possible quantum applications.

References

[1] A.F. May, et al. *ACS Nano* **13**, 4 (2019).
[2] R. Fujita, et al. *ACS Nano* **16**, 7 (2022).
[3] V.L. Berezinskii. *Sov. Phys. JETP* **34**, 610 (1972)
[4] J.M. Kosterlitz, et al. *J. Phys. C: Solid State Phys*. **6**, 7 (1973).

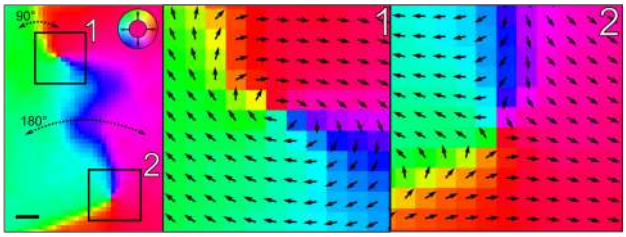


Figure 1. Domain wall topology of 4L Fe_5GeTe_2. The domain wall (shown in yellow) facilitates a ~90° rotation (green → red). The magnetization rotates by ~180° across a quasi-ordered phase (QOP; green → blue → pink). Scale bar = 100 nm. These XPEEM data were acquired at 50 K.

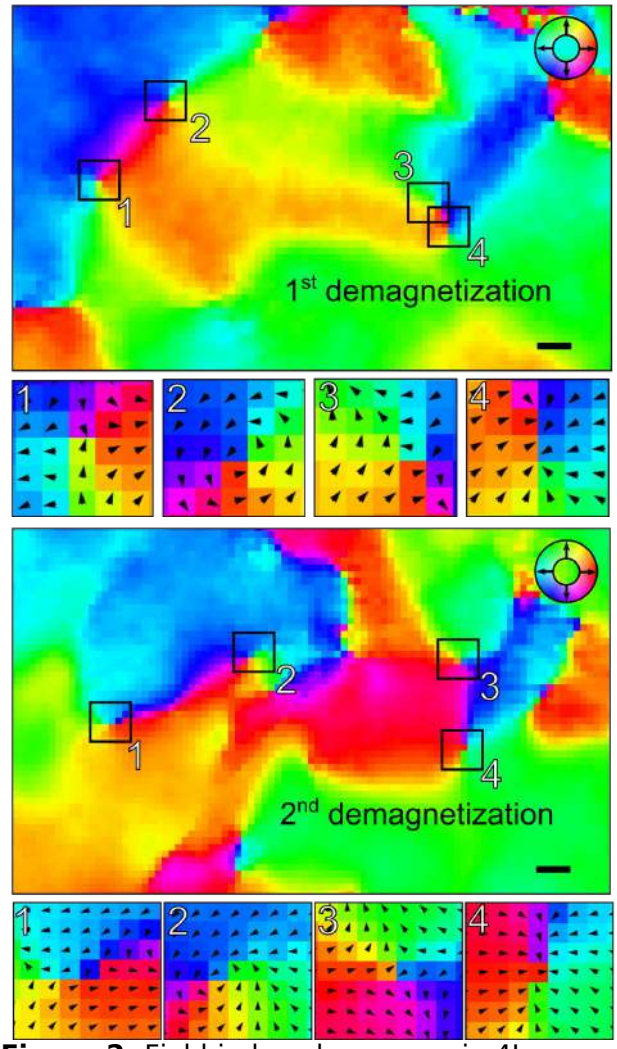


Figure 2: Field-induced response in 4L Fe_5GeTe_2. Field pulses of alternating polarity were applied. In response, textures 2 and 3 move, while textures 1 and 4 remain stationary. Scale bar = 100 nm. These XPEEM data were acquired at 50 K in zero field.

Magnetic properties of MBE-grown $MnSb_2Te_4$

Carmen Gómez Carbonell[1,2]
Thomas Guillet [1,2], Adriana I. Figueroa[1,3], Sergio O. Valenzuela[1,4]

1. *Institut Català de Nanociència I Nanotecnologia, UAB Campus, Bellaterra (Barcelona), Spain*
2. *Universitat Autònoma de Barcelona, Bellaterra, 08193 Barcelona, Spain*
3. *Universitat de Barcelona, 08028 Barcelona, Spain*
4. *Institució Catalana de Recerca i Estudis Avançats (ICREA), 08010 Barcelona, Spain*
carmen.gomez@icn2.cat

carmen.gomez@icn2.cat

Abstract

Magnetic topological insulators (TIs) are expected to open new doors in the field of spintronics, electronics, quantum computation and metrology. $MnSb_2Te_4$ has attracted great interest due to its ferromagnetic behaviour, thanks to Mn-Sb antisites [1], and its relatively high Curie temperature. In this work we study the MBE growth of highly crystalline $MnSb_2Te_4$ layers. SQUID magnetometry under zero–field-cooled (ZFC) show a Curie temperature around 40K and the average magnetic moment per Mn atom of the order of 1–1.5μB, similar to that of bulk $MnSb_2Te_4$ single crystals [2]. Ferromagnetism is demonstrated by the M(H) hysteresis loops, magnetotransport measurements and x-ray magnetic circular dichroism (XMCD). Finally, transmission electron microscopy (TEM) reveals that Mn is incorporated as a structural component to form septuple layers (SLs) with the presence of Mn-Sb anitisites.

References

[1] Ido Levy et al. Cryst. Growth Des.2022, 22, 3007-3015.
[2] S. Wimmer, et al. Advanced Materials, volume 33, issue 42, (2021)

Figures

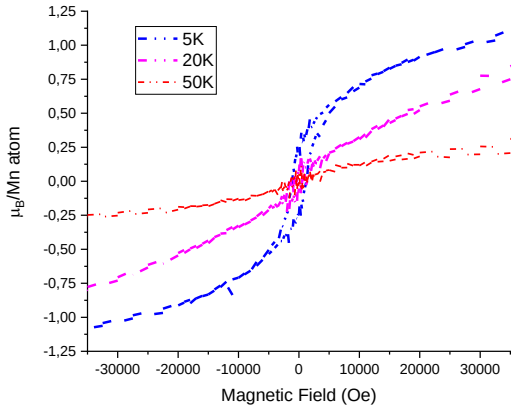


Figure 1: Magnetization in out of plane magnetic fields measured of 40 nm $MnSb_2Te_4$.

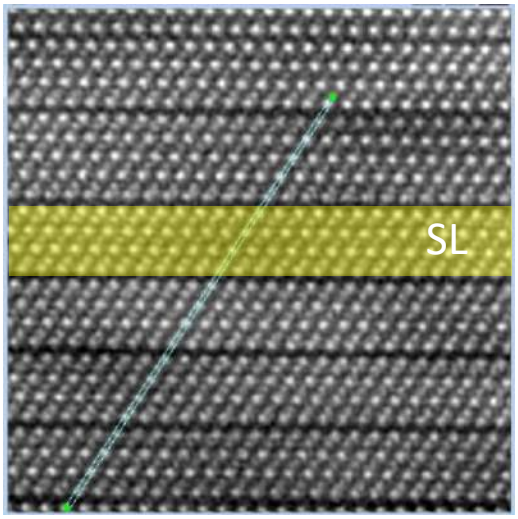


Figure 2: Cross-sectional HAADF-STEM image of 30nm $MnSb_2Te_4$.

Exploration of Topological Magnetic Objects at Interfaces using Resonant Elastic X-Ray Scattering

Speaker: Thorsten Hesjedal[1,2]
Shilei Zhang[3], Gerrit van der Laan[2]

[1]Clarendon Laboratory, University of Oxford, Parks Road, Oxford, OX1 3PU, UK; [2]Diamond Light Source, Harwell Science and Innovation Campus, Didcot, OX11 0DE, UK; [3]School of Physical Science & Technology, ShanghaiTech University, Shanghai 200031, China

Thorsten.Hesjedal@physics.ox.ac.uk

A major challenge in topological magnetism lies in the three-dimensional (3D) exploration of their magnetic textures. A recent focus has been the question of how 2D skyrmion sheets vertically stack to form distinct types of 3D topological strings, what happens to these strings when they are clamped at an interface, how these topological objects couple across interfaces of dissimilar materials, and how these states can be further manipulated?

In this talk, I will present an overview of the capabilities of polarization- and energy-dependent resonant elastic x-ray scattering (REXS) for the study of three-dimensional structural variations of magnetic skyrmions [1-4] and related topological objects, such as chiral bobber lattices [5], hybrid skyrmions [6], and the folding and unfolding of magnetic skyrmion strings [7].

References

[1] S. L. Zhang *et al.*, *Phys. Rev. B* **93**, 214420 (2016). DOI.
[2] S. L. Zhang *et al.*, *Phys. Rev. B* **96**, 094401(2017). DOI.
[3] S. Zhang *et al.*, *Phys. Rev. Lett.* **120**, 227202 (2018). DOI.
[4] S. Zhang *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **115**, 6386 (2018). DOI.
[5] K. Ran *et al.*, Phys. Rev. Lett. **126**, 017204 (2021). DOI.
[6] K. Ran *et al.*, *Nano Lett.* **22**, 3737 (2022), DOI.
[7] Haonan Jin *et al.*, *Nano Lett.* **23**, 5164 (2023), DOI

Figures

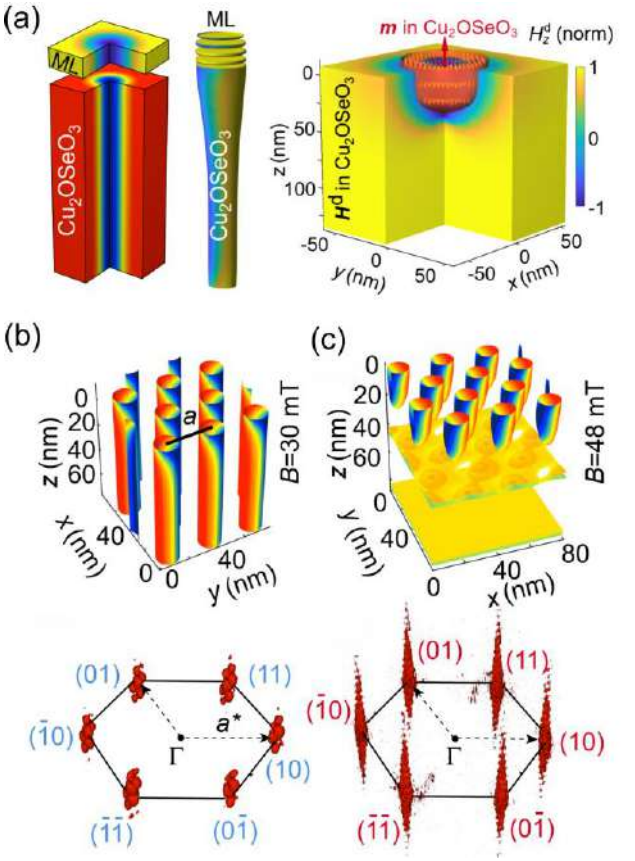


Figure 1: (a) Creation of a chiral bobber structure via heterostructure engineering by joining two different skyrmion species with comparable lateral dimensions. (b) Magnetic truncation rod analysis of (b) skyrmions and (c) chiral bobbers.

Ferromagnetic hybrid nanostructure and its zero-field application

Yu Liu[1]

Saulius Vaitiekėnas[1], Sara Martí-Sánchez[2], Sean Hart[3], Zheng Cui[3], Charles M. Marcus[1], Jordi Arbiol[2], Kathryn A. Moler[3], Peter Krogstrup[4]

[1] *Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark.*
[2] *ICREA & Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Campus UAB, Bellaterra, 08193 Barcelona, Catalonia, Spain.*
[3] *Department of Applied Physics, Stanford University, Stanford, California 94305, USA.*
[4] *NNF Quantum Computing Programme, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark.*

yu.liu@nbi.ku.dk

Material development plays a vital role in the search for topological states that have been predicted to be formed in semiconductor (SE) nanowires coupled to conventional superconductors (SUs) [1-2]. This prediction has been followed by a series of experiments that are consistent with the predictions [3-4]. In the system, the Zeeman energy, that is required for hybrid nanowires to enter the topological phase, is provided by external magnetic fields exceeding the induced gap, which is detrimental to the parent super-conductivity. Is it possible to further develop hybrid materials and thus minimize the need for the external field? It is well-known that materials combining ferromagnetism and semi-conductivity, that is ferro-magnetic insulators (FMIs), have been developed for spin-based electronics, and intrinsic magnetism can be induced by them. The ferromagnetic hybrid nanowires, which integrates a FMI into SE–SU NWs, i.e. SE–SU–FMI NWs, is derived from this idea. In this talk, I will present our recent works on epitaxial SE–SU–FMI InAs-Al-EuS hybrid nanowires in-situ grown in a molecular beam epitaxy system [5-6]. The results suggest that these hybrid NWs have a superconducting hard gap, a hysteresis transport behaviour and a shape-defined magnetic single domain structures based on well-controlled epitaxy. They can strongly support the zero-field applications of quantum devices, e.g., revealing the evidence of zero-field topological superconductivity in InAs-Al-EuS NW based devices [7].

References

[1] R. M. Lutchyn et al, Phys. Rev. Lett., 105 (2010) 077001
[2] Y. Oreg et al, Phys. Rev. Lett., 105 (2010) 177002
[3] A. Das et al, Nat. Phys., 8 (2012) 887
[4] R. M. Lutchyn et al, Nat. Rev. Mater., 3 (2018) 52
[5] Y. Liu et al, ACS Appl. Mater. Interfaces, 12 (2020) 8780
[6] Y. Liu et al, Nano Lett., 20 (2020) 456
[7] S. Vaitiekėnas et al, Nat. Phys., 17 (2021) 43

Figures

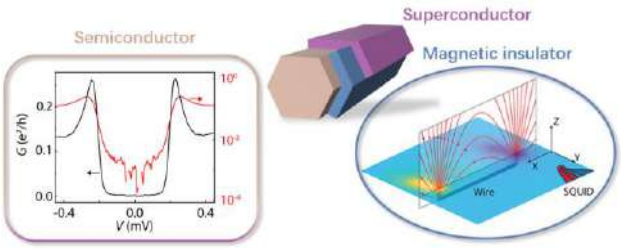


Figure 1: SE–SU–FMI NWs as a promising platform for zero-field applications. Middle panel: schematic of InAs-Al-EuS NWs; left panel: superconducting hard gap of InAs-Al-EuS NWs; right panel: magnetic single domain of InAs-Al-EuS NWs.

Topologically protected spin chirality beyond room temperature

Ferhat Katmis[1,2]
Valeria Lauter[3], Luri Brandt[4], Clodoaldo I. L. de Araujo[4], Arash M. Cheghabouri[5], Rawana Yagan[5], Don Heiman[6], Mehmet C. Onbasli[5,7], & Jagadeesh S. Moodera[1,2,†]
[1] Department of Physics, Massachusetts Institute of Technology, Cambridge, MA-02139, USA
[2] Francis Bitter Magnet Laboratory & Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, MA-02139, USA
[3] Neutron Scattering Division, Neutron Sciences Directorate, Oak Ridge National Laboratory, Oak Ridge, TN-37831, USA
[4] Departamento de Física, Universidade Federal de Viçosa, Viçosa, 36570-900, Brazil
[5] Department of Electrical and Electronics Engineering, Koç University, Istanbul, 34450, Türkiye
[6] Department of Physics, Northeastern University, Boston, MA 02115, USA
[7] Department of Physics, Koç University, Istanbul, 34450, Türkiye†
katmis@mit.edu (F.K.), moodera@mit.edu (J.S.M.), monbasli@ku.edu.tr (M.C.O.)

Topological magnetic heterostructures are promising layers with unique unidirectional magnetotransport properties and band structures that enable a wide range of new physics and advanced spin polarised devices. Here, we grew magnetically coupled heterostructures of topological insulators (Bi_2Se_3) sandwiched between two ferromagnetic insulator (FMI) layers (EuS) to create FMI/TI/FMI tri-layers and elucidated the induced spin chirality using Lorentz transmission electron microscopy (LTEM), superconducting quantum interference device hysteresis and temperature-dependent magnetism measurements (SQUID), polarized neutron reflectometry (PNR) and micromagnetic modelling.

The robust (unique) interfacial DMI brings the magnetic order of the system above room temperature. This steady-state magnetization profile through the TI is not commensurate with the crystal or interface chemical structure. The conical phase is located along the growth direction, (000L), where the total moment rotates depending on the interaction strength. The conical phase is getting more energetically stable at much lower temperatures of 4 K (below the Curie temperature of EuS) because of the local moment saturation. The modulated phase is a consequence of competing magnetic interaction between bulk EuS and interface magnetism due to DMI, resulting in a particular topological spin configuration at higher temperatures. Above the Curie temperature, the bulk in-plane component of magnetism due to EuS smears out and the out-of-plane component along the growth direction remains. Finally, the trilayer structure undergoes a phase transition to either a ferromagnetic or a skyrmion phase, where real space observation is confirmed by Lorentz transmission electron microscopy. Such an exotic state of matter exists up to room temperature and above and is quite stable against any external perturbations.

The origin of magnetism observed in the LTEM, SQUID and PNR data at different temperatures has been investigated by developing micromagnetic models based on the Landau-Lifshitz-Gilbert formalism. Experimental observations of the chiral spin were reproduced using micromagnetic models and their numerical solutions. Phase diagrams of the triangular skyrmion lattice at 0 K and room temperature have been generated with a variety of saturation magnetizations and DMI settings. The parameter window M_s and DMI that stabilizes the skyrmion lattice in the models are consistent with the earlier experimental temperature dependent SQUID results [1] with M_s~17 ± 5 kA/m and D_i (DMI) ~ 4.56 ± 0.78 μJ/m^2, which was not measured directly previously.

The experimental and modelling results suggest that the chiral nature is driven by the interfacial DMI between adjacent FMI and TI. The coupling strength of the two interfaces increases the possibility of forming a non-collinear spin texture and a skyrmion lattice. Our results might pave the way for engineering new strong interlayer coupling effects in topological magnetism for room temperature operation.

References

[1] F. Katmiş, Nature, 533(2016) 513-6.

Photo-induced electronic and spin topological phases in monolayer single-element ferroelectrics

Bo Peng[1, *]
Gunnar F. Lange[1], Daniel Bennett[2], Kang Wang[3], Robert-Jan Slager[1], and Bartomeu Monserrat[1, 3]

[1] *Theory of Condensed Matter Group, Cavendish Laboratory, University of Cambridge, UK*
[2] *John A. Paulson School of Engineering and Applied Sciences, Harvard University, USA*
[3] *Department of Materials Science and Metallurgy, University of Cambridge, UK*

* bp432@cam.ac.uk

Abstract

Monolayer group-V materials exhibit rich physics such as single-element ferroelectricity, nontrivial topology, varied spin-orbit coupling, and light-induced structural dynamics. We show with *ab initio* calculations that light can induce hidden transient phases in both the ferroelectric and paraelectric monolayers. We illustrate the nontrivial topological character of these system by using the recently introduced idea of spin bands and spin-resolved Wilson loops, and show that the topology changes via the closing of the respective band gaps in the presence or absence of photo-induced structural phase transitions. The evolution of topological edge states is also discussed. Our study provides multiple strategies to tailor electronic and spin topology via ultrafast control of photo-excited carrier and structural dynamics.

References

[1] B Peng, GF Lange, D Bennett, K Wang, RJ Slager and B Monserrat. *Physical Review Letters*, in press (2024)

Figures

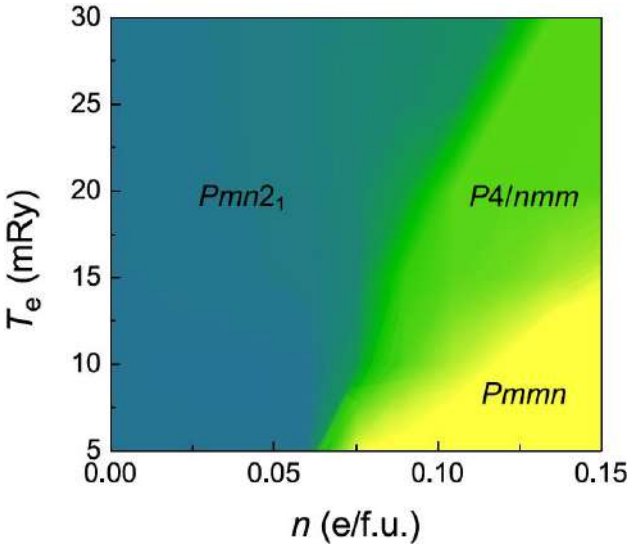


Figure 1: Phase diagram for monolayer ferroelectric $Pmn2_1$ Bi as a function of photoexcited carrier density n in electron-hole pairs per unit cell (e/f.u.) and electronic temperature T_e in mRy.

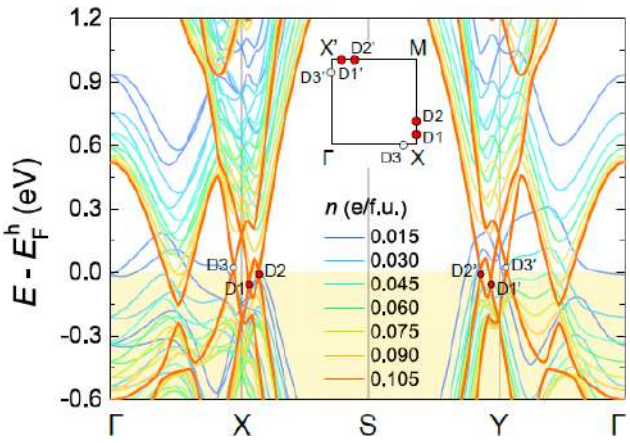


Figure 2: Band structure of $Pmn2_1$ Bi as a function of n for T_e = 20 mRy, with the quasi-Fermi level for holes E_F^h set to zero. At n = 0.105 e/f.u., the doubled quantum spin Hall insulator becomes a 2D Dirac semimetal with space group $P4/nmm$. The inset shows the 2D Brillouin zone with the Dirac points denoted as D.

Fast optical-manipulation of a coherent hole-spin in an open microcavity

Timon L. Baltisberger[1]
Mark R. Hogg[1], Nadia O. Antoniadis[1], Malwina A. Marczak[1], Giang N. Nguyen[1], Alisa Javadi[1], Rüdiger Schott[2], Sascha R. Valentin[2], Andreas D. Wieck, Arne Ludwig[2], and Richard J. Warburton[1]
1 – University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland
2 - Ruhr-Universität Bochum, Universitätsstrasse 150, 44780 Bochum, Germany
timon.baltisberger@unibas.ch

Spin-photon interfaces are a key ingredient for quantum technologies, enabling quantum information to be mapped between stationary spins and photons travelling at the speed of light. Spin-photon interfaces are also promising as a deterministic source of entangled photonic graph-states [1], which are resource states for measurement-based quantum computation and one-way quantum repeaters. The ideal spin-photon interface combines both a highly coherent spin and coherent, efficient photon emission.

Self-assembled semiconductor quantum dots (QDs) are demonstrated excellent on-demand sources of indistinguishable, single-photons. Gated devices allow deterministic charging of the QDs, and impressive progress has been achieved in mitigating the impact of magnetic noise from the host nuclear spins on electron-spin decoherence [2]. Although the ingredients for a leading spin-photon interface (high-fidelity spin control, long coherence times, high-efficiency photon extraction) have been demonstrated in individual quantum dot experiments, combining all these components at a state-of-the-art level is an important outstanding challenge.

Here, we demonstrate a system that combines the best of all worlds: we achieve fast and high-fidelity coherent control of a QD hole-spin, a spin decoherence-time T_2^* of 500 ns, all on a QD embedded in a tunable open microcavity with an exceptionally high end-to-end single photon source efficiency. Many spin rotations can be carried out and many photons can be created before the spin loses its coherence; the photons are extracted with high efficiency. We use a microwave-modulated control scheme [3], making coherent rotations around an arbitrary Bloch sphere axis trivial and allowing all-optical cooling of the host nuclei to extend the hole spin coherence. We achieve a maximum π-pulse fidelity of 98.7%, and ultra-fast Rabi frequencies above 1 GHz. Our work demonstrates the potential for semiconductor QDs as fast, efficient, and coherent spin-photon interfaces.

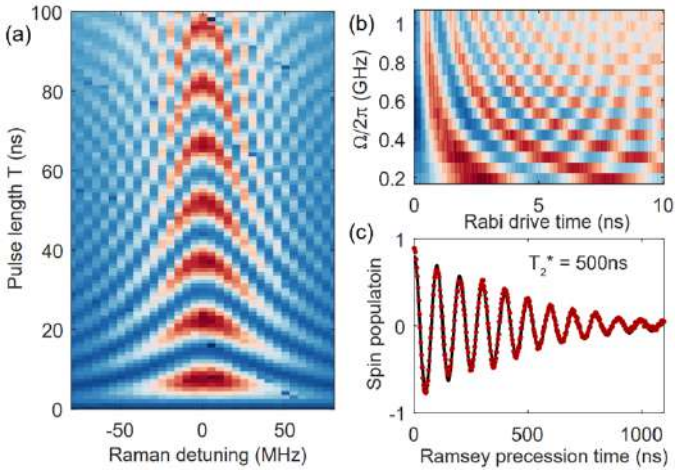


Figure 1: (a) High-quality Rabi chevron pattern obtained following nuclear bath cooling. (b) Cavity-enhanced ultra-fast spin control, showing Rabi oscillations up to 1 GHz Rabi frequency. (c) Ramsey interferometry performed after nuclear bath cooling, demonstrating T_2^*=500 ns.

References
[1] P. Thomas *et al.*, Nature, 608 (2022) 677-681
[2] D.M. Jackson *et al.*, Phys. Rev. X, 12 (2022) 031014
[3] J.H. Bodey *et al.*, npj Quantum Information, 5 (2019) 95

Statistical properties of light emission in current-driven single-molecule STM-junctions

Andrés Bejarano[1,2], Rémi Avriller[2], Thomas Frederiksen[1,3], and Fabio Pistolesi[2]

[1] Donostia International Physics Center (DIPC), E-20018 Donostia-San sebastián, Spain
[2] Univ. Bordeaux, CNRS, LOMA, F-33405 Talence, France
[3] Ikerbasque, Basque Foundation for Science, E-48013 Bilbao, Spain

andres.bejarano@dipc.org

Abstract

The atomic resolution of the scanning tunnelling microscope (STM) enables fluorescence on the scale of single molecules. Recent experiments demonstrate the change from a broad plasmonic resonance to a sharp peak in the photon emission spectrum, by moving the tip laterally from the bare substrate towards the molecule [1].
These systems are of particular interest to the quantum cryptography community because they have been reported to emit non-classical light (antibunching) [2, 3].
We propose a microscopic model based on the quantum master equation approach for the reduced density matrix of the central system. In particular, we focus on the description of the emission spectrum, conductivity and photon coherence. Additionally, by using full counting statistics, we calculate the Fano factor and correlations between emission and currents. The model provides a simple framework to explain the features observed experimentally in the photon spectrum and the electronic conductance.

References

[1] B. Doppagne et al., Science (2018) 361, 251
[2] P. Merino et al., Nat. Commun. (2015) 6, 8461
[3] L. Zhang et al., Nat. Commun. (2017) 8, 580

Figures

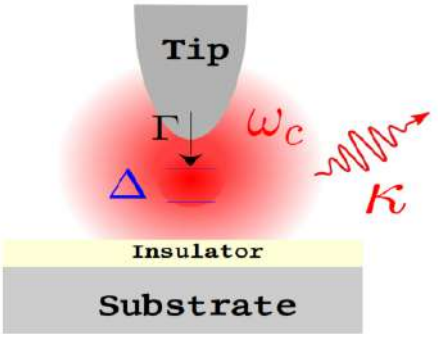


Figure 1: Schematic of two metallic electrodes forming a plasmonic nanocavity. A two-level system in the nanogap couples to the confined electromagnetic field. Electrons can tunnel from the tip to the molecule, activating the fluorescence of the molecule.

Quantum simulator based on electromechanically coupled carbon nanotube

Marta Cagetti
Stefan Forstner, Roger Tormo Queralt, Cristoffer Moller,David Czaplewsky, Adrian Bachtold
ICFO-The Institute of Photonic Science, Av. Carl Friedrich Gauss, Barcelona, Spain
Marta.cagetti@icfo.eu

Mechanical resonators are systems with high-quality factors and can easily couple to a wide range of forces rendering them excellent candidates for sensing. They are also increasingly promising candidates for quantum information technology. In particular, capacitively coupled, suspended carbon-nanotubes (CNTs) can enable new research-avenue due to their unparalleled electromechanical coupled strength [1] . Quantum dots (QD) have been defined in nanotubes to read out and control the mechanical motion electrically [2]. One of the main difficulties in quantum dots defined in a carbon nanotube is to measure the system's dynamics when the electrons are bounded in the quantum dot, where common techniques based on conductance measurements are not applicable. This state is however interesting for the realization of electro-mechanical qubits , ultraprecise sensors, and quantum simulators [3-4]. The target is to employ CNT-based sensing dots to carry out real-time measurements of a carbon nanotube electromechanical system hosting a double quantum dot at a timescale faster than the mechanical period. This can enable exploration of interesting phenomena, especially in the context of quantum simulator

Figures

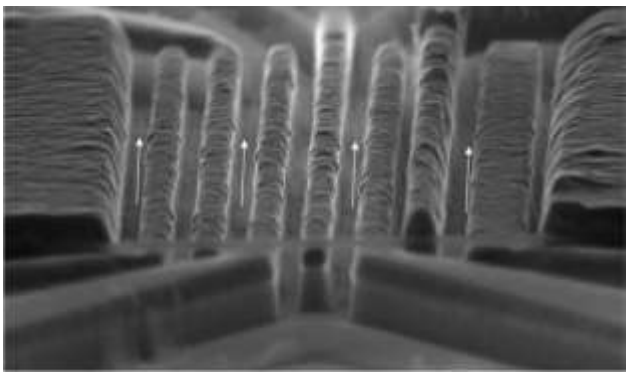


Figure 1: SEM imagine of a suspended CNT(indicated by white arrow). The CNT is suspended over 5 electrodes used to define QD.
An extra electrode has been added to define a 3th QD used as charge sensor

References

[1] Cleland, Foundations of nanomechanics: from solid-state theory to device applications. Springer Science Business Media, 2013.
[2] B. Lassagne et al., Science, 5944 (2009) 1170-1110
[3] F.Pistolesi et al., Phys. Rev X, 3 (2021) 031027
[4] U. Bhattacharya et al., Nano Lett. 21 (2021) 9661-9667

Remote spin-spin interactions mediated by superconducting circuits for quantum applications.

C. del Río[1]
Marcos Rubín[1], D. Rodriguez[2], M. C. de Ory[2], D. Granados[3], D. Pinkowicz,[4] N. Crivillers,[5] M. C. Pallarés,[1] A. G. Lostao,[1] D. Zueco[1], M. J. Martínez-Pérez[1], A. Gomez[2], F. Luis[1]

1. Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC - Universidad de Zaragoza, 50009 Zaragoza, Spain
2. Centro de Astrobiología (CAB) CSIC-INTA, 28850 Torrejón de Ardoz, Madrid, Spain
3. IMDEA-Nanoscience, Cantoblanco,28049 Madrid, Spain
4. Jagiellonian University, Faculty of Chemistry, Krakow, Poland.
5. Instituto de Ciencia de Materiales de Barcelona, CSIC, Barcelona, Spain.
cdrio@unizar.es

Hybrid platforms combining molecular spins and superconducting circuits allow scaling up quantum computational resources by either exploiting the chemical design of molecules behaving as multiple qubits or qudits or via a proper engineering of the superconducting circuit [1-3]. Here, we address experimentally this second option. We focus on circuits based on lumped element LC resonators. Their relevant properties, resonance frequency ω_r and quality factor Q, can be widely tuned without affecting the transmission through the readout line. Here, we realize resonator pairs able to introduce communication channels between remote spin qubit ensembles (Fig. 1). A superconducting chip consisting of seven LC resonator couples has been designed and fabricated. Resonators have ω_r ranging from 1.7 GHz to 3.0 GHz, which makes them individually addressable. Couplings between resonators in each pair have been engineered by the design of the two capacitors and their mutual distances. We explore their coupling to free radicals, model *S*=1/2 spin qubits, deposited onto either one or the two inductors of each pair (Fig.2). In the first case, we observe strong coupling of the spin ensemble to "its local" resonator and, besides, to photon modes in its remote companion. In resonator pairs hosting two different organic radicals we have observed evidences for the coherent coupling between the polaritonic light-matter states of both resonators. These experiments provide a method for performing spin resonance on a given specimen at two resonances simultaneously and pave the way for introducing coherent communication channels between two remote spin qubit ensembles, thus for scaling up this hybrid platform.

References

[1] M. D. Jenkins, D. Zueco, O. Roubeau, G. Aromí, J. Majer and F. Luis, Dalton Trans. 45, 16682-16693 (2016)
[2] S. Carretta, D. Zueco, A. Chiesa, Á. Gómez-León, and F. Luis, Appl. Phys. Lett. 118, 240501 (2021)
[3] A. Chiesa, S. Roca, S. Chicco, M.C. de Ory, A. Gómez-León, A. Gomez, D. Zueco, F. Luis, and S. Carretta, Phys. Rev. Applied **19**, 064060 (2023)

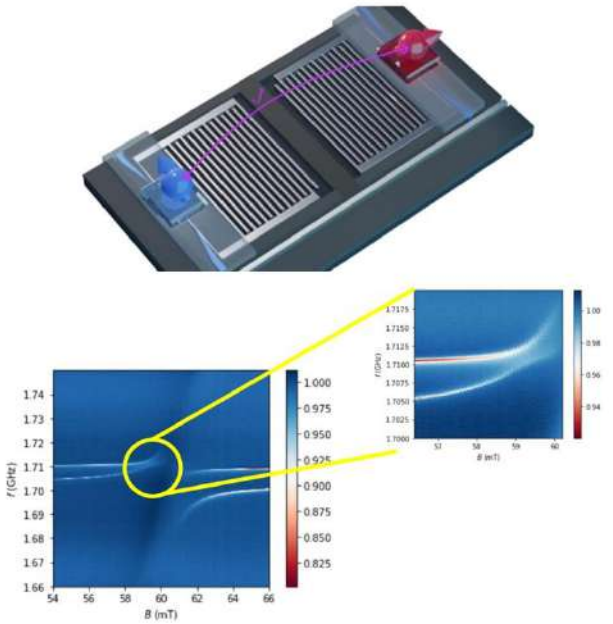


Figure 1: Top: sketch of two coupled resonators hosting two different molecular spin ensembles. Bottom: Microwave transmission data showing an additional anticrossing between two polaritons, which bears evidence of coherent communication between the spin ensembles.

In situ modification of the Quantum Hall effect with cavity vacuum fields

J. Enkner[1]
L. Graziotto[1], F. Appugliese[1], D. Borici[3], M. Beck[1]. C. Reichl[2], W. Wegscheider[2], G. Scalari[1], C. Ciuti[3], and J. Faist[1]

[1]*Institute of Quantum Electronics, ETH Zürich, Zürich 8093, Switzerland*
[2]*Laboratory for Solid State Physics, ETH Zürich, Zürich 8093, Switzerland*
[3]*CNRS, Laboratoire Matériaux et Phénomènes Quantiques, Université Paris Cité, F-75013 Paris, France*
enknerj@phys.ethz.ch

Even in the absence of external illumination, a resonator exhibits modes populated with virtual photons, known as cavity vacuum fields. Placing a complementary split ring resonator (CSRR) around a GaAs-based heterostructure Hall bar, effectively immersing it in cavity vacuum fields, introduces a long-range perturbation that manifests itself effectively in opening a scattering channel for electrons in both bulk and edge states. Using this platform, previous investigations have demonstrated a breakdown of the topological protection of edge states within the integer quantum Hall regime [1]. Instead of the expected quantized Hall resistance and associated zero longitudinal resistance, quantization in Hall plateaus is lost paired with a finite longitudinal resistance. The theoretical interpretation of this effect, termed "cavity-mediated electron hopping" by C. Ciuti [2], describes the anti-resonant interaction between cavity vacuum fields and electrons in neighboring Landau levels, enabling electrons to scatter in and out of topologically protected edge states. This anti-resonant effect decays exponentially in magnetic field, with a decay rate associated to the system's Rabi frequency.

In a recent experiment, we improved the experimental platform by introducing an in situ technique to vary the coupling between the cavity and the electrons inside the Hall bar. Utilizing three Atto cube micro-positioners, we can dynamically align and adjust the position of the 2D cavity plane relative to the Hall bar, enabling selective coupling with the extruding fringing fields of the cavity. This configuration allows for real-time tuning of the coupling as a function of the distance between the cavity plane and the Hall bar sample.
As the resonator is brought closer to the Hall bar, thus increasing the coupling, we observe intriguing phenomena such as the reduction of the g factor and the hardening of the gap for fractional Laughlin states 7/5, 5/3, and 4/3 [Fig. 1].

These experimental findings offer exciting perspectives and hint at the potential emergence of a novel phenomenon within the field of cavity-engineered quantum materials.

References

[1] F. Appugliese, et.al. Science, 375(6584):1030–1034, 2022.
[2] C. Ciuti. Physical Review B, 104(15):155307, 2021.

Figures

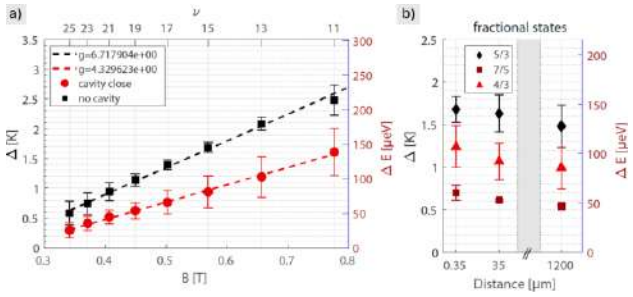


Figure 1: Figure 1a) shows the energy gap of the Zeeman-split states as a function of the magnetic field. From the corresponding linear fit, we infer the g-factor of the system indicated in the legend; in 1b) we show the activation energy for the fractional states.

Dual frame optimization for informationally complete quantum measurements

Laurin E. Fischer (presenting author), Timothée Dao, Ivano Tavernelli, Francesco Tacchino

IBM Quantum, IBM Research Europe – Zürich, Säumerstrasse 4, 8803 Rüschlikon, Switzerland

aur@zurich.ibm.com

Abstract

Randomized measurement protocols such as classical shadows [1] represent powerful resources for quantum technologies, with applications ranging from quantum state characterization and process tomography to machine learning and error mitigation.
Recently, the notion of measurement dual frames, in which classical shadows are generalized to dual operators of POVM effects, resurfaced in the literature [2]. This brought attention to additional degrees of freedom in the post-processing stage of randomized measurements that are often neglected by established techniques.
In this work, we leverage dual frames to construct improved observable estimators from informationally complete measurement samples [3]. While standard classical shadows use a canonical dual frame to build observable estimators, we introduce novel classes of dual frames which can be optimized to reduce the variance of expectation value estimations significantly while retaining computational efficiency, see Figure 1.
Remarkably, this comes at almost no quantum or classical cost, thus rendering dual frame optimization a valuable addition to the randomized measurement toolbox.

References

[1] Huang, Hsin-Yuan, Richard Kueng, and John Preskill. *Nature Physics* 16, no. 10 (2020): 1050-1057

[2] Innocenti, Luca, Salvatore Lorenzo, Ivan Palmisano, Francesco Albarelli, Alessandro Ferraro, Mauro Paternostro, and G. Massimo Palma. *PRX Quantum* 4, no. 4 (2023): 040328.

[3] Fischer, Laurin E., Timothée Dao, Ivano Tavernelli, and Francesco Tacchino. *arXiv preprint arXiv:2401.18071* (2024).

Figures

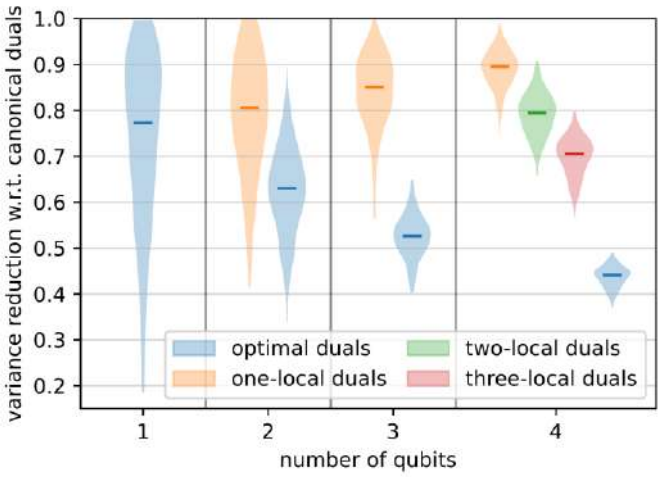


Figure 1: Variance reduction for the estimation of expectation values compared to standard classical shadows for different types of empirical frequencies dual frames, taken from [3]. Violin plots show the distribution over 200 random pairs of states and observables for the indicated qubit number.

Experimental Realization of a Quantum Zero-Knowledge Proof

Marta Irene Garcia Cid
Dileepsai Bodanapu, Alberto Gatto, Paolo Martelli, Vicente Martin and Laura Ortiz

Indra Sistemas S.A., 28108, Madrid, Spain
Universidad Politecnica de Madrid, 28660, Madrid, Spain
Cohaerentia S.r.l, 20133, Milano, Italy
Politecnico di Milano, 20133, Milano, Italy

migarcia@indra.es

An interactive quantum zero-knowledge protocol [1] is proposed and demonstrated in modified Quantum Key Distribution devices [2][3] executing two fundamental cases between a verifier and a prover who pre-share a secret. In the first case, all players are honest, while in the second case, one of the users is a malicious player. The acceptance or rejection of the proof is determined by the Quantum Bit Error Rate (QBER) where an increase around 25% is demonstrated in the second case over the case of honesty. Additional proofs have also been carried out for distances up to 60 km between verifier and prover. The security and robustness of the protocol has been analysed, demonstrating its completeness, soundness and zero-knowledge properties.

References

[1] S. Goldwasser, S. Micali and C. Rackoff. The knowledge complexity of interactive proof-systems, ACM, 2019
[2] C.H. Bennett and G. Brassard. Quantum cryptography: Public key distribution and coin tossing, TCS (1), 7-11, 2014
[3] A. Gatto et al. A BB84 QKD field-trial in the Turin metropolitan area, PSC Conference, Vol. 2 OSA Technical Digest (OPG, 2021), paper Tu1A.

Figures

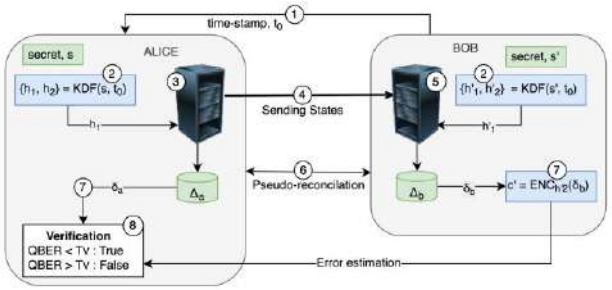


Figure 1: Quantum Zero Knowledge Protocol

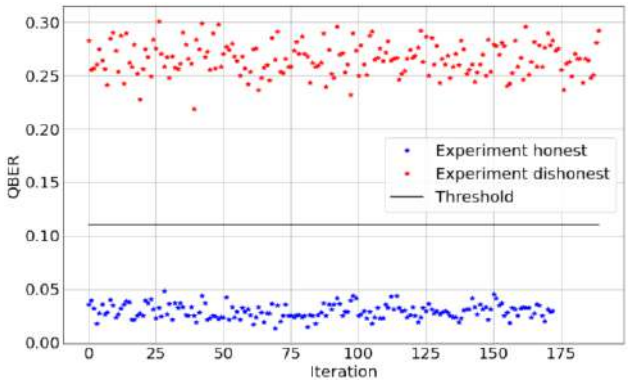


Figure 2: QBER Comparison between honest and dishonest cases

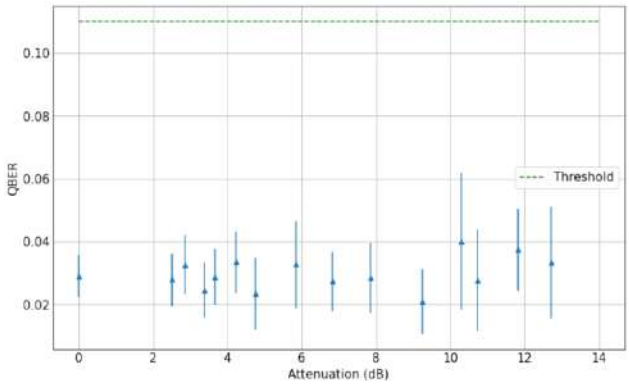


Figure 3: QBER versus link losses in the honest case

Overhead-constrained circuit knitting for variational quantum dynamics

Gian Gentinetta
Friederike Metz, Giuseppe Carleo

École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland
gian.gentinetta@epfl.ch

Simulating the dynamics of large quantum systems is a formidable yet vital pursuit for obtaining a deeper understanding of quantum mechanical phenomena. While quantum computers hold great promise for speeding up such simulations, their practical application remains hindered by limited scale and pervasive noise. In this work, we propose an approach that addresses these challenges by employing circuit knitting [2-3] to partition a large quantum system into smaller subsystems that can each be simulated on a separate device. The evolution of the system is governed by the projected variational quantum dynamics (PVQD) [2] algorithm, supplemented with constraints on the parameters of the variational quantum circuit, ensuring that the sampling overhead imposed by the circuit knitting scheme remains controllable. We test our method on quantum spin systems with multiple weakly entangled blocks each consisting of strongly correlated spins, where we are able to accurately simulate the dynamics while keeping the sampling overhead manageable. Further, we show that the same method can be used to reduce the circuit depth by cutting long-ranged gates.

References

[1] G.G., F. Metz and G. Carleo. *arXiv:2309.0785* (2023).
[2] S. Bravyi, G. Smith, J. A. Smolin. *Phys. Rev. X 6, 021043* (2016).
[3] K. Mitarai, K. Fujii. New Journal of Physics 23, 023021 (2021).
[4] S. Barison, F. Vicentini, G. Carleo. *Quantum 5, 512* (2021).

Figures

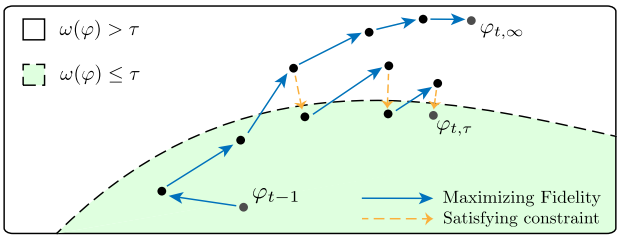


Figure 1: Solving the PVQD optimization problem with a constrained sampling overhead. The fidelity in the PVQD-loss is maximized using gradient descent. Once the sampling overhead imposed by the parameters exceeds the threshold, the corresponding parameters are projected back to satisfy the constraint.

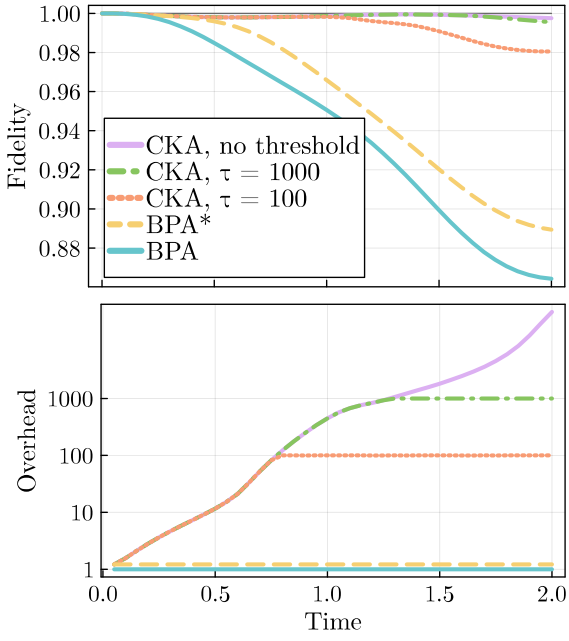


Figure 2: Simulating the dynamics of a TFIM spin chain consisting of 3 blocks with 2 spins each. On the top panel, we show the fidelity of our time evolved ansatz with respect to the exact solution. The lower panel shows the sampling overhead required to measure the full circuit on multiple quantum devices using the circuit knitting scheme. We compare a block product approximation (BPA) with the circuit knitting ansatz (CKA) with different thresholds for the sampling overhead.

Empowering Qudit Quantum Computing by Traversing the Dual Bosonic Ladder

Noah Goss
Long Nguyen, Karthik Siva, Yosep Kim, Ed Younis, Bingcheng Ching, Akel Hashim, David I. Santiago, Irfan Siddiqi

Department of Physics, University of California, Berkeley

noahgoss@berkeley.edu

High-dimensional quantum information processing has emerged as a promising avenue to transcend hardware limitations and advance the frontiers of quantum technologies. Harnessing the untapped potential of qudits necessitates the development of quantum protocols beyond the established qubit methodologies. Here, we present a robust, hardware-efficient, and scalable approach for operating multidimensional solid-state systems using Raman-assisted two-photon interactions. We then utilize them to construct extensible multi-qubit operations, realize highly entangled multidimensional states including atomic squeezed states and Schrödinger cat states, and implement programmable entanglement distribution along a qudit array. Our work illuminates the quantum electrodynamics of strongly driven multi-qudit systems and provides the experimental foundation for the future development of high-dimensional quantum applications such as quantum sensing and fault-tolerant quantum computing.

References

[1] Nguyen*, Goss*, et al., *arXiv:2312.17741* (2023)

Figures

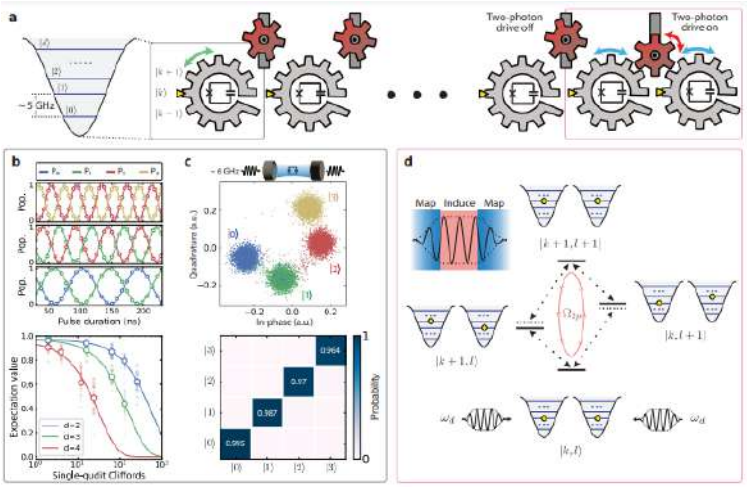


Figure 1: Overview of the experiment. Each qudit in the array is fully programmable, with single shot qudit state readout. Neighbouring qudits are entangled via a two-photon Raman process.

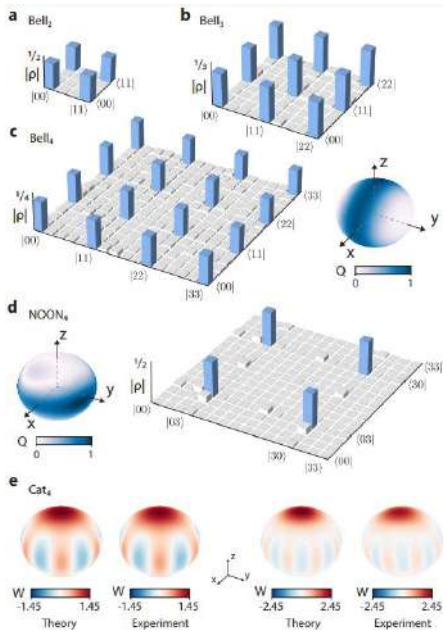


Figure 2: Experimental tomography results of high-dimensional qudit states generated by two-photon Raman entanglement.

Telecom O-band quantum dots in an open access fiber-based microcavity

Jonas Grammel[1],
Nam Tran[2], Julian Maisch[2], Simone Luca Portalupi[2], Peter Michler[2], David Hunger[1]

1) Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Wolfgang-Gaede Str. 1, Karlsruhe 76131, Germany

2) Institut für Halbleiteroptik und Funktionelle Grenzflächen, University of Stuttgart, Allmandring 3, Stuttgart 70569, Germany

jonas.grammel@kit.edu

Semiconductor single photon sources are fundamental building blocks for quantum information applications. The current limitations of such quantum dot sources are the emitting wavelength and insufficient collection efficiency in fiber-based implementations. For low optical attenuation in quantum network applications, it is favourable to get single photons at telecom wavelengths. Here, we present a comprehensive study of semiconductor quantum dots (QDs), emitting in the telecom O-band [1], integrated in an open fiber-cavity [2]. We utilize the full tunability in all spatial dimension to investigate the lifetime shortening of spatially and spectrally varying samples. The outstanding emitter performances of semiconductor QDs, in terms of brightness, indistinguishability and single-photon purity, have been shown on the open cavity platform for near infrared wavelengths [3]. However, our cavity's inherent fiber coupling holds promise for enhancing these properties further and allowing an application-oriented use case as fiber-pigtailed single photon source [4]. For a full description of our platform, we did a thorough theoretical description comprising different cavity-emitter regimes and the influence of vibrational noise. We show that the current limitations of our platform are (in descending order of importance) the natural linewidth of the emitter, the surface roughness and surface defects of the advanced MOVPE growth of the QDs and the vibrational noise of the system.

References

[1] Matthias Paul et al., Appl. Phys. Lett. 106 (2015), 122105
[2] David Hunger et al., New J. Phys. 12 (2010) 065038
[3] Natasha Tomm et al., Nature Nanotechnology volume 16 (2021), pages 399–403
[4] Alexander Schlehahn, Scientific Reports volume 8 (2018), Article number: 1340

Figures

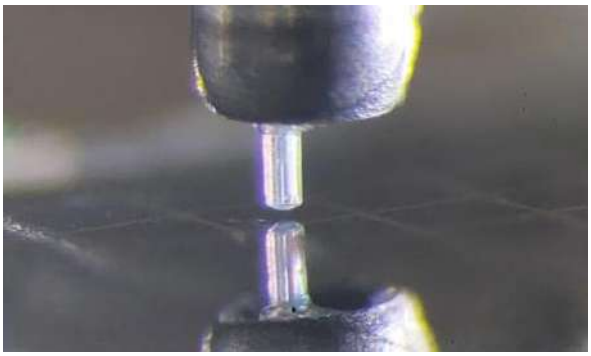


Figure 1: Image of the setup. The fiber (top) is held above the semiconductor sample and mirrored in the surface (bottom). The semiconductor and fiber tip form the cavity.

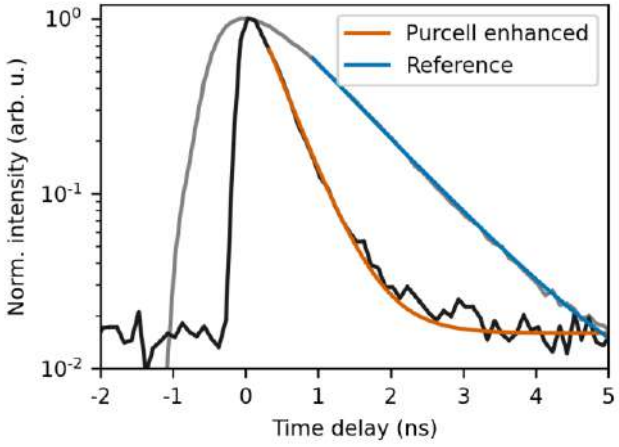


Figure 2: Time-resolved single-photon counting and lifetime shortening inside the fiber-based microcavity. The decay time is shortened by a factor of 2.45.

Superconducting MoSi Thin Films for Single-Photon Detection

Stefanie Grotowski[1]
L. Zugliani[2], R. Flaschmann[2], C. Schmid[2], S. Strohauer[1], F. Wietschorke[2], S. Ernst[1], M. Althammer[3], R. Gross[3], K. Müller[2], J. J. Finley[1]

[1]*Walter Schottky Institute, TUM School of Natural Sciences, Technical University of Munich, Germany*
[2]*Walter Schottky Institute, TUM School of Computation, Information and Technology, Technical University of Munich, Germany*
[3]*Walther-Meißner-Institute, Bayerische Akademie der Wissenschaften, Germany*

stefanie.grotowski@wsi.tum.de

Superconducting Nanowire Single-Photon Detectors (SNSPDs) are a leading technology for the detection of faint light. They combine high system detection efficiency and high maximum count rates, while maintaining low dark counts and low timing jitter. Thin MoSi superconducting films are of very strong interest for single-photon sensing in the near to mid-infrared regime [1, 2, 3] due to their amorphous character that allows reproducible lithography.

In this contribution, we show our recent progress on the deposition of MoSi thin films on Si/SiO_2 substrates, determine their microscopic properties optimize them for SNSPDs operating in the IR regime. By systematically varying the deposition parameters we vary the stoichiometry and map the superconducting metrics, aiming at high critical temperatures (T_c). The stoichiometry and crystalline phase of the thin films was shown to be controllable via the deposition conditions. Grazing incidence X-ray diffraction measurements show the presence of a polycrystalline phase above a critical concentration of 80% molybdenum. Fully optimized films exhibited a maximum T_c=8.4K for 20nm thick $Mo_{0.71}Si_{0.29}$ and T_c=6.2K for 4.5nm films, respectively.

Finally, we defined SNSPDs to link the detector performance to the obtained superconducting metrics. Figure 1 shows normalized detector count rates for different operating temperatures, where the switching current of the detector increases with lower temperature. This facilitates higher bias currents leading to a saturating count rate (indicating unitary internal quantum efficiency) and low dark count rate. Figure 2 shows the wavelength dependent sensitivity with the expected shift of the count rate curve towards higher bias levels for longer wavelengths. Our results provide design rules for optimizing the performance of MoSi SNSPDs.

References

[1] Yu P Korneeva et al, Supercond. Sci. Technol. 27 095012 (2014).
[2] Varun B Verma et al, Optics Express 23, 033792 (2015).
[3] Dileep V Reddy et al, Optica 7, 1649-1653 (2020).

Figures

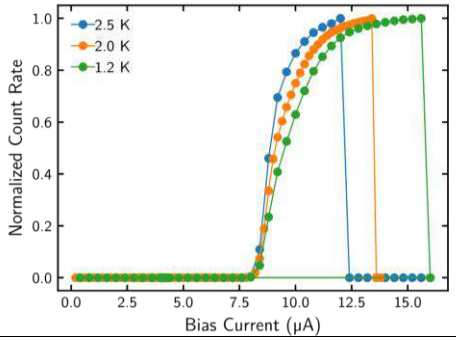


Figure 1: Normalized count rates at different operating temperatures of the SNSPD

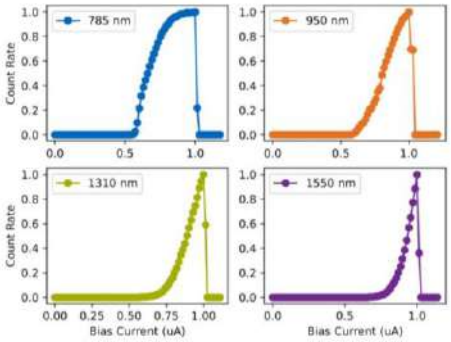


Figure 2: Normalized count rates for different excitation wavelengths at 0.5 K

Controlling the generation of large cluster states with residual visibility measurements

Valentin Guichard[1], Leonid Vidro[2], D. Fioretto[1,3], D. Istrati[2], Y. Pilnyak[2], M. Pont[3], M. Morassi[1], A. Lemaître[1], I. Sagnes[1], N. Somaschi[3], N. Belabas[1], P. Senellart[1], H. Eisenberg[2]

1.CNRS, Centre for Nanosciences and Nanotechnologies, Université Paris-Saclay, UMR 9001,91120 Palaiseau, France
2.Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem 91904, Israel
3.Quandela SAS, 10 Boulevard Thomas Gobert, 91120 Palaiseau, France
valentin.guichard@universite-paris-saclay.fr

Entanglement is a key resource to scale up photonic quantum technologies pertaining to quantum computing or quantum communications [1].
We present a resource-efficient way to generate large states of entangled photons, known as photonic linear cluster (LC) states. We use a bright single photon source, here an InGaAs quantum dot embedded within a micropillar cavity [2], and a fibered entangler (See Fig. 1a) [3], composed of a polarizing beamsplitter and a fibre delay loop.
To increase the number of photons in the LC state, we develop a practical optimization of the experimental setup, based on residual visibility measurements. By changing the phase in the delay loop, we extract a visibility measurement that is directly related to the quality of the generated state. We usually post-select on measuring the same number of input and output photons. The residual visibility method consists in looking at the visibility measurements of 2 to n-1 photons entangled together, in a n-photon experiment – measurement that require much smaller acquisition time. Optimizing the residual visibilities attests the high level of alignment of the experiment and allows to extract information on the system comprised of the source and the loop. Using this method, we demonstrate entanglement of up to 6 photons in a linear cluster state.

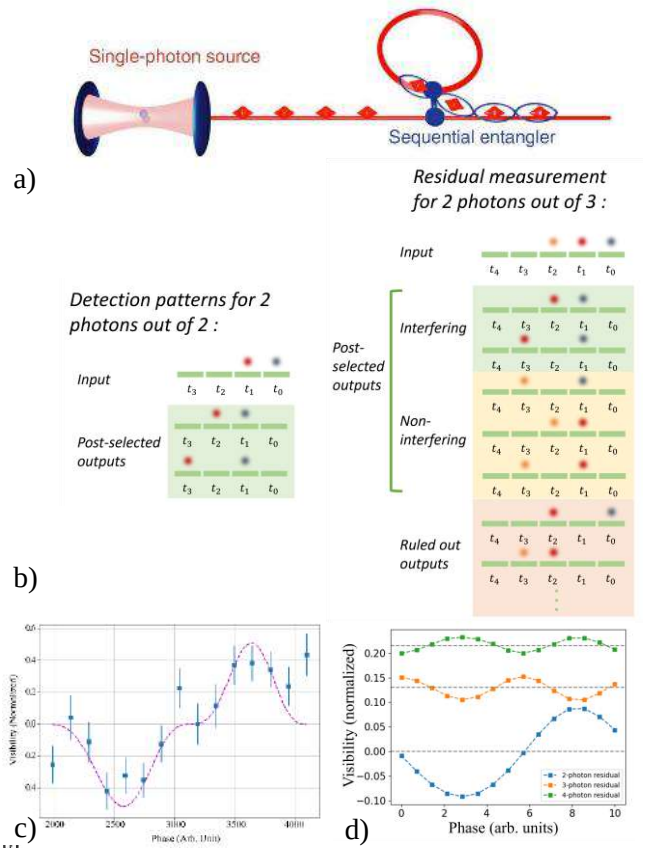


Figure 1: a) Principle of our resource efficient linear cluster state generation protocol [3]
b) Principle of residual visibility measurement – We look at patterns in the temporal modes, removing 1 or more photons leads to a global addition of interfering and non-interfering events to the measurement –
c) 6-photon entanglement measurement - A visibility higher than 0.3 ensures genuine 6-photon entanglement - Experimental value of 0.5±0.1 in agreement with the theoretical model considering 86% Hong-Ou-Mandel
d) Residual visibility measurement of 2, 3, 4 photons out of the 6-photon experiment.

References

[1] R. Raussendorf, H. J. Briegel, Phys. Rev. Lett. 56, 5188 (2001).
[2] N. Somaschi et al., Nat. photon. 10, 340-345 (2016).
[3] D. Istrati et al., Nature Comm. 11, 5501 (2020).

Quantum Zeno effect: preventing a photon from exiting a cavity.

Vidul Joshi
A. Koottandavida, A. Miano, R. Cortinas,
A. Ding, C. Wang, B.J. Chapman, M.H. Devoret

Department of Applied Physics, Yale University, New Haven, USA

vidul.joshi@yale.edu

The quantum Zeno effect refers to the freezing of the time evolution of a quantum system subjected to repeated measurements. In this talk we try to answer the question, as to whether the Zeno effect can stop stochastic decay events like a photon jump from a cavity. There is a time scale governing the rate at which the photon in the cavity gets entangled with the environment. Performing a projective and quantum non-demolition photon number measurement on the cavity faster than this time scale prevents the system from entangling with the environment, thereby freezing photon jumps. To demonstrate this, we use a 3D microwave resonator as the cavity and an auxiliary resonator as a toy environment. The auxiliary resonator is coupled to a transmon, which is continuously measured to detect photon jumps (see figure 1). Conditioning the evolution under "no jumps" serves to experimentally show the time scale of system-environment entanglement. Our experiments show that measuring the photon number at a rate faster than the system-environment entanglement rate freezes the decay (figure 2).

Figures

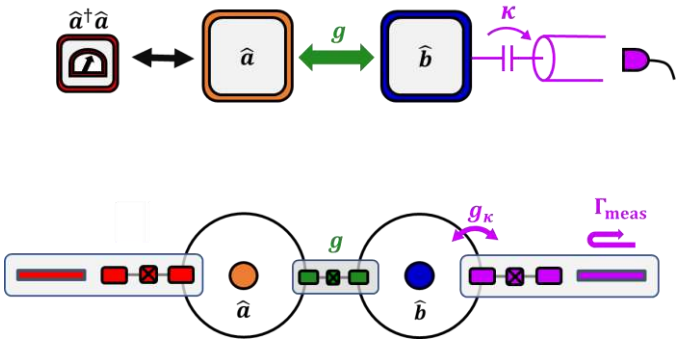


Figure 1: Schematic of the experimental setup

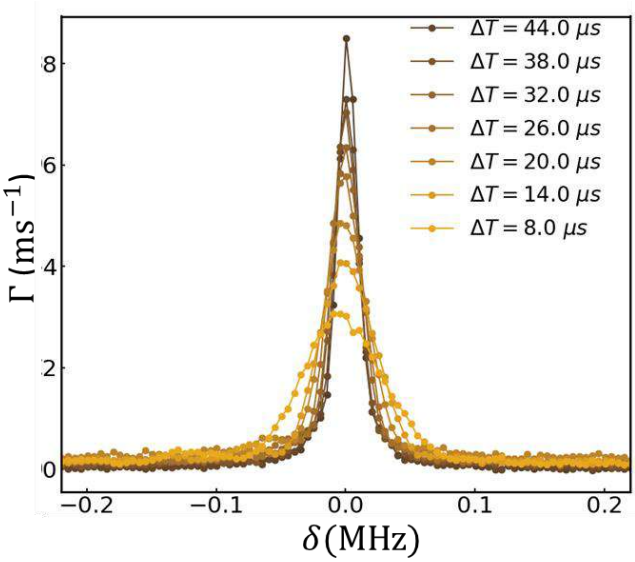


Figure 2: Decay rate of mode 'a' as a function of detuning from environment for different Zeno measurement rates.

Gottesman-Kitaev-Preskill State Preparation Using Periodic Driving

Xanda Kolesnikow
Raditya Bomantara, Andrew Doherty, Arne Grimsmo

The University of Sydney, NSW 2006, Sydney, Australia

xkol5335@uni.sydney.edu.au

The Gottesman-Kitaev-Preskill (GKP) code may be used to overcome noise in continuous variable quantum systems [1]. However, preparing GKP states remains experimentally challenging [2-5]. We propose a method for preparing GKP states by engineering a time-periodic Hamiltonian whose Floquet states are GKP states. This Hamiltonian may be realized in a superconducting circuit comprising a SQUID shunted by a superinductor and a capacitor (see Fig. 1), with a characteristic impedance twice the resistance quantum. The GKP Floquet states can be prepared by adiabatically tuning the frequency of the external magnetic flux drive (see Fig. 2). We predict that highly squeezed >11.9 dB (10.8 dB) GKP magic states can be prepared on a microsecond timescale, given a quality factor of 10^6 (10^5) and flux noise at typical rates. This work fits into the conference topic of 'Quantum Computing and Technologies' and applies techniques from Quantum Matter such as Floquet engineering. A preprint of this work is available at arXiv:2303.03541 and has been accepted to be published in Phys. Rev. Lett.

Figures

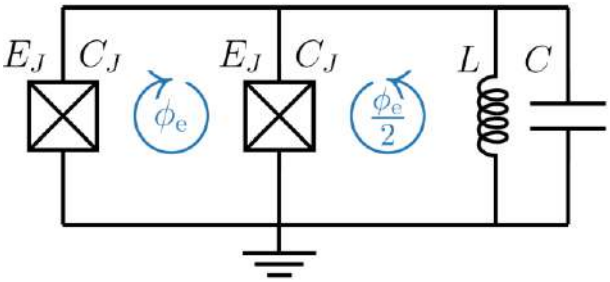


Figure 1: Superconducting circuit diagram for GKP state preparation

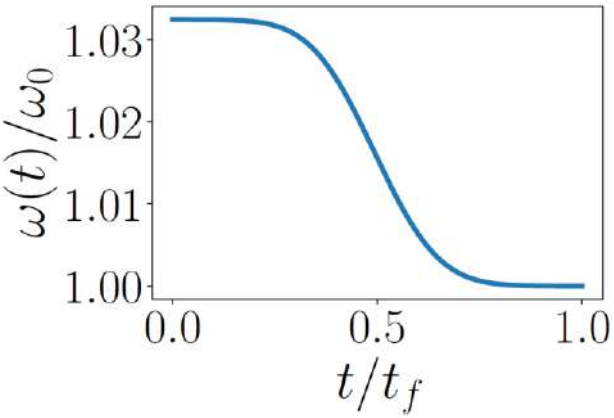


Figure 2: Adiabatic frequency ramp for external magnetic flux drive (denoted by ϕ_e in Fig. 1) to prepare GKP states

References

[1] D. Gottesman, A. Kitaev, and J. Preskill, Phys. Rev. A, 64 (2001) 012310
[2] C. Flühmann, *et al.*, Nature 566 (2019) 513
[3] P. Campagne-Ibarcq, *et al.*, Nature 584 (2020) 368
[4] B. de Neeve, T.-L. Nguyen, T. Behrle, and J. P. Home, Nat. Phys. 18 (2022) 296
[5] V. V. Sivak, *et al.*, Nature 616 (2023) 50

Tunable charge-4e supercurrent in Ge-based JoFET

Axel LEBLANC
Chotivut TANGCHINGCHAI, Zahra SADRE MOMTAZ, Elyjah KIYOOKA, Jean-Michel Hartmann, Gonzalo TRONCOSO, Boris BRUN, Vivien SCHMITT, Simon ZIHLMANN, Romain MAURAND, Etienne DUMUR, Silvano DE FRANCESCHI and François LEFLOCH

Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG, PHELIQS, 38000 Grenoble, France
axel.leblanc@cea.fr

Parity-protected superconducting qubits, in which the quantum information is encoded in wave-functions with disjoint support, have recently emerged as promising candidates to enhance the lifetime of quantum states [1, 2, 3]. This innovative approach leverages cos(2φ) Josephson elements dominated by charge-4e supercurrent – the coherent transfer of pairs of Cooper pairs. In this work, we investigate highly transparent S-Sm-S Josephson field effect transistor (JoFET) fabricated from SiGe/Ge heterostructures. First, using a SQUID with a wide and a narrow JoFET, we show that the current phase relation is composed of multiple and gate tunable harmonics corresponding to charge-2ne (with n an integer) supercurrent. Their contribution is confirmed by DC measurements under radio-frequency irradiation that exhibit integer and half-integer Shapiro steps. Second, by harnessing the superconducting diode effect in a SQUID with two similar JoFETs, we identify the regime of perfect critical current symmetry (Fig.1)[4]. In this configuration, Shapiro steps measurements at half flux quantum reveal a pronounced reduction in the first harmonic thereby realizing a cos(2φ) Josephson element (Fig.2). These results pave the way for the realization of Ge-based parity-protected qubits using CMOS compatible processes.
Associated article: arXiv: 2311.15371

References

[1] T. W. Larsen et al., Physical Review Letters, 125 (2020)
[2] A. Maiani et al., PRX Quantum, 3 (2022)
[3] C. Schrade et al., PRX Quantum, 3 (2022)
[4] R. S. Souto et al., Physical Review Letters, 129 (2022)

Figures

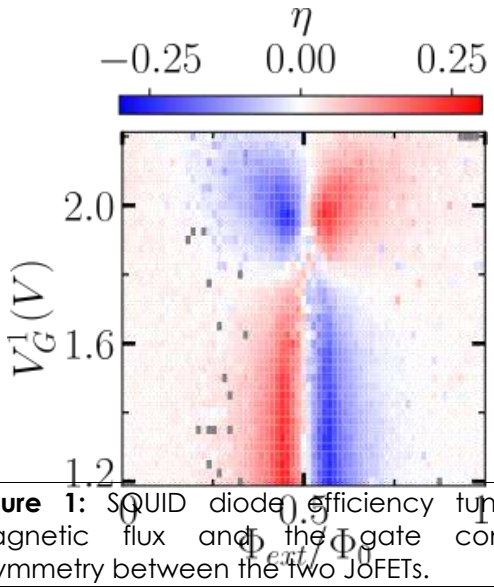
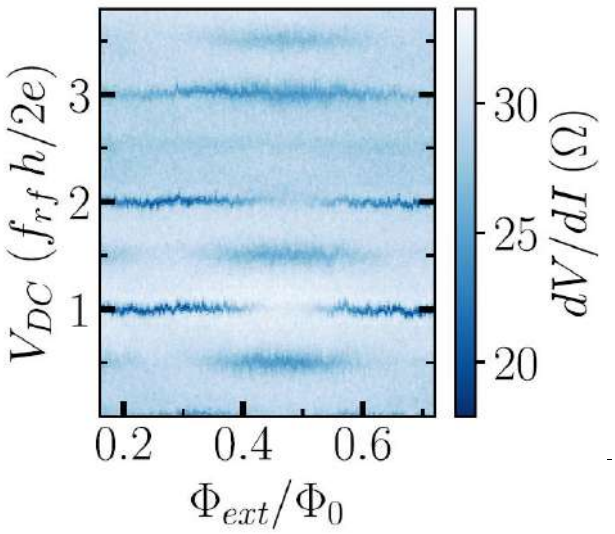


Figure 1: SQUID diode efficiency tuned by magnetic flux and the gate controlled asymmetry between the two JoFETs.



proximity to half of the flux quantum. At Φ0/2, the charge-4e supercurrent dominates, giving rise to half-integer steps.

Optimal Charge-to-Spin Conversion Tuned by Intraparticle Entanglement

Joaquín Medina Dueñas
José H. García, Stephan Roche

ICN2 – Institut Català de Nanociència i Nanotecnologia, Campus UAB, Barcelona, Spain

joaquin.medina@icn2.cat

Charge-to-spin conversion lies at the heart of next-generation spintronic devices, where spin-orbit coupling (SOC) efficiently generates a current-driven spin polarization to control a magnetic state. Van der Waals materials present a unique platform for the development of such devices as their electron, spin and optical properties can be enriched by proximity effects [1]. In this context, graphene emerges as a promising spintronic platform, as SOC is activated by proximity with a transition metal dichalcogenide (TMD) [2]. This allows to generate a current-driven spin polarisation via the Spin Hall and Rashba-Edelstein effects in a graphene/TMD bilayer, as well as long distance spin transport in an isolated graphene layer [3]. Understanding the role of intraparticle entanglement between spin and sublattice degrees of freedom remains a challenge in this topic. These effects have been proposed to be detrimental for spin diffusion [4] and spin-momentum locking [5]. Here, we understand intraparticle entanglement as a limiting factor for charge-to-spin conversion in graphene, which we minimize by adequately tuning SOC. By these means, we achieve charge-to-spin conversion with *maximal efficiency* throughout a wide spectral range. We additionally show that intraparticle entanglement enables novel charge-to-spin conversion mechanisms in spin-orbit torque devices [6].

References

[1] J.F. Sierra, J. Fabian, R.K. Kawakami, *et al.* Nat Nanotechnol **16** (2021) 856-868

[2] M. Gmitra and J. Fabian, Phys Rev B, **92** (2015) 155403

[3] L. Antonio Benítez, W. Savero Torres, J.F. Sierra, *et al.* Nat Matter, **13** (2020) 170-175

[4] D. Tuan, F. Ortmann, D. Soriano, *et al.* Nature Phys, **10** (2014) 857-863

[5] B.G. de Moraes, A.W. Cummings and S. Roche, Phys Rev B, **102** (2020) 041403

[6] J. Medina Dueñas, J.H. García and S. Roche, arXiv: 2310.06447 (2023)

Figures

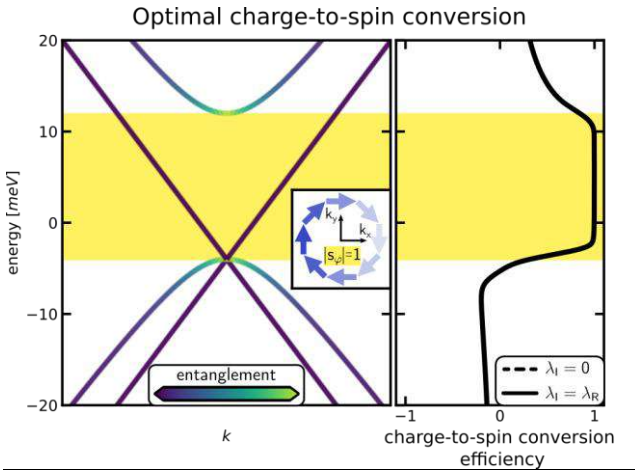


Figure 1. Charge-to-spin conversion with maximal efficiency is obtained across the entire Rashba pseudogap, highlited in yellow, where only a single spin-helical band with no intraparticle entanglement crosses the Fermi level

Impact of vacancies on the transport in twisted bilayer graphene quantum point contacts

Pablo Moles Matías
Leonor Chico and Francisco Domínguez-Adame
Universidad Complutense de Madrid, Avenida Complutense s/n, 28040, Madrid, Spain
pmoles@ucm.es

Quantum point contacts (QPC), short one-dimensional conductors that can be electrostatically defined or etched in two-dimensional materials, are the center of attention for their prospective applications in spin, valley and charge nanodevices. Although fabrication by etching generally produces defects and roughness which hinder the properties of the pristine materia, recent cryoetching techniques overcome these problems and have demonstrated the fabrication of low-defect graphene QPCs via etching processes, in which quantization of electron transport was experimentally observed. This is especially important for the study of twisted bilayer graphene QPCs, where the interplay of moiré and edge localization should be studied in systems with well-defined edges.

In this work we provide a theoretical background to those systems. We study the electronic transport properties of a twisted bilayer graphene QPC consisting of a bilayer flake contacted by two monolayer graphene nanoribbons which act as leads. Numerical simulations are carried out with the help of the package Kwant for quantum transport, using a tight-binding model. The conductance and the spatial distribution of electronic states in the QPC are computed. Conductance quantization presents a strong dependence with the rotation angle between layers and the electron-hole symmetry is broken in pristine samples.

Despite the progress on fabrication techniques, some defects or impurities might be present in experimental devices, so furthermore we study the effect on the conduction caused by adding vacancy defects to the system. Remarkably, the electron-hole symmetry is partially recovered due to the effect of vacancies.

References

[1] Moles, P., Domínguez-Adame, F., & Chico, L. Physical Review B, 109(4), 045415 (2024).
[2] V. Clericó, J. A. Delgado-Notario, M. Saiz-Bretín, C. Hernández Fuentevilla, A. V. Malyshev, J. D. Lejar-reta, E. Diez, and F. Domínguez-Adame, physica status solidi (a), 215, 1701065 (2018).
[3] Pelc, M; Morell, E. S; Brey, L; & Chico, L. The Journal of Physical Chemistry C, 119, 1007610084 (2015).
[4] Groth, C. W; Wimmer, M; Akhmerov, A. R; & Waintal, X. New Journal of Physics, 16, 063065 (2014).

Figures

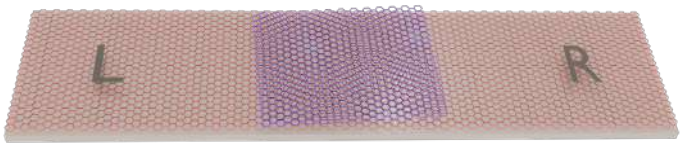


Figure 1: Sketch of the device

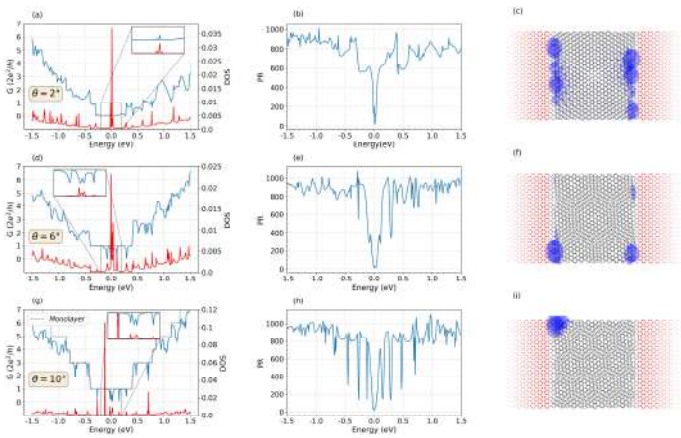


Figure 2: Conductance, Participation Ratio and Local Density of States of the system.

Efficient decoupling of a non-linear qubit mode from its environment

Frederik Pfeiffer[1]
M. Werninghaus, C. Schweizer, N. Bruckmoser, L. Koch, N. J. Glaser, G. B. Huber, G. Krylov, C. A. Riofrío, S. Filipp

[1]*Technical University of Munich & Walther-Meissner-Insitute, Walther-Meißner-Straße 8, Garching, Germany*

frederik.pfeiffer@wmi.badw.de

To control and measure the state of a quantum system it must necessarily be coupled to external degrees of freedom. This inevitably leads to spontaneous emission via the Purcell effect, photon-induced dephasing from measurement back-action, and errors caused by unwanted interactions with nearby quantum systems. To tackle this fundamental challenge, we make use of the design flexibility of superconducting quantum circuits to form a multi-mode element -- an artificial molecule -- with symmetry-protected modes. The proposed circuit consists of three superconducting islands coupled to a central island via Josephson junctions. It exhibits two essential non-linear modes, one of which is flux-insensitive and used as the protected qubit mode. The second mode is flux-tunable and serves via a cross-Kerr type coupling as a mediator to control the dispersive coupling of the qubit mode to the readout resonator. We demonstrate the Purcell protection of the qubit mode by measuring relaxation times that are independent of the mediated dispersive coupling. We show that the coherence of the qubit is not limited by photon-induced dephasing when detuning the mediator mode from the readout resonator and thereby reducing the dispersive coupling. The resulting highly protected qubit with tunable interactions may serve as a basic building block of a scalable quantum processor architecture, in which qubit decoherence is strongly suppressed [1].

Figures

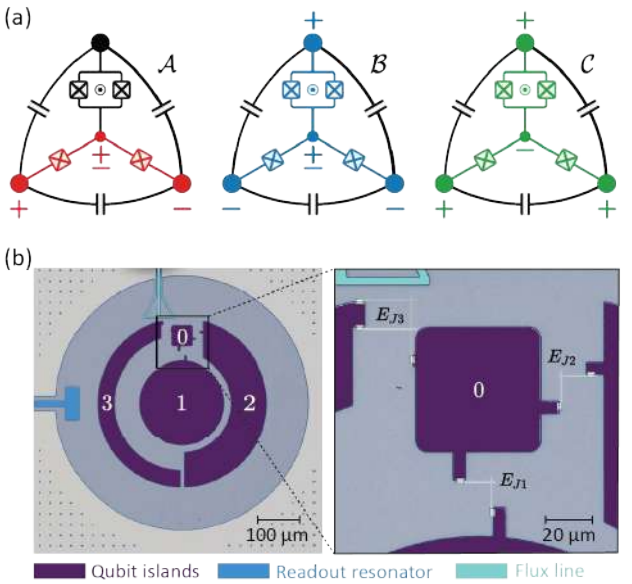


Figure 1: Oscillating charge distributions of the circuit modes indicated by positive ('+') and negative ('-') charge, '±' indicates charge neutrality. (b) False-color microscope image of the qubit sample.

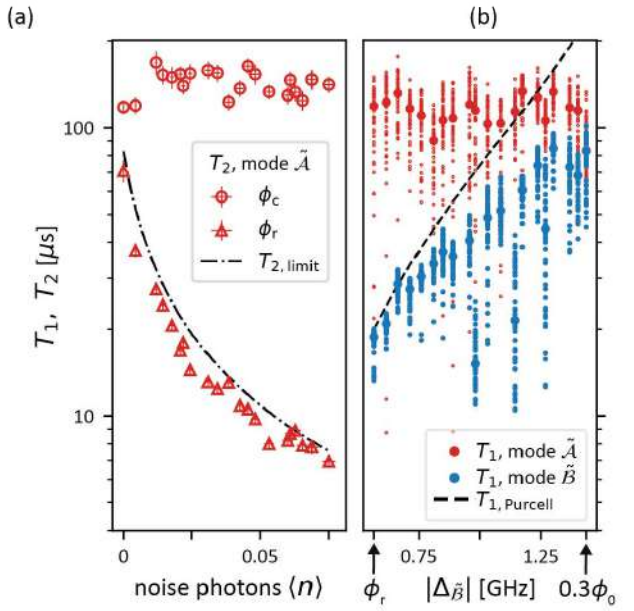


Figure 2: (a)T_2 of the qubit mode vs. noise photon-number at operation points of maximal and suppressed dispersive coupling.
(b) T_1 of qubit and mediator mode vs. resonator-mediator detuning.

References

[1] F. Pfeiffer et al. arXiv:2312.16988 (2023)

Minimal Kitaev-transmon qubit based on double quantum dots

D. Michel Pino
Rubén Seoane Souto and Ramón Aguado

Instituto de Ciencia de Materiales de Madrid (ICMM), Consejo Superior de Investigaciones Científicas (CSIC), Sor Juana Inés de la Cruz 3, 28049 Madrid, Spain

dmichel.pino@csic.es

Minimal Kitaev chains composed of two semiconducting quantum dots coupled via a superconductor have emerged as a promising platform to realize and study Majorana bound states (MBSs), which appear for fine-tuned configurations [1, 2]. We propose a hybrid qubit based on a Josephson junction between two such double quantum dots (DQDs) embedded in a superconducting qubit geometry (Fig. 1). The qubit makes use of the 4π-Josephson effect in the Kitaev junction to create a subspace based on the even/odd fermionic parities of the two DQD arrays hosting MBSs. Deep in the transmon regime, we demonstrate [3] that by performing circuit QED spectroscopy, one could observe distinct MBS features in perfect agreement with precise analytical predictions in terms of DQD parameters only (Fig. 2). This also allows us to extract the Majorana polarization in the junction.

References

[1] T. Dvir et al., Nature 614, 7948 (2023) 445.

[2] M. Leijnse and K. Flensberg, Phys. Rev. B 86, 13 (2012) 134528.

[3] D. Michel Pino, Rubén Seoane Souto and Ramón Aguado, Phys. Rev. B 109, 7 (2024) 075101.

Figures

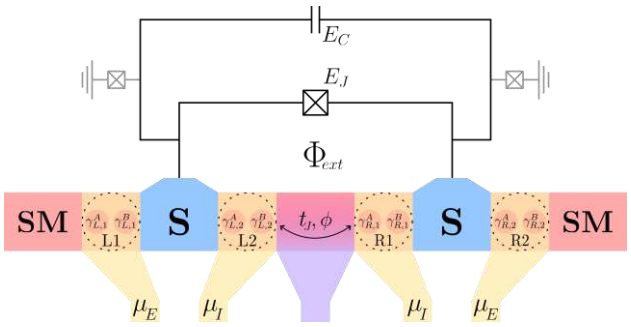


Figure 1: Schematic illustration of the Kitaev-transmon device.

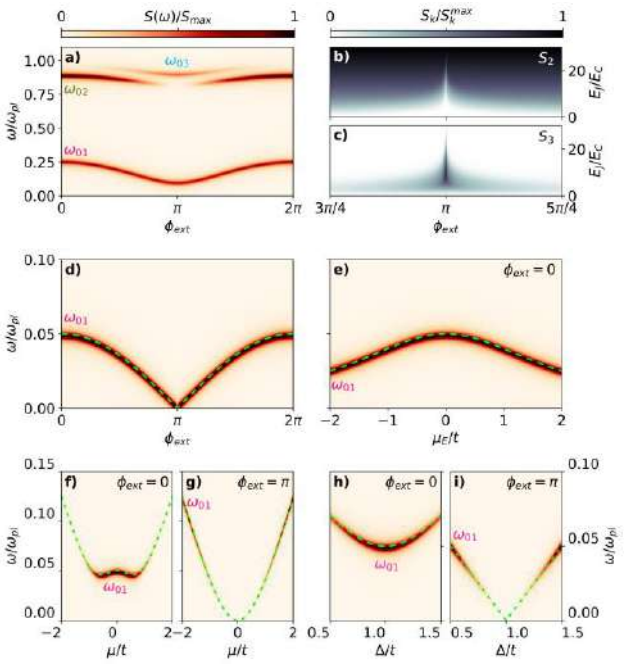


Figure 2: Kitaev-transmon qubit spectroscopy.

Circularly Polarized Driving and Commensurate Pulses for Fast Single-Qubit Gates with Fluxonium

David A. Rower[1,3]*
Leon Ding[1,3]*, Helin Zhang[1], Max Hays[1], Ilan T. Rosen[1], Junyoung An[1,2], Bethany M. Niedzielski[4], Mollie E. Schwartz[4], Jonilyn L. Yoder[4], Kyle Serniak[4], Jeffrey A. Grover[1], William D. Oliver[1,2,3]

[1]*Research Laboratory of Electronics, MIT*
[2]*Dept. of Electrical Eng. & Computer Science, MIT*
[3]*Department of Physics, MIT*
[4]*MIT Lincoln Laboratory*

rower@mit.edu
*These authors contributed equally.

This work focuses on achieving fast, high-fidelity single-qubit gates. To this end, we introduce two complementary protocols and experimentally demonstrate them with a fluxonium qubit. The first protocol utilizes simultaneous charge and flux drives with a relative phase, enabling arbitrarily polarized qubit drive fields. We demonstrate drive polarization tunability and use a circularly-polarized drive field to avoid counter-rotating effects often neglected in the rotating-wave approximation for Rabi-based gates. The second protocol involves commensurate pulses, where pulse durations match the qubit Larmor precession, reducing coherent errors from non-uniform waveform shapes. Implementing both protocols, we demonstrate state-of-the-art single-qubit gates with fidelities exceeding 0.99997 measured with Clifford randomized benchmarking. Our results offer straightforward methods for increasing gate performance, and are broadly applicable to the fast control of quantum systems in the rotating frame.

References

[1] D. A. Rower*, L. Ding*, (*In Preparation*), 2024

Figures

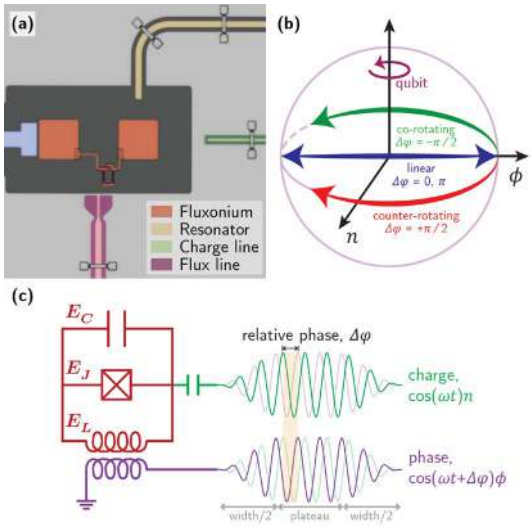


Figure 1: (a) Fluxonium qubit. **(b)** Bloch sphere picture of the qubit Larmor precession and a linear drive, and co/counter-rotating drives. **(c)** Circuit schematic showing simultaneous charge and flux drives applied with a relative phase, enabling the generation of arbitrarily-polarized drive fields.

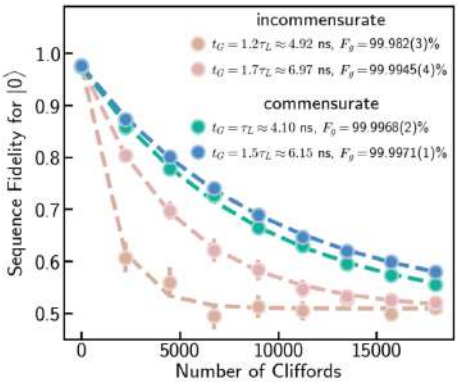


Figure 2: Clifford randomized benchmarking of single-qubit gates utilizing only a flux drive, for gate durations that are commensurate (1 and 1.5 Larmor periods) and incommensurate (1.2 and 1.7 Larmor periods).

Dispersive readout of molecular spin qubits

Marcos Rubin Osanz
M. C. Pallares, M. C. de Ory, I. Gimeno, N. Crivillers, I. Ratera, J. Veciana, A. Lostao, A. Gomez, F. Luis

INMA, C/ Pedro Cerbuna, 12, Zaragoza, Spain

mrubin@unizar.es

Magnetic molecules are attractive candidates to encode spin qubits [1,2]. We have performed the first experiments to test the dispersive readout of qubits encoded in the spin states of magnetic molecules by means of a superconducting circuit [3]. The molecules are coupled to lumped-element resonators (LERs) fabricated at the Centro of Astrobiología (CAB) [4]. Sweeping the external magnetic field magnetic changes the detuning $\Delta = \omega_q - \omega_r$ between the frequency of operation of the qubit, ω_q, and the resonator frequency, ω_r. If the detuning is larger than the qubit-resonator coupling, we can perform a non-demolition measurement of the state of the qubit by monitoring the change $\delta\omega_r$ in the resonator's frequency.

As a starting point, we chose the simplest system possible: PTM_r, a free radical (Fig. 1, inset) with spin 1/2 [5] and the qubit states encoded in its two spin projections. The absorption spectrum of the radical can be obtained, at a given field, by sweeping the frequency of a driving electromagnetic pulse, ω_{pump}, and then measuring the shift of the LER resonance (Fig. 1). The spectrum width comes from the inhomogeneous broadening of the sample. By increasing the time delay between the pump pulse and the readout measurement, we have determined the longitudinal relaxation time T_1, which becomes as long as 10-20 s at very low temperatures. The shape of the decay agrees with the distribution of spin-photon couplings generated by a small nano-constriction in the inductor, which locally enhances the coupling. Finally, the first signs of a coherent manipulation of the spin ensemble have been detected using this measurement procedure in a specific superconducting chip designed for that purpose.

References

[1] A. Gaita-Ariño, F. Luis, S. Hill and E. Coronado, Nat. Chem., 11 (2019) 301-309
[2] S. Carretta, D. Zueco, A. Chiesa, A. Gomez-Leon and F. Luis, Appl. Phys. Lett., 118 (2021) 240501
[3] A. Gomez-Leon, F. Luis and D. Zueco, Phys. Rev. Appl., 17 (2022) 064030
[4] B. Aja, M. C. de Ory, L. de la Fuente, E. Artal, J. P. Pascual, M. T. Magaz, D. Granados and A. Gomez, IEEE Trans. Microw. Theory Tech., 69 (2021) 578-589
[5] O. Armet, J. Veciana, C. Rovira, J. Riera, J. Castaner, E. Molins, J. Rius, C. Miravitlles, S. Olivella and J. Brichfeus, J. Phys. Chem., 91 (1987) 5608-5616

Figures

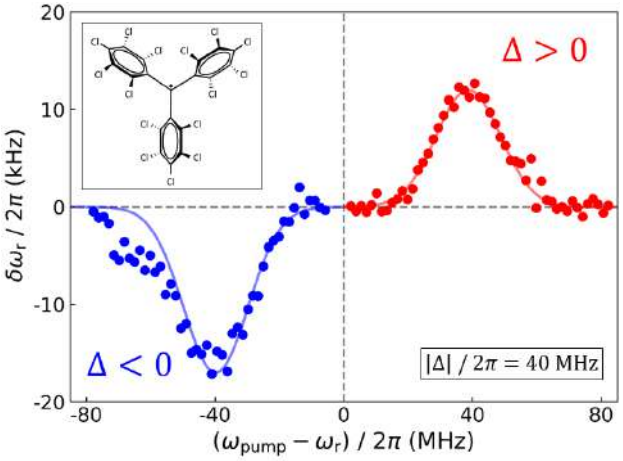


Figure 1: PTM_r spectrum for positive and negative detuning Δ, measured through the shift $\delta\omega_r$ of the resonator's frequency. Inset: The PTM_r molecule.

Microwave-driven two-hole spin qubits

Jaime Saez-Mollejo[1]
Daniel Jirovec[1], Yona Schell[1], Josip Kukucka[1], Andrea Ballabio[2], Daniel Chrastina[2], Giovanni Isella[2] and Georgios Katsaros[1]

1. ISTA, Am Campus 1, Klosterneuburg, Austria
2. L-NESS, Physics Deparment, Politecnico di Milano, Como, Italy

jaime.saezmollejo@ist.ac.at

Group IV spin qubits are promising candidates for realizing quantum processors due to their scalability, CMOS compatibility, and long coherence times. In particular, Ge has become a very attractive platform because of the low effective mass and low hyperfine interaction. In addition, strong spin-orbit interaction allows the spin to be driven electrically. From 2018 and within a few years, a Loss-DiVincenzo [1], a singlet-triplet hole spin qubit [2], a two-qubit [3], and a four-qubit Ge quantum processor [4] have been realized, demonstrating the potential of Ge for quantum information.

Manipulation of spin qubits can be achieved via multiple driving mechanisms: Electron Spin Resonance [5], Electron Dipole Spin Resonance [6], g-tensor modulation [7], or exchange interaction [8]. Owing to the low effective mass of holes in Ge, exchange interaction can have a much stronger effect compared to Silicon [9], thereby warranting the study of its effects.

Here, we show a spin qubit in a double quantum dot hosted in Ge/SiGe heterostructure operated in a regime where the exchange interaction dominates over the Zeeman energy difference. We measure three microwave-driven transitions of two-hole spin states that can be coherently manipulated. To investigate the impact of exchange on the driving mechanism, we study the Rabi frequency dependence as a function of magnetic field, B, and detuning, ϵ.

References

[1] Watzinger et al. Nat. Comm 9, 3902 (2018)
[2] Jirovec et al. Nat. Mat. 20, 1106 (2021)
[3] Hendrickx et al. Nature 577, 487 (2020)
[4] Hendrickx et al. Nature 591, 580 (2021)
[5] Koppens et al. Nature 442, 766(2006)
[6] Nadj-Perge et al. Nature 468, 1084 (2010)
[7] Crippa et al. PRL 120,1337702 (2018)
[8] Takeda et al. PRL 124, 117701 (2020)
[9] Wu et al. IEEE Trans.Comput. Aided Des. Integr. Circuits Syst. 42, 257 (2023)

Figures

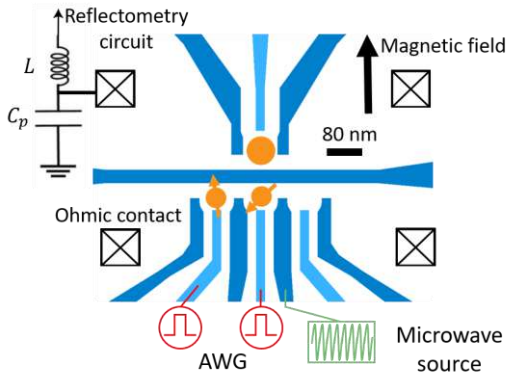


Figure 1: Computer-aided design of the gate layout of the device under study.

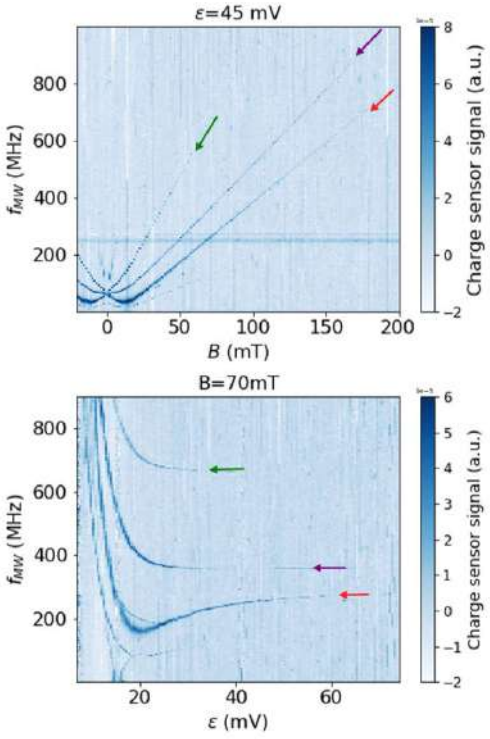


Figure 2: Spectroscopy of the three spin transitions as a function of magnetic field and detuning.

Tuning the coherent interaction of an electron qubit and a many-body register

Noah Shofer
Leon Zaporski, Martin Hayhurst Appel, Alex Ghorbal, Urs Haeusler, Claire Le Gall, Mete Atatüre, Dorian Gangloff
Cavendish Laboratory, University of Cambridge, Cambridge, UK

Michał Gawelcyk
Institute of Theoretical Physics, Wrocław University of Science and Technology, Wrocław, Poland

Santanu Manna, Saimon Covre da Silva, Armando Rastelli
Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Linz, Austria

njs73@cam.ac.uk

A central spin qubit interacting coherently with a large register of nuclear spins can be used for the realization of a quantum memory [1,2] or for the realization of coherent collective phenomena [3]. Here we demonstrate tuning of the coherent interaction between an electron spin qubit and a register of nuclear spins in a GaAs quantum dot (QD). The low inhomogenous broadening of the nuclear spin satellite transitions in the GaAs system, paired with an all-optical nuclear cooling algorithm, allows us to perform high-resolution spectroscopy of the nuclear ensemble, enabling measurement of the electronic Knight field and time-dependent revivals of electronic coherence, which fully characterize the electron-nuclear interaction. By precisely selecting the nuclear mean-field polarization via a polarization locking pulse sequence, we vary the strength of the electron-nuclear exchange interaction *in situ*, a result enabled by the electron g-factor anisotropy mediated nature of the interaction. We then demonstrate tuning of the coherent interaction explicitly via the activation rate of a single collective nuclear excitation and the coherence time of the electron spin qubit. This technique enables the programmatic tuning of the Hamiltonian of a central-spin system in the many-body regime.

References

1. J.M. Taylor, C.M. Marcus, M.D. Lukin, PRL **91**, 246802 (2003)
2. E.V. Denning, D.A. Gangloff, M. Atatüre, J. Mørk, C. Le Gall, PRL **123**, 140502 (2019)
3. L. Zaporski, S.R. De Wit, T. Isogawa, M. Hayhurst Appel, C. Le Gall, M. Atatüre, D.A. Gangloff, PRX Quantum **4**, 040343 (2023)

Figures

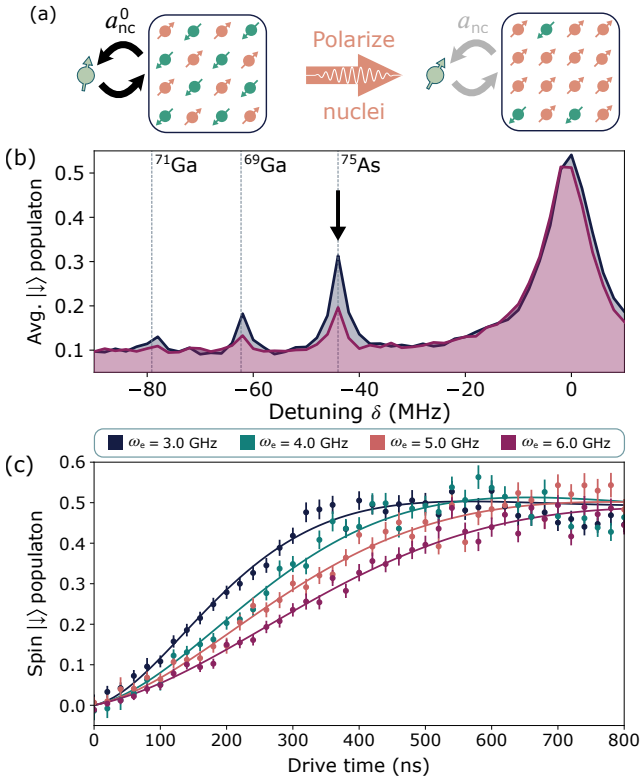


Figure 1: (a) Left: the optically addressed electron spin is in contact with a bath of ~10^5 As and Ga nuclear spins, forming a central spin system. An electron g-factor anisotropy leads to a different quantization axis for the electron and for the nuclei, leading to a non-collinear interaction. Right: As the nuclei are polarized, increasing the mean-field Overhauser shift, the electron and nuclear quantization axes tilt together, decreasing the non-collinear interaction. (b) The electron spin resonance spectrum. The blue line is the spectrum measured at the unpolarized electron Zeeman frequency of 3GHz, while the maroon line is measured for a polarized nuclear ensemble at 6GHz. (c) The spin down population of the negative ^{75}As sideband as a function of Rabi drive time for several electron splittings.

Charge-4e superconductivity in a Hubbard model

Martina Ondina Soldini,
Mark H. Fisher, Titus Neupert.

University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland

msoldi@physik.uzh.ch

A phase of matter in which fermion quartets form a superconducting condensate, rather than the paradigmatic Cooper pairs, is a recurrent subject of experimental and theoretical studies. However, a comprehensive microscopic understanding of charge-4e superconductivity as a quantum phase is lacking. Here, we study a two-orbital tight-binding model with attractive Hubbard-type interactions. Such a model naturally provides the Bose-Einstein condensate as a limit for electron quartets and supports charge-4e superconductivity, as we show by mapping it to a spin-1/2 chain in this perturbative limit. Using infinite density matrix renormalization group calculations for the one-dimensional case, we further establish that the ground state is indeed a superfluid phase of 4e charge carriers and that this phase can be stabilized well beyond the perturbative regime. Importantly, we demonstrate that 4e condensation dominates over 2e condensation even for nearly decoupled orbitals, which is a more likely scenario in electronic materials. Our model paves the way for both experimental and theoretical exploration of 4e superconductivity and provides a natural starting point for future studies beyond one dimension or more intricate 4e states.

Figures

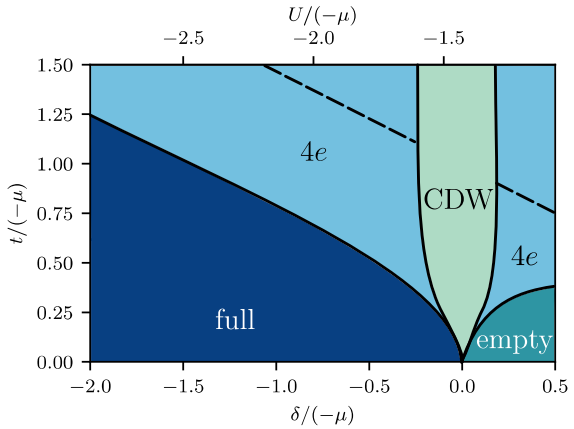


Figure 1: Phase diagram for the one-dimensional model that displays charge-4e superconductivity. In two of the regions the ground state is either the fully empty or fully occupied state, the central region has a charge density wave (CDW), and the intermediate regions realise a charge-4e superconducting phase.

Proximity-induced Magnetism and Spin-orbit Coupling in Graphene/$V_xW_{1-x}Se_2$ Heterostructure

Josef Světlík[1,2]
L. Camosi[1], W. Savero Torres[1], L. A. Benítez[1,2], Ch. Stefani[1,2], I. Verzhbitskiy[3], I. Fernández Aguirre[1,2], J. F. Sierra[1], G. Eda[3], S. O. Valenzuela[1,4]

[1]*ICN2, Bellaterra (Barcelona), Spain*
[2]*UAB, Bellaterra, 08193 Barcelona, Spain,*
[3]*NUS, 21 Lower Kent Ridge Rd, 119077 Singapore*
[4]*ICREA, 08010 Barcelona, Spain*

Josef.svetlik@icn2.cat

Graphene has shown great potential as an elementary building block of future spintronic devices. Its high carrier mobility and intrinsically low spin-orbit coupling (SOC) lead to long spin diffusion length, making graphene an ideal spin-channel material. Moreover, its atomic thickness promotes proximity-induced effects that provide new ways to control spin transport [1]. For instance, graphene in contact with semiconducting transition metal dichalcogenides (e. g. WSe_2) develops a proximity SOC and a complex spin texture. Such a modification results in anisotropic spin relaxation [2] and allows to efficiently interconvert charge and spin-currents [1,3,4]. Alternatively, interfacing graphene with magnetic materials induces exchange splitting [5], possibly allowing gate-tuneable spin-polarized currents. Doping TMDCs with magnetic atoms has been reported to induce long-range magnetism up to room temperature. In particular, $V_xW_{1-x}Se_2$ shows (anti-)ferromagnetic behaviour depending on the doping level [6]. By performing nonlocal spin precession measurements, we observe signatures of magnetism together with proximity-induced SOC in graphene/$V_xW_{1-x}Se_2$ heterostructure and investigate the interplay of these two effects.

We acknowledge funding from the EU H2020 Marie Sklodowska-Curie grant agreement No. 754558 and FET-PROACTIVE project TOCHA under Grant No. 824140.

References

[1] Sierra J. F., et al., Nature Nanotechnology, **8** (2021), 856–868.
[2] Benítez, L. A., et al., Nature Materials, **3** (2018), 303–308.
[3] Safeer, C.K., et al., Nano Letters, **2** (2019), 1074–1082.
[4] L. A. Benítez et al., Nature Materials, **2** (2020), 170 -175.
[5] Ghiasi, T.S. et al., Nature Nanotechnology, **7** (2021), 788–794.
[6] Pham, Y.T.H. et al., Advanced Materials, **45** (2020), 2003607.

Figures

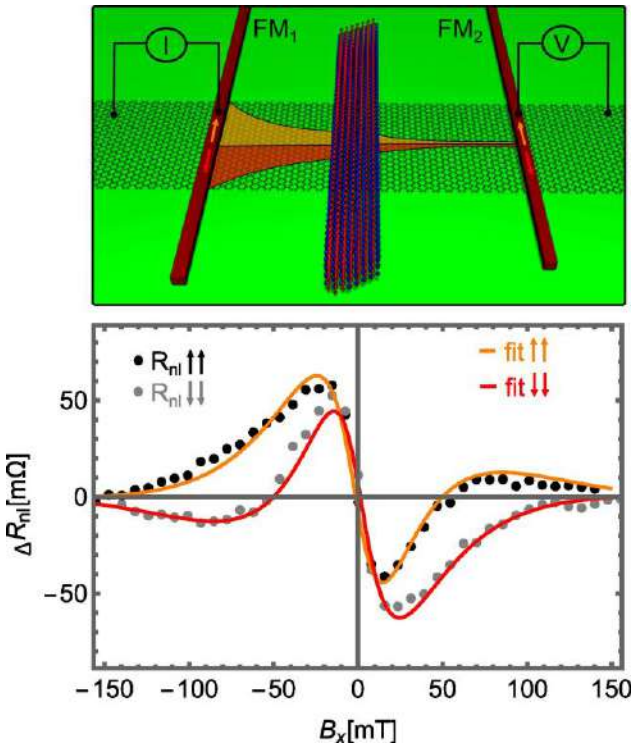


Figure 1: Schematics of the measurement configuration of lateral spin-valve made of $V_xW_{1-x}Se_2$ partially covering graphene channel, and two ferromagnetic electrodes used as spin injector (FM_1) and detector (FM_2), respectively (Top). Representative spin-precession curves obtained by measuring nonlocal resistance as a function of magnetic field applied along graphene channel (Bottom). Arrows indicate magnetization of the ferromagnetic electrodes.

A variational toolbox for analog quantum simulators

Cristian Tabares[1]
J. Schneider[1], A. Muñoz de las Heras[1], L. Tagliacozzo[1], D. Porras[1], D. González-Cuadra[2,3] and A. González-Tudela[1]
[1]*Institute of Fundamental Physics IFF-CSIC, Calle Serrano 113b, 28006 Madrid, Spain*
[2]*Institute for Theoretical Physics, University of Innsbruck, 6020 Innsbruck, Austria*
[3]*Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, 6020 Innsbruck, Austria*
cristian.tabares@csic.es

Current experimental quantum devices do not meet the requirements for building fault-tolerant quantum computers, but they still can be used to address many-body problems as analogue quantum simulators. Different physical platforms, like superconducting circuits [1], trapped ions [2], and cold atoms [3,4], have different interactions between their components. However, the systems simulated are constrained by the type of interactions that can be engineered in the platform, limiting the range of models that can be simulated.

Variational methods have been suggested as a way to go beyond this limitation [5]. Among the different proposals, Variational Quantum Time Evolution algorithms (VarQTE) can perform either real or imaginary time evolution within the same framework [6]. In this work, we propose to use this variational approach to fully harness the interactions present in analogue quantum simulators.

In the first part of the talk, we demonstrate how the long-range interactions present in certain analog quantum simulators can be used to solve some of the limitations of VarQTE algorithms [5]. Then, in the second part, we focus on fermionic quantum simulators and show how VarQTE algorithms can be used to prepare ground states of exotic fermionic models in more efficient ways than standard methods (either because the target interactions cannot be efficiently generated or because adiabatic methods fails while variational ones do not). These results provide analog quantum simulators with a new set of tools that fully leverage their current capabilities.

References

[1] X. Zhang et al., Science **379**, 278-283 (2023).
[2] C. Kokail et al., Nature **569**, 355–360 (2019).
[3] S. Ebadi et al., Nature **595**, 227–232 (2021).
[4] J. Argüello-Luengo et al., Nature **574**, 215–218 (2019).
[5] C. Tabares et al., Phys. Rev. Lett. **131**, 073602 (2023).
[6] X. Yuan et al., Quantum **3**, 191 (2019).

Figures

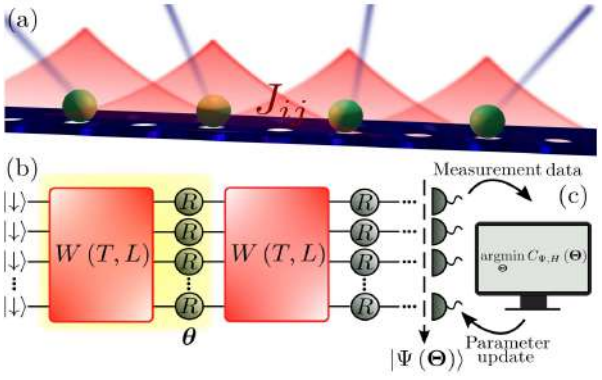


Figure 1: (a) Schematic depiction of atoms coupled to a waveguide, an analog quantum simulator with long-range interactions. (b,c) Quantum-classical algorithm using this interaction.

Hot Schrödinger Cat States

Ian Yang
Thomas Agrenius, Vasilisa Usova, Oriol Romero-Isart, Gerhard Kirchmair

Institute for Experimental Physics, University of Innsbruck, 6020 Innsbruck, Austria

Ian.yang@uibk.ac.at

Abstract

The observation of quantum phenomena often necessitates sufficiently pure states, a requirement that can be challenging to achieve. In this study, we prepare a non-classical state originating from a mixed state, utilising dynamics that preserve the initial purity of the state (i.e. without removing entropy or purifying the system with measurement). We generate a Schrödinger cat state within a circuit quantum electrodynamics setup [1], in which a transmon is coupled to a high coherence microwave cavity. We initialise the cavity with a thermal state of up to n_{th}=7.6(2) average photons or mode temperature of up to 1.8 Kelvin, which is sixty times hotter than its physical environment. Hot Schrödinger's cat states are deterministically prepared with two protocols [2,3] (Figures 1 and 2). Our realisation of non-pure but quantum coherent superposition states could guide the preparation of similar states in other continuous-variable quantum systems. Wigner function measurements confirm the quantum coherent nature of the prepared states through the observation of interference fringes and Wigner negativities.

Figures

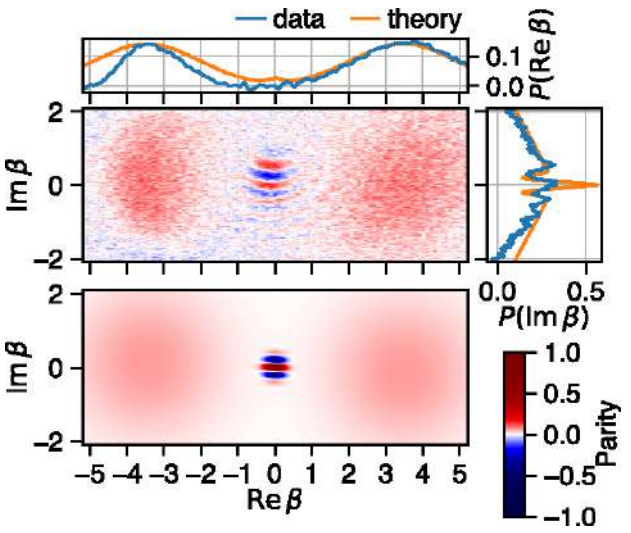


Figure 1: Starting from an initial thermal state with nth = 3.48(7), the result of the Wigner function measurement on the hot Schrödinger cat states prepared with the qcmap protocol [2] are shown together with the numerically obtained marginal distributions. For comparison, we plot the corresponding theoretical Wigner functions.

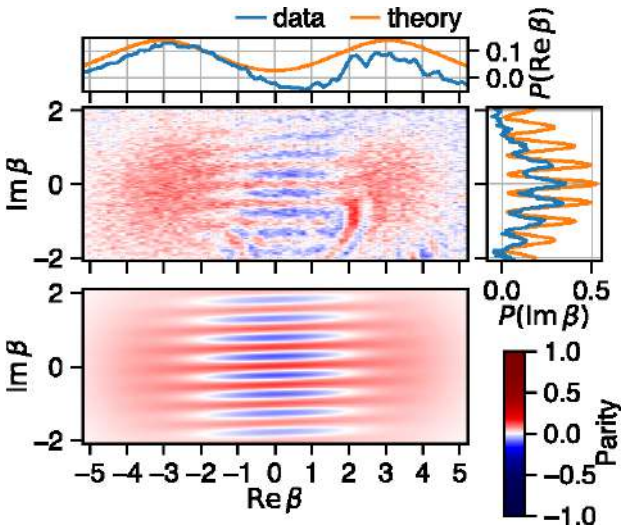


Figure 2: : Starting from an initial thermal state with nth = 3.48(7), the result of the Wigner function measurement on the hot Schrödinger cat states prepared with the echo conditional displacement protocol [3] are shown together with the numerically obtained marginal distributions. For comparison, we plot the corresponding theoretical Wigner functions

References

[1] M. Reagor et al., Phys. Rev. B, 94 (2016) 014506
[2] Z. Leghtas et al., Phys. Rev. A, 87 (2013) 042315
[3] A. Eickbusch et al., Nat. Phys. 18 (2022) 1464-1469

Hermetic packaging for cryogenic experiments

Eric Planz[1]

Fabio Ansaloni[1], Kyle E. Castoria[2], David G. Rees[2], Heenjun Byeon[2], Merlin von Soosten[1], Soren Andresen[1] and Jonatan Kutchinsky[1]

[1]*Quantum Machines, Denmark*
[2]*EeroQ Corporation, Chicago, Illinois, USA*

eric.planz@quantum-machines.co

Abstract

Realizing a universal quantum computer is a complex task. Among the multiple challenges to be solved, extending the coherence times of qubits implemented in solid state nanodevices is of the utmost importance. Implementing qubits made of electrons trapped at the surface of superfluid helium with vacuum offers the opportunity to realize qubits in a noiseless environment, extending the qubit lifetime [1]. Furthermore, these qubits are compatible with standard circuit quantum electrodynamic (CQED) techniques for manipulation and readout [2].

In this talk we introduce our newest commercial packaging, used to perform experiments in completely sealed environments at cryogenic temperatures. The technology is based on our recently developed QCage chip carrier [3], which has been optimized for CQED experiments [4,5]. We demonstrate the superfluid helium tightness of this packaging by investigating how the resonance frequency of superconducting coplanar waveguide resonators is evolving as the chip cavity is filled with superfluid helium at cryogenic temperatures.

References

[1] Platzman, P. M. et al., Science 284, 1967 (1999).
[2] Koolstra, G. et al., Nat Commun 10, 5323 (2019)
[3] https://www.quantum-machines.co/products/qcage/
[4] Simbierowicz, S. et al, Rev. Sci. Instrum. 94, 054713 (2023)
[5] Crowley, K. D. et al., Phys. Rev. X, 4, 041005 (2023)

A frequency network through parallel processing of frequency-bin entangled photons from a 21 GHz SOI micro-resonator

Nadia Belabas[1],
Antoine Henry[1,2], Dario Fioretto[1], Lorenzo Procopio[1], Stéphane Monfray[4], Frederic Boeuf[4], Laurent Vivien[1], Eric Cassan[1], Carlos Ramos[1], Kamel Bencheikh[1], Isabelle Zaquine[2]

[1]*Centre for Nanosciences and Nanotechnology, CNRS, Université Paris-Saclay, France* [2]*LTCI, Télécom Paris, Institut Polytechnique de Paris, France* [3]*Weizmann Institute of Science, Rehovo, Israel*
[4]*STMicroelectronics SAS, France*
nadia.belabas@c2n.upsaclay.fr

Harnessing the frequency degree of freedom of photons offers interesting perspectives for quantum information processing (QIP), allowing dense coding in a single spatial mode, hyperentanglement, multiplexing, parallelization and large distance traveling without stabilization or drift compensation. State-of-the-art integrated schemes to generate frequency-entangled states for frequency QIP through spontaneous four-wave-mixing (FWM) are limited by trade-offs in size, number of frequency modes and spectral separation. We have developed a bright and low footprint (<0.05 mm^2) photon pair sources emitting at telecom wavelength and generate efficiently **frequency-entangled photon pairs from a Silicon On Insulator (SOI) micro-resonator with a free spectral range (FSR) 21 GHz (Fig 1a-b), harnessing 83 signal-idler pairs** (S_n-I_n) over a >1.5 THz bandwidth (Fig 1d) to encode qubits or even qudits (cf. Fig 1b).

The low 21 GHz FSR is designed for optimal use of off-the-shelf fibered electro-optic phase modulators (EOM) and programmable filters (PF) in an EOM-PF-EOM configuration [1] to **manipulate in parallel several frequency-entangled qubits.** We thus perform quantum state tomography (Fig 1c) applying two parallel quantum gates to two qubits encoded in adjacent modes. We demonstrate such quantum state tomography independently on 17 frequency entangled qubits (coloured modes in Fig 1d) achieving fidelities above 85%. We report [2] for the first time the use of frequency entangled pairs, frequency demultiplexing and parallelized frequency quantum gates on those states to create **in the frequency domain a 5-user-fully-connected network without trusted node (Fig 2).**

References

[1] H-H. Lu et al., Phys. Rev. Letters, 2020.
[2] A. Henry et al., arXiv:2305.03457 (2023)

Figures

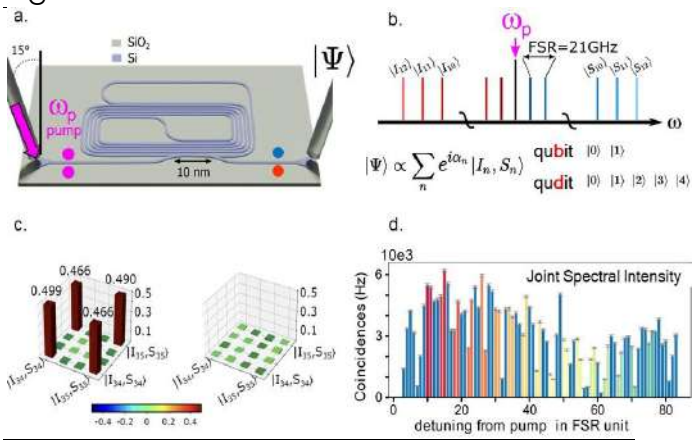


Figure 1: a. FWM photon pair generation in a 21 GHz SOI resonator [shape optimized using Bezier curves to minimize losses, modal phase matching condition setting the silicon waveguide width to achieve abnormal dispersion] pumped by ω_p ~1540 nm cw laser tuned in resonance (b.) c. Real and Imaginary part of the reconstructed density matrix of a 4-frequency-entangled state (fidelity of 0.96% to a maximally entangled state). The generated frequency entangled state $|\psi\rangle$ can be used to encode qubits or qudits for QIP across 166 frequencies (d.)

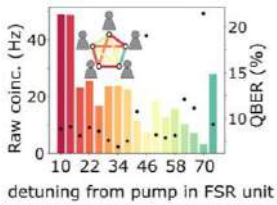


Figure 2: Raw key rate and QBER (qubit error rate) for a frequency fully connected network without trusted node. Reliable (QBER>11%) pairs are exchanged in a frequency fully-connected network following the colour code of Figure 1d.

An integrated microwave-to-optics interface for scalable quantum computing

Alexandra C. Bernasconi
Matthew J. Weaver, Pim Duivestein, Thierry C. van Thiel, Selim Scharmer, Mathilde Lemang, Frederick Hijazi, Bas Hensen, Federico Berto, Kiki L. Schuurman, Martin Žemlička, Ella Lachman, Mark Field, Yuvraj Mohan, Fokko K. de Vries, Cornelius C. Bultink, Jules van Oven, Josh Y. Mutus, Robert Stockill, Simon Gröblacher

QphoX B.V., Elektronicaweg 10, 2628 XG Delft, The Netherlands, Rigetti Computing Inc., 775 Heinz Avenue, Berkeley, California, 94710, United States, Qblox B.V., Delftechpark 22, 2628XH, Delft, The Netherlands

alexandra@qphox.eu

Superconducting qubits hold great potential as building blocks for reliable quantum computers. However, their operating frequency in the microwave range poses challenges for scalability. Converting a microwave signal into an optical signal allows us to address some of these challenges. The connections between different quantum processors become less noisy over an optical link and the cabling for a single quantum processor requires less space and dissipates less heat when the coaxial lines are replaced by multiplexed optical fibres.
We present here a piezo-optomechanical transducer that couples a silicon photonic crystal cavity through a lithium niobate block to a tuneable superconducting microwave resonator. We use a mechanical intermediary, which is predominantly in the ground state. We achieve an input referred added noise of 6 photons by using an optical pulse power of 5 fJ [1]. Additionally, we show that we can use it to read out a superconducting qubit using a demolition multi-shot readout technique [2]. This scalable design paves the way not only for scaling up a single quantum processor but also for distributed quantum computing.

References

[1] Weaver, M.J., Duivestein, P., Bernasconi, A.C. et al., Nat. Nanotechnol., (2023) 1-7
[2] van Thiel, T. C., et al., arXiv preprint arXiv:2310.06026 (2023)

Figures

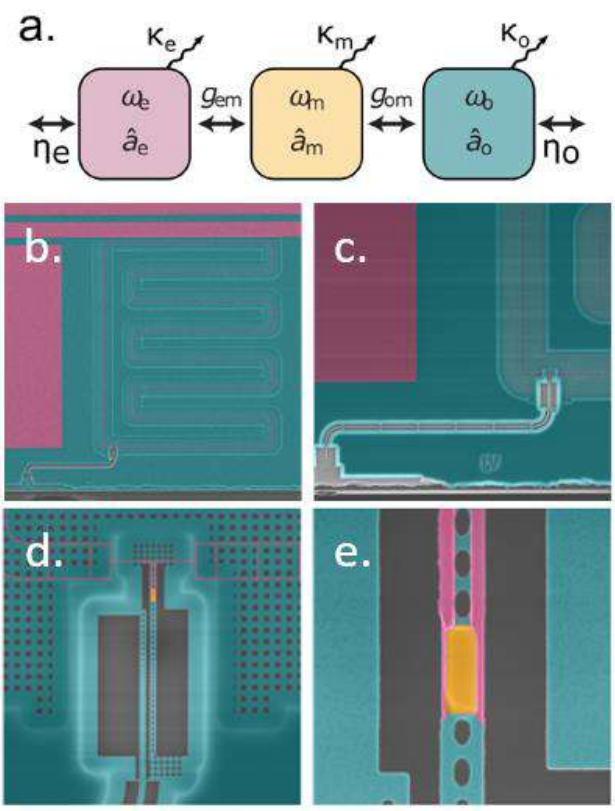


Figure 1: a. Bosonic modes that make up the optomechanical transducer: electromechanical mode (magenta) couples with gem to mechanical mode (yellow) that couples with gom to optical mode (cyan). They each have a frequency of $\omega/2\pi$ and a loss rate of $\kappa/2\pi$. b.-e. scanning electron microscope images of the transducer. [1]

Vulnerabilities of the Reset Operation on Superconducting Qubits

Sorin Bolos
Adrian Colesa, Radu Mărginean

Transilvania Quantum, str. Victor Hugo nr. 21, Cluj Napoca, Romania

sorin.bolos@transilvania-quantum.com

The impact of quantum computing on classical cybersecurity has been discussed extensively over the past 30 years, leading to the development of post-quantum cryptography. At the same time, relatively little attention has been paid to the security of quantum computers themselves.
The little research that studied vulnerabilities of quantum computers until now has focused on a scenario where circuits belonging to different users are executed on the same quantum chip at the same time. [1][2] This mode of operation is not yet in possible.
We focused on vulnerabilities of superconducting QPUs that are available today.
We conducted two experiments on the ibm_osaka quantum chip where we leveraged the imperfections of the reset operation, and we show that: (1) an attacker can infer the final state of the circuit that ran before him, stealing the results of the computation. (2) an attacker can leave qubits in a higher excited state so that the circuit that runs after him will start in a state that is not the ground state, compromising the results.

Figures

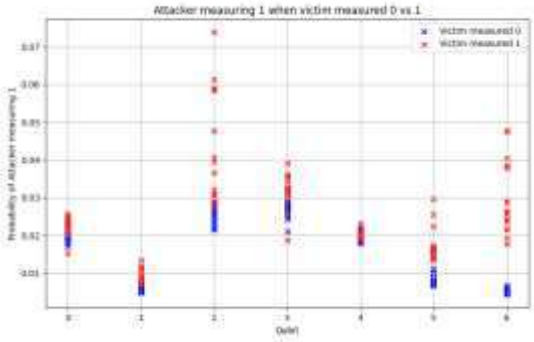


Figure 1: Attacker measuring '1' when victim measured '0' vs '1'.

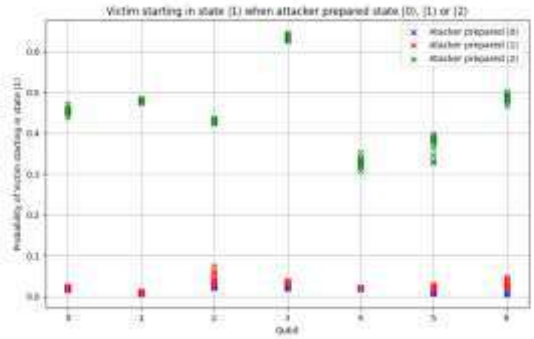


Figure 2: Probability of victim qubits starting in state $|1\rangle$ when the attacker has prepared the qubits in state $|0\rangle$, $|1\rangle$, or the second excited state ($|2\rangle$).

References

[1] S. Deshpande et al., 2022 IEEE International Symposium on Hardware Oriented Security and Trust, 2022, Pp. 37–40.
[2] A. Ash Saki et al, arXiv: 2106.06081
[3] A. Mi, S. Deng, J. Szefer, CCS '22: Proceedings, 2022, Pp. 2279–2293
[4] A. Ash Saki and S. Ghosh, arXiv: 2104.05899, 2021

Pseudo-Qubit Quantum Circuit Modelling: Enabling Large Scale Application Simulations

Gianni Casonato

EUMETSAT, Eumetsat-Allee 1 - Darmstadt (Germany)

gianni.casonato@eumetsat.int

Abstract

This abstract presents an innovative quantum circuit modelling approach, able to open large-scale simulations on commercial computers, and it shows as example an application for Quantum Machine Learning problems.
The simulation of a quantum circuit on classical computers is a challenging task due to the very peculiar physical properties occurring in quantum systems. The complex coefficient linear model typically used in simulation ([1]) is conceptually simple, but it grows exponentially with the size of a qubit register (qureg), and, consequently, it limits the general-purpose quantum circuits size to 30-35 qubits max on commercial computers ([2] and [3]).
To overcome this limitation, an innovative approach is proposed in this paper. The idea is to model a qureg through its elementary qubits instead of the states, and to effectively capture the cross-qubit entanglement relationships, when present. Based on that, a qureg state can be modelled as a linear combination of separable "pseudo" states, which are directly built from elementary qubit ones, embedding in them all the entanglement information. For this reason, the entities used in the model are called "pseudo-qubits", due to their conceptual deviation from the "standard" single state qubit physical model. This pseudo-qubit model supports, with proper internal terms manipulation, all 1-qubit single and 2-qubit controlled transformations in any layout (superset of universal gates), and it provides exact and general-purpose applicability to quantum circuits.
Compared with state-based models where the whole state is instantiated already at state preparation stage, this model makes a progressive use of the parameter space, encompassed with the transformation applications. This key difference has huge impacts in the simulation capabilities, allowing the modelling of very large quantum circuits, under a certain number of transformations limit, opening to research problems not accessible until now.
The pseudo-qubit model is in principle applicable to any circuit, and for its validation, various types of tests are ongoing, particularly in the area of on Quantum Machine Learning (QML) applications. Specifically, the model is being used for Earth Observation image classification problems using from 10 to 40 qubits, implementing different algorithms, in order to support cross validation of the new approach through toy and "realistic" examples, and to perform comparative analysis and discussion of QML enhanced models versus the traditional one.
the quantum advantage assessment on QML enhanced models vs. their "classical" ML counterpart.
The results collected so far are successful and promising for a general validity of the pseudo-qubit model, and its capability of outperforming state-based models in the simulation of large quantum problems (not only QML related) on commercial computers.

References

[1] Quantum Computing and Quantum Information, Nielsen and Chuang, 2017 §1.2 and §1.3
[2] Exploiting GPU-based Parallelism for Quantum Computer Simulation A Survey, S. Heng, Y. Han
[3] Available IBM Quantum simulators - IBM Quantum Documentation, https://docs.quantum.ibm.com/verify/cloud-based-simulators

Ultra-narrow inhomogeneous spectral distribution of telecom-wavelength vanadium centres in isotopically enriched silicon carbide

Pasquale Cilibrizzi
M. J. Arshad, B. Tissot, N. T. Son, I. G. Ivanov, T. Astner, P. Koller, M. Ghezellou, J. Ul-Hassan, D. White, C. Bekker, G. Burkard, M. Trupke, C. Bonato.

School of Engineering and Physical Sciences, SUPA, Heriot-Watt University, Edinburgh, EH14 4AS, United Kingdom.

p.cilibrizzi@hw.ac.uk

Abstract

Spin-active quantum emitters have emerged as a leading platform for quantum technologies [1]. However, one of their major limitations is the large spread in optical emission frequencies, which typically extends over tens of GHz.

Here, we investigate single vanadium (V^{4+}) centres in 4H-SiC [2], which feature telecom-wavelength emission and a coherent S = 1/2 spin state. We perform spectroscopy on single emitters and report the observation of spin-dependent optical transitions, a key requirement for spin-photon interfaces. By engineering the isotopic composition of the SiC matrix, we reduce the inhomogeneous spectral distribution of different emitters down to 100 MHz, significantly smaller than any other single quantum emitter. Additionally, we tailor the dopant concentration to stabilise the telecom-wavelength V^{4+} charge state, thereby extending its lifetime by at least two orders of magnitude.

Our results reveal the potential of single vanadium emitters in SiC as material nodes in scalable telecom quantum networks [3].

References

[1] M. Atatüre, D. Englund, N. Vamivakas, S.-Y. Lee, and J. Wrachtrup, Nature Reviews Materials **3**, 38 (2018).

[2] Cilibrizzi, P., Arshad, M.J., Tissot, B. *et al.*, Nat Commun **14**, 8448 (2023).

[3] S. Wehner *et al.*, Science **362**, eaam9288 (2018).

Figures

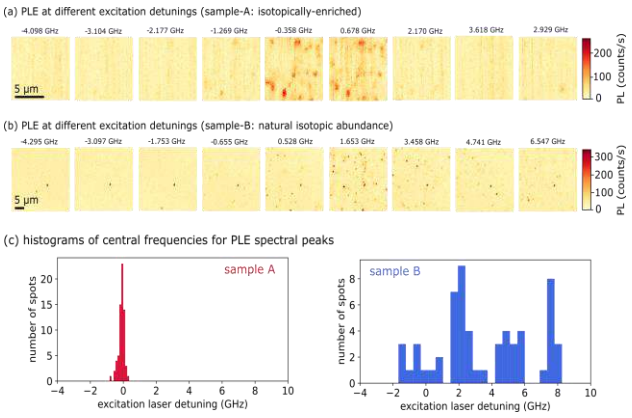


Figure 1: (a), (b) Sequence of PLE maps at different detunings of the excitation laser, respectively for the isotopically enriched sample (A) and the natural-abundance sample (B). In the isotopically enriched sample, the vast majority of emitters appear only in a narrow frequency range. **(c)** Histograms for the central frequencies of 181 PL spots associated to vanadium centres in the natural-abundance (right) and 61 spots in isotopically enriched (left) samples. In the sample with a natural abundance of silicon and carbon isotopes, the vanadium centres are spectrally spread over several GHz, presenting a distribution with multiple peaks. In contrast, the distribution is much narrower in the isotopically enriched sample, with a standard deviation of about 100 MHz. Figure taken from Ref. [2].

Flexible stripline I/O with embedded filtering: scalable signal delivery platform with proven qubit performance

Nikolai Drobotun
Kiefer Vermeulen
Wouter Bos
Marc de Voogd
Daan Kuitenbrouwer
Jakob Kammhuber
Artem Nikitin
Sal Bosman

Delft Circuits, Schieweg 15A,2627 AN, Delft, The Netherlands

nikolai@delft-circuits.com

Scaling up the cryogenic wiring for transmon qubit experiments became a vital challenge in building multiqubit quantum computers [1]. Existing conventional wiring in combination with general-purpose microwave components has a low ability for scaling due to the mechanical dimensions and thermal properties of the material.[2]
Our work demonstrates a novel approach to making a quantum I/O. Fully embedded channels for transmon qubit Drive, Flux/Bias, and Pump signals are based on stripline transmission lines with integrated conditioning/filtering components.
We optimized the performance of the proposed I/O to reach high signal integrity in combination with specific filtering to reject high-frequency modes and photonic noise.
Another important aspect we studied is the thermal properties of a physical transmission line based on our stripline stack-up.
We demonstrate the results of the superconducting qubit experiments (T1, T2, T2echo). The obtained results show that our flexible I/O is not a limiting factor for transmon coherence below a value of 40 us.

References

[1] S. Krinner, S. Storz, P. Kurpiers, P. Magnard, J. Hein-soo, R. Keller, J. Lütolf, C. Eichler, and A. Wallraff, Engineering cryogenic setups for 100-qubit scale superconducting circuit systems, EPJ Quantum Technol. 6, 2 (2019).

[2] J. C. Bardin, D. H. Slichter, and D. J. Reilly, "Microwaves in quantum computing," IEEE Journal of Microwaves 1, 403–427 (2021) IEEE Journal of Microwaves 1, 403–427 (2021).

Figures

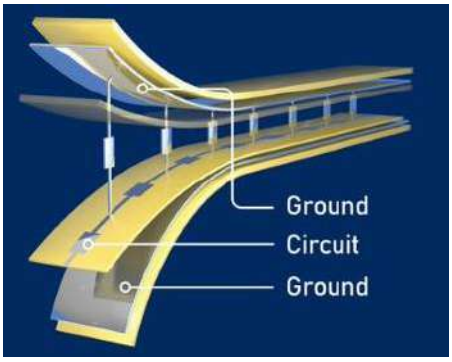


Figure 1: Flexible stripline structure

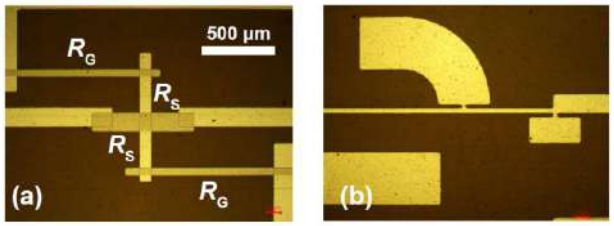


Figure 2: Signal conditioning layout structures: (a) – integrated attenuator, (b) – integrated low-pass filter

Scaling spin qubit devices: vertical interconnects through Al_2O_3

H.G.J. Eenink[1]
S.V. Amitonov[1], S.D. Oosterhout[1], L Tryputen[1], A. Sammak[1], D.J. Michalak[1], F. Borsoi[2], V.John[2], L.E.A. Stehouwer[2], M.W.H. De Smet[2], Y. Matsumoto[2], G. Scappucci[2], L.M.K. Vandersypen[2], M. Veldhorst[2]

1 QuTech and TNO Netherlands Organisation for Applied Scientific Research, Stieltjesweg 1 2628 CK, Delft, Netherlands
2 QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1 2628 CJ, Delft, Netherlands
gertjan.eenink@tno.nl

To successfully scale quantum devices to larger numbers of qubits, the fabrication toolkit needs to be expanded. While conventional semiconductor devices use multi-layered metal lines with vertical interconnects, this technique is not yet adapted and employed for quantum devices. We have developed two processes for this purpose, first an etching and metallization process that enables vertical connection through Al_2O_3. This functionality enables an upgrade of current devices [1] to perform conveyor-mode single electron shuttling in Si/SiGe [2] over distances of 10 µm and more. 8 sets of 15 gates each can be contacted in parallel. In addition, we have adapted platinum germanosilicide ohmic contacts [3] for small footprints of ~200x200 nm. In combination with vertical contacts, this enables advancing dense 2D arrays of Ge/SiGe quantum dots [4] by integration of a single electron transistor charge sensor inside the array. In this talk we will describe the development, challenges and results of both processes, and show how characterization of the diffusion process allows us to ensure low-resistance contact to the quantum well. Finally we will discuss the implications for the scaling of quantum devices.

References

[1] Zwerver, A.M.J. et al., PRX Quantum 4, 030303 (2023)
[2] Seidler, I. et al., npj Quantum Inf 8, 100 (2022)
[3] Sammak, A. et al., Adv. Funct. Mater. 29, 1807613 (2019)
[4] Borsoi, F. et al., Nat. Nanotechnol. 19, 21-27 (2024)

Figures

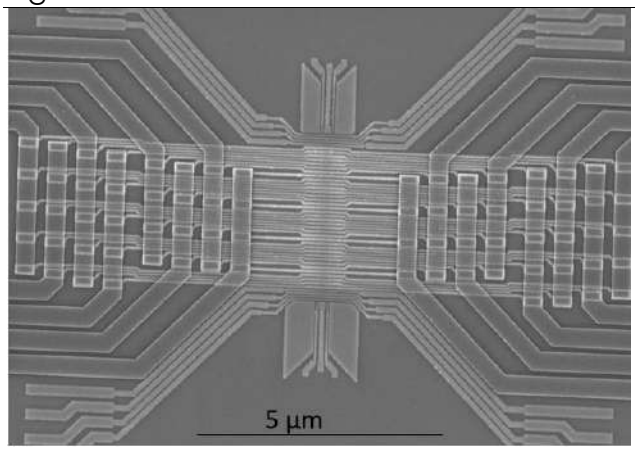


Figure 1: SEM image of conveyor gates spanning 3 µm. 8 sets of Ti/Pd gates are contacted by vias.

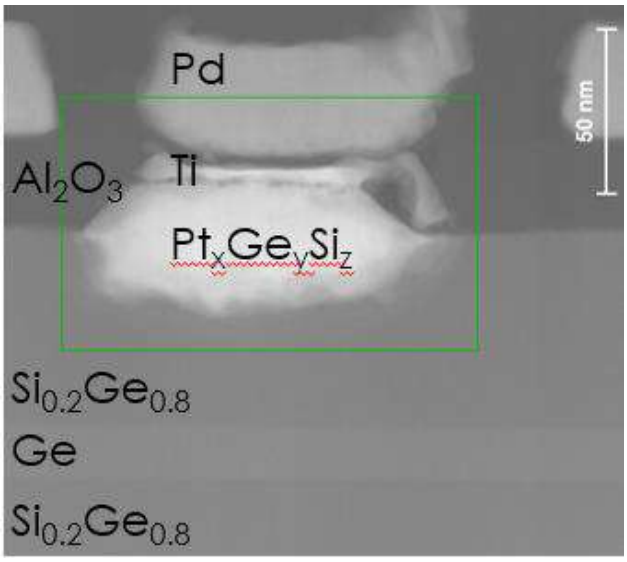


Figure 2: TEM image of nanoscale platinum germanosilicide ohmic contact. Platinum diffuses partly into the SiGe buffer.

High-Fidelity Quantum Information Processing with Machine Learning-Characterized Photonic Circuits

Andreas Fyrillas,[1,2,*] Olivier Faure,[1], Nicolas Maring [1], Jean Senellart [1] and Nadia Belabas [2]

[1] *Quandela, 7 rue Léonard de Vinci, Massy 91300, France*
[2] *Centre for Nanosciences and Nanotechnologies, CNRS, Université Paris-Saclay, UMR 9001, 10 Boulevard Thomas Gobert, 91120, Palaiseau, France*
[*] *andreas.fyrillas@quandela.com*

Abstract: Photonic integrated circuits (PICs) are attractive platforms for manipulating quantum light. Imperfections limit the fidelity of photonically integrated quantum information protocols. We use machine learning and a clear box approach to characterize large PICs and mitigate imperfections, achieving high-fidelity for scalable implementations.

Photonic integrated circuits (PICs), compact platforms for light manipulation, have a great potential in quantum computing, communication, cryptography, sensing, and a wide range of classical applications. PIC imperfections pose challenges, leading for instance to a severe degradation in performance of optical neural networks and a marked decrease in the fidelity of quantum gates. Existing self-configuration protocols, that mitigate imperfections without requiring detailed knowledge of the device, fall short in addressing these issues. Leveraging machine learning, particularly neural networks in so-called black-box model-based approaches, has shown promise but faces scalability challenges regarding the number of data samples and computational resources required to train the model. We propose a clear-box approach, where physical intuition is embedded in an explicit model of PIC imperfections [1]. We thus significantly enhance sample efficiency and scalability of the PIC characterization. We introduce an iterative machine learning-assisted PIC characterization process to train a virtual replica of the physical device that is then harnessed by an imperfection mitigation. We achieve unparalleled optimal control on a 12-mode Clements universal interferometer (see Fig. 1b), demonstrating the effectiveness of our approach on one of the largest PICs available. Our work [1] is also the first demonstration of the retrieval of individual component parameters such as crosstalk coefficients and beamsplitter reflectivity values in complex interferometer meshes.

1. Optimal control of photonic circuit using a clear-box model-based approach

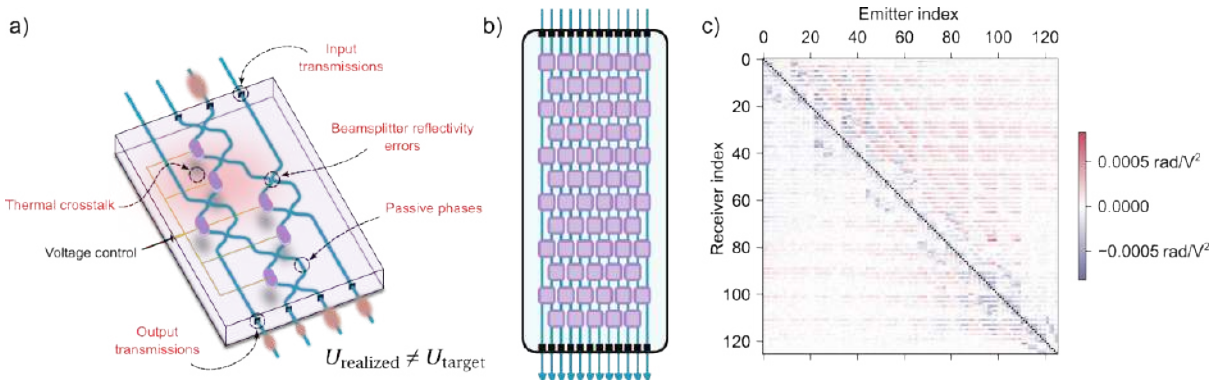


Fig. 1. **a)** Example of photonic integrated circuit (PIC) and imperfections that degrade the fidelity of photonic quantum information processing. As a result, the implemented unitary matrix U_{realized} differs from the targeted operation on light U_{target}. **b)** 12-mode Clements interferometer. Each block contains two phase shifters and two beamsplitters. Input light comes from the top and reaches the detectors on the bottom. **c)** Estimated 126×126 crosstalk matrix of a 12-mode Clements interferometer featuring 126 thermo-optic phase shifters linking the applied voltages squared to the implemented phases. An ideal circuit without crosstalk would yield a diagonal matrix.

In more details, PIC imperfections (see Fig. 1a) decrease the fidelity of the implemented matrix with respect to the target unitary matrix to apply on the input photons. We create a virtual replica of the physical device, which is built using physical models for each imperfection. For instance, thermal crosstalk is taken into account by using a crosstalk matrix to link the implemented phases to the applied voltages, where diagonal elements represent the self-heating coefficients and off-diagonal elements account for crosstalk.

Our PIC characterization method tunes the model parameters such that the virtual replica reproduces the behavior of the physical device. The model is trained using an iterative protocol which alternates between interference fringe measurements and machine learning stages. The machine learning stages, which update the estimated crosstalk matrix in particular, consist in a gradient descent algorithm that learns from acquired data samples on the physical device. This iterative process aims at enhancing the accuracy of the virtual replica at each new iteration.

Universal-scheme PICs, like Clements interferometers, can by definition implement any unitary matrix acting on the spatial input modes. Our imperfection mitigation process leverages the knowledge of the physical device acquired during the characterization stage to compute the voltages that implement the target unitary matrix, compensating for beamsplitter reflectivity errors and thermal crosstalk leading to a high-fidelity implementation of the target matrix and e.g. quantum protocols.

2. Experimental validation on a 12-mode Clements interferometer

The experimental validation of our process is conducted on a 12-mode universal-scheme PIC with a Clements mesh as shown on Fig. 1b, featuring 126 reconfigurable thermo-optic phase shifters and 132 directional couplers [3]. We characterize the phase-voltage relation, beamsplitter reflectivity errors, and input/output transmissions. We show on Fig. 1c the estimated crosstalk matrix. Experimental assessment of the characterization accuracy yields a circuit amplitude fidelity of $\mathscr{F}_a = (99\ 92 \pm 0\ 02)\,\%$ for 100 random phase configurations, demonstrating high precision of the virtual replica predictions with orders of magnitude lower sample and computational requirements compared to previous demonstrations. Compilation of 100 Haar-random unitary matrices using a deterministic method with detector relabelling achieves a unitary amplitude fidelity of $(99\ 77 \pm 0\ 04)\,\%$, resulting in the highest reported values in the literature for Clements interferometers on the most complex PIC characterized with machine learning to date (see Table 1).

Ref	Number of modes	Amplitude fidelity
[2]	6	1.3 %
[4]	20	2.6 %
[1] (this work)	**12**	**0.23%**

Table 1. State of the art in photonic circuit optimal control demonstrated on Clements meshes.

3. Discussion and outlook

Our characterization method combines machine learning with a clear-box approach, modeling both the physical PIC and its imperfections, overcoming accuracy limitations of existing methods relying solely on interference fringe measurements. Our approach requires orders of magnitude fewer training samples and computational power thanneural network-based methods, ensuring scalability, while also achieving the highest recorded fidelities. Future work includes investigating and mitigating other PIC imperfections, while developing faster compilation method. The increased reliability of photonic devices holds promise for transformative advances in quantum information processing. Photonic quantum computing reaps substantial benefits from increased PIC accuracy, by achieving for instance higher qubit fidelities. These advances open the way to efficient near-term quantum processors with demonstrations of boson sampling with reconfigurable circuits or graph problem solvers and are essential buiding blocks for fault-tolerant quantum computing harnessing integrated photonic components.

References

1. A. Fyrillas, O. Faure, N. Maring, J. Senellart, N.Belabas “Scalable machine learning-assisted clear-box characterization for optimally controlled photonic circuits“ arXiv:2310.15349. Accepted to Optica. 2024.
2. S. Bandyopadhyay. et al. Single chip photonic deep neural network with accelerated training. arXiv.2208.01623 (2022).
3. C. Taballione et al. A universal fully reconfigurable 12-mode quantum photonic processor. Mater. Quantum. Technol. 1, 035002 (2021).
4. C. Taballione et al. 20-Mode Universal Quantum Photonic Processor. Quantum 7, 1071 (2023).

Accelerating resonator spectroscopy using microwave pulses

Oscar Gargiulo
Felix Rucker

kiutra GmbH, 81369, Munich, Germany.

oscar.gargiulo@kiutra.com

The characterization of microwave resonators is an established method to evaluate materials losses [1] to improve the fabrication process for qubit chips. In addition, high quality resonators are essential for reliable qubit readout at low powers. A typical characterization consists of a measurement of the resonator's quality factor as a function of the number of photons and temperature.

Typically, such measurements rely on a vector network analyser (VNA) specifically designed and calibrated to evaluate the scattering matrix parameters of a system. In this article, we explore the potential of employing pulsed instruments as an alternative to speed up resonator characterization. Such instruments can deliver precise microwave pulses with stable timing and phase and are used for the characterization and control of qubits. Despite the intricacies involved in precisely executing the resonator characterization compared to using a VNA, tailoring unique pulses for individual resonators enables us to accelerate the process while maintaining high data quality. We compare the results with those obtained using a VNA and demonstrate that equivalent results can be achieved almost 3 times faster.

Figures

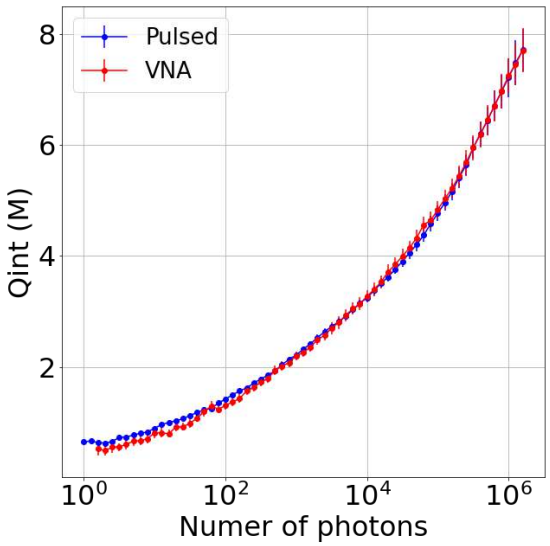


Figure 1: Comparison between a resonator characterization using a pulsed instrument (blue) and a network analyser (red). Q_{int} is extracted using a circle fit routine [2]. Power is converted to photons after calibrating the instruments output powers, cryostat lines and room temperature cables. The measurement was performed at 100 mK using a kiutra L-Type Rapid cryostat.

References

[1] McRae *et al.*, Review of Scientific Instruments, 91, 091101 (2020)
[2] Probst *et al.*, Review of Scientific Instruments, 86, 024706 (2015)

Coherent control and large-scale characterisation of silicon quantum devices fabricated using 300-mm wafer processes

Miguel Fernando Gonzalez-Zalba

University of Cambridge

mg507@cam.ac.uk

Silicon-based quantum computing has seen substantial progress in the last few years - developments include demonstrations of fidelities above the fault-tolerant threshold and scaling to several-qubit devices. Industrial fabrication processes are now being used to take full advantage of the scaling and cryo-electronics co-integration capabilities offered by silicon technologies. We present Quantum Motion's recent work on devices fabricated using 300-mm wafer processes, including exchange-driven spin-spin interactions, rapid characterisation of 1000+ quantum dots, and on-chip deep-cryogenic thermometry

Quantum Operations and Business Innovation: Leveraging Sustainability and Energy Efficiency for Accelerated Impact

Carlos Kuchkovsky

qcentroid

carlos@qcentroid.xyz

Join Carlos Kuchkovsky at QCENTROID for an engaging presentation that explores the intersection of quantum computing with sustainability and energy efficiency in business operations. This talk will introduce a groundbreaking problem-centered framework designed to enhance the business impact of quantum technologies. Focusing on the integration of quantum operations and business strategies, Carlos will guide the audience through the critical stages of leveraging quantum computing—from the identification of problems to the implementation of practical, impactful solutions. This approach aims to align technological advancements in quantum computing with pressing environmental goals, fostering both innovation and sustainability.

The discussion will underscore the importance of continuous benchmarking and seamless integration of quantum solutions into existing business ecosystems. By navigating the complexities of algorithm evolution, hardware improvements, and data proliferation, Carlos will demonstrate how a problem-centered perspective can unlock unprecedented opportunities in quantum computing. This methodology not only promises to elevate the sustainability and efficiency of business operations but also positions companies at the forefront of the quantum revolution, driving competitive advantage and environmental stewardship.

Characterising frequency fluctuations in superconducting qubits

Abhishek Agarwal
Lachlan Lindoy, Yannic Rath, Deep Lall, Ivan Rungger

National Physical Laboratory, Teddington, United Kingdom

abhishek.agarwal@npl.co.uk

Non-Markovian noise is an important source of noise in superconducting qubits available today [1]. In this presentation we show that including the effects of non-Markovian noise allows us to have a model that can accurately capture the device physics. We further develop a method to perform experiments on a superconducting qubit quantum computer to resolve qubit frequency fluctuations at different time scales, and show that the frequency fluctuations are the dominant source of observed non-Markovian noise in the device [2]. The methods allow us to see the effects of quasiparticle induced charge parity fluctuations, as well as frequency fluctuations due to two level fluctuators. We analyse the magnitude and rate of charge parity fluctuations, as well as fluctuations in the asymmetric charge parity frequency splitting. The understanding of these non-Markovian noise sources provided by our model and by our experiments can allow us to optimize the calibration of the devices and to further mitigate the effects of noise.

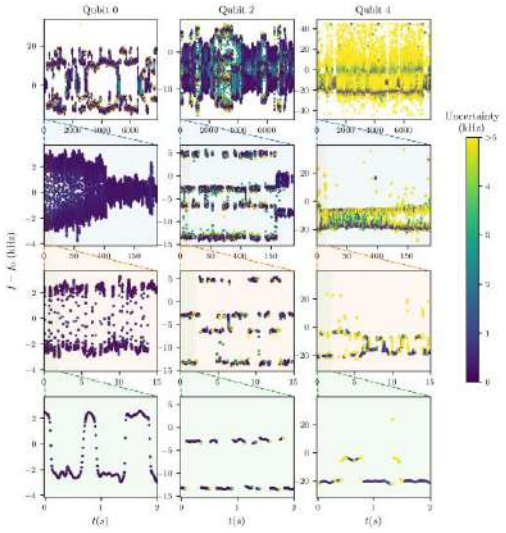


Figure 1: Estimated qubit frequency errors for three qubits (columns) as a function of time for different timescales (rows). Discrete jumps in qubit frequency between two values are visible and explained by charge parity fluctuations. For qubit 2, further jumps are observed and explained by interactions with a two-level-fluctuator.

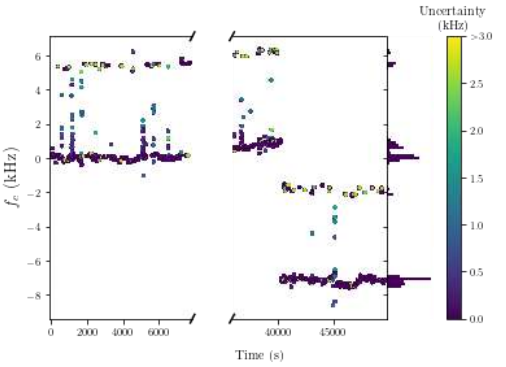


Figure 2: The centre of the frequencies corresponding to the two charge parity states for qubit 0, extracted after disambiguating the different kinds of fluctuations. Jumps in the centre frequency between two values can be seen, corresponding to a two-level fluctuator. A further jump at ~40,000s can be explained by an additional, slower fluctuator.

References

[1] Abhishek Agarwal, et al. "Modelling non-Markovian noise in driven superconducting qubits.", arXiv:2306.13021 (2023)

[2] Abhishek Agarwal, et al. " Characterising qubit frequency fluctuations in superconducting qubits." (2024) (in preparation)

Figures

Polarization-wavevector correlation in entangled photons from cavity-embedded quantum dots

Alessandro Laneve[1]
Michele B. Rota[1]
Mattia Beccaceci[1]
Valerio Villari[1]
Tobias M. Krieger[2]
Thomas Oberleitner[2]
Saimon F. Covre da Silva[2]
Quirin Buchinger[3]
Sandra Stroj[4]
Sven Hoefling[3]
Francesco Bassso Basset[1]
Tobias Huber-Loyola[3]
Armando Rastelli[2]
Rinaldo Trotta[1]

[1]*Sapienza University of Rome, Piazzale Aldo Moro 5, Rome, Italy*
[2]*Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Altenbergerstraße 69, Linz 4040, Austria*
[3]*Technical Physics, University of Wuerzburg, Am Hubland, D-97074 Wuerzburg, Germany*
[4]*Forschungszentrum Mikrotechnik, FH Vorarlberg, Hochschulstr. 1, A-6850 Dornbirn, Austria*

Alessandro.laneve@uniroma1.it

We demonstrate that emitters coupled to cavities may feature a pronounced polarization pattern, by experimentally investigating the correlation between polarization and wavevector of photons emitted by GaAs quantum dots embedded in different types of cavities. We analyse the polarization pattern of the radiation Back Focal Plane, determining the effect on the polarization profile of the cavities. We show that the polarization reshaping is stronger for more efficient cavities, as for the case of bullseyes [7]. By sampling photon pairs using differently sized and differently centred collection cones, we demonstrate a strong interplay between quantum correlation of photons and their wavevectors, a result that can open the path towards the design and the fabrication of near-ideal entangled photon sources in the solid state.

Reliable generation of entangled photons is crucial for the realization of efficient quantum communication and cryptography protocols. Radiative atomic cascades have been a fundamental resource of quantum light, enabling milestone experiments in quantum information [1, 2]. The development of efficient emitters of the same kind, such as quantum dots, is pivotal for establishing reliable quantum networks [3,4].
An ideal source of this kind is generally regarded as producing maximally entangled photon pairs; on the other hand, seminal works [5,6] highlighted an expected correlation between polarization state of photons and their wavevector, that affects the degree of entanglement.
Such effect is negligible for emitters in vacuum since it occurs to effectively unreachable emission angles. Nevertheless, state-of-the-art emitters are generally embedded in cavity, engineered to enhance the collection efficiency of emitted photons.

References

[1] Freedman, Stuart J., and John F. Clauser, *Physical Review Letters,* 28.14 (1972): 938.
[2] Aspect, A., Grangier, P., & Roger, G.. *Physical review letters*, *47* (1981): 460.
[3] Lodahl, P., *Quantum Science and Technology* 3.1 (2017): 013001
[4] Schimpf, C., Reindl, M., Basso Basset, F., Jöns, K. D., Trotta, R., & Rastelli, A., *Applied Physics Letters*, *118*.10 (2021).
[5] Clauser, J. F., Horne, M. A., Shimony, A., & Holt, R. A., *Physical review letters*, *23*.15 (1969), 880
[6] A Shimony. "Foundations of quantum mechanics". In: Proc. Intern. Sch. Phys. Enrico Fermi 182 (1971).
[7] Davanco, M., Rakher, M. T., Schuh, D., Badolato, A., & Srinivasan, K., *Applied Physics Letters*, *99*.4 (2011).

Quantum for Logistics: solving real-world bin packing and package delivery routing problems using quantum annealers

Eneko Osaba
Esther Villar-Rodriguez

TECNALIA, Basque Research and Technology Alliance (BRTA), 48160 Derio, Spain.

eneko.osaba@tecnalia.com

Research focused on the conjunction between quantum computing and logistic problems has been very prolific in recent years. This talk is focused on two problems of this kind: the three-dimensional Bin Packing Problem and a real-world-oriented package delivery routing problem. More concretely, how such realistic problems can be addressed from the perspective of a quantum annealer will be detailed. For doing that, two quantum-classical hybrid systems will be described, coined ***Quantum for Real Bin Packing Problem*** (*Q4RealBPP [1,2]*) and ***Quantum for Real Package Delivery*** (*Q4RPD*), respectively. The main strength of these systems is their ability to cope with real-world restrictions. Indeed, the two optimization problems addressed in this talk have been defined involving a Spanish company specializing in transport and logistics. On the one hand, *Q4RealBPP* deals with constraints such as overweight restrictions, preferences for package ordering, and affinities among item categories, among many others. On the other hand, *Q4RPD* deals with a heterogeneous fleet of vehicles, priority demands, and the representation of the capacities using two values (weight and dimension), among others. Both *Q4RealBPP* and *Q4RDP* resort to the Leap Constrained Quadratic Model (*CQM*) Hybrid Solver of D-Wave. Finally, different kinds of visual demonstrations will be shown to illustrate the practical potential of the developed systems (examples in Figure 1 for the *Q4RealBPP* and Figure 2 for the *Q4RPD*.

References

[1] Romero, S. V., Osaba, E., Villar-Rodriguez, E., Oregi, I., & Ban, Y. (2023). Hybrid approach for solving real-world bin packing problem instances using quantum annealers. Scientific Reports, 13(1), 11777.

[2] Romero, S. V., Osaba, E., Villar-Rodriguez, E., & Asla, A. (2023). Solving Logistic-Oriented Bin Packing Problems Through a Hybrid Quantum-Classical Approach. arXiv preprint arXiv:2308.02787.

Figures

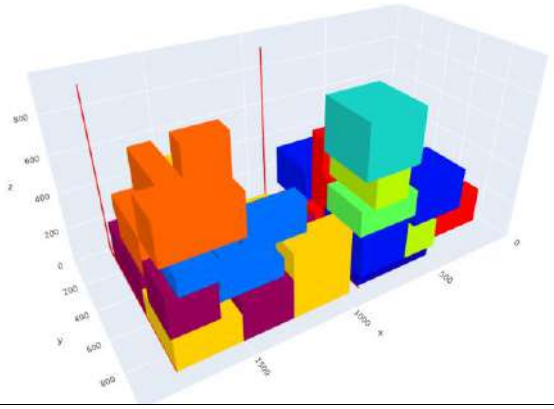


Figure 1: Example of a *Q4RealBPP* output

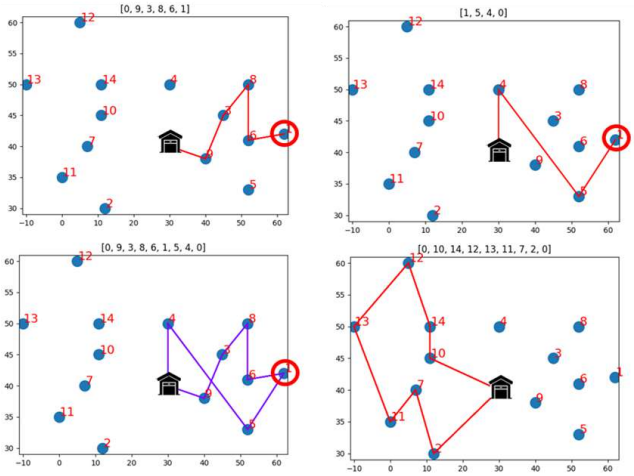


Figure 2: Examples of *Q4RPD* outputs

A single-photon-based quantum computing platform

Mathias Pont[1]

Nicolas Maring,[1] Andreas Fyrillas,[1] Edouard Ivanov,[1] Petr Stepanov,[1] Nico Margaria,[1] William Hease,[1] Anton Pishchagin,[1] Aristide Lemaître,[2] Isabelle Sagnes,[2] Thi Huong Au,[1] Sébastien Boissier,[1] Eric Bertasi,[1] Aurélien Baert,[1] Mario Valdivia,[1] Marie Billard,[1] Ozan Acar,[1] Alexandre Brieussel,[1] Rawad Mezher,[1] Stephen C. Wein,[1] Alexia Salavrakos,[1] Patrick Sinnott,[1] Dario A. Fioretto,[2] Pierre-Emmanuel Emeriau,[1] Nadia Belabas,[2] Shane Mansfield,[1] Pascale Senellart,[2] Jean Senellart,[1] and Niccolo Somaschi [1]

[1] *Quandela, 7 rue Léonard de Vinci, 91300 Massy, France*

[2] *Université Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies, 91120, Palaiseau, France*

mathias.pont@quandela.com

Quantum computing with light has recently been brought by several demonstrations at the edge of quantum computational advantage. These demonstrations were obtained making use of squeezed light and Gaussian Boson Sampling protocols. However, most of the roadmaps to fault-tolerant universal quantum computing are based on encoding the information on single photons.

In this work, we present the first general-purpose quantum computing platform based on single photons named *Ascella* [1]. It relies on a record efficiency monolithic bright source of pure and indistinguishable singe photons [2] that feeds a universal and reconfigurable 12-mode linear optical network with 6 photonic qubits. *Ascella,* enhanced by machine learning which corrects hardware imperfections, shows state-of-the-art performances in terms of photonic qubit quality together with unparalleled number of manipulated photons and sampling rates. The system can be operated from the *Quandela Cloud* with gate-based logical circuits or directly manipulating single photons.

For gate-based computation we benchmark 1-, 2- and 3-qubit gates with fidelities of 99.6±0.1%, 93.8±0.6% and 86±1.2% respectively, at the very best level all platforms considered. As a use case of the platform in the gate-based quantum computation framework we implement a variational quantum eigensolver to calculate the energy levels of H_2 with record accuracy for photonic implementations. For photon native computation, we perform the first photon-based quantum machine learning classification using a 3-photon-based quantum neural network, and report a first 6-photon Boson Sampling on-chip. Finally, we demonstrate the very first heralded generation of a 3-photon GHZ state. Such heralded entanglement schemes combined with the recent demonstration of efficient generation of linear cluster states directly from the same quantum dot source technology [3] open the path to fault tolerant quantum computing with reasonable hardware resource overheads.

Figures

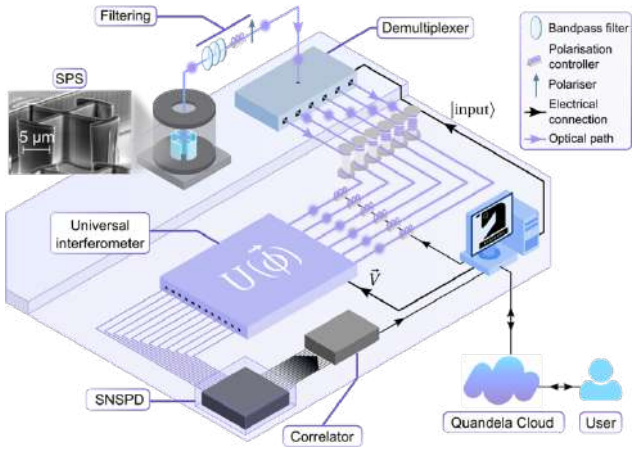


Figure 1: Sketch of the overall architecture of the 6 single-photon quantum computer.

References

[1] **Maring, Nicolas, et al. *arXiv preprint arXiv:2306.00874* (2023).**

[2] Somaschi, Niccolo, et al. *Nature Photonics* 10.5 (2016): 340-345

[3] Coste, N., et al. *Nature Photonics* (2023): 1-6.

Variational diabatic annealing schedules with Landau-Zener-Stückelberg interference

Arnau Riera
Matthias Werner, Jeremy Côté, Marta P. Estarellas, Matías Jonsson and Artur García

Qilimanjaro Quantum Tech., Carrer dels Comtes de Bell-Lloc, 161, 08014 Barcelona, Spain

arnau.riera@qilimanjaro.tech

In recent years there have been great advances in improving the coherence of quantum annealing hardware. First experiments show the presence of coherence in large devices, sparking hopes for quantum advantage through quantum annealers. However, exponentially closing spectral gaps are a major obstacle to solving computational problems with adiabatic quantum annealers. In a recent paper, variationally optimized diabatic annealing schedules were investigated and an exponential speed-up over the adiabatic model was observed [1].

Here, we propose a theoretical explanation for this observation. We identify the interference between amplitudes of different energy levels after consecutive Landau-Zener crossings, also known as Landau - Zener - Stückelberg (LZS) interference, as the basic mechanism of the observed speed-up. We then proceed by defining a class of variational diabatic annealing schedules that make use of LZS interference and thus drastically reduces the search space for the optimal parameters. We prove that if an efficient, optimal annealing schedule is in this schedule class, the parameters can be optimized efficiently, which also allows us to state conditions when variational schedules provide an exponential speed-up over adiabatic annealing, even if the optimization cost is considered. After trotterization, our results readily extend to gate-based variational algorithms.

References

[1] Jeremy Côté et al. Quantum Sci. Technol. 8 045033 (2023)

Figures

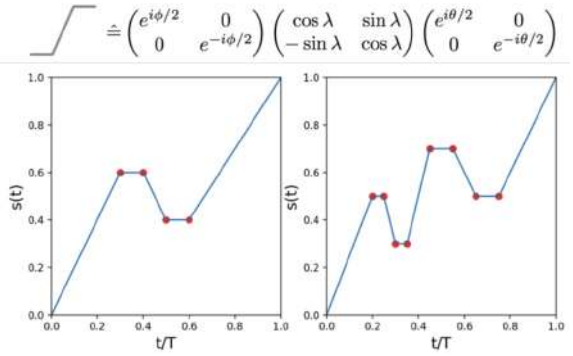


Figure 1: Illustration of a schedule fragment consisting of a ramp flanked with waiting periods (top), which is equivalent to three rotations where j and q are free parameters and l is free within some range. Schedules build from this fragment (bottom) can be optimized to overcome exponentially closing gaps.

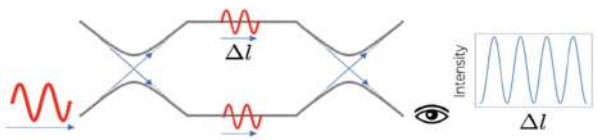


Figure 2: Different energy levels can be thought of as different beam paths: the system starts in the ground state and the population splits when the system is ramped. By adjusting the path length Dl, the measured intensity / ground state population can be adjusted.

SPOQC: a Spin-Optical Quantum Computing architecture

Paul Hilaire, Grégoire de Gliniasty, Pierre-Emmanuel Emeriau, Stephen Wein, Alexia Salavrakos, Shane Mansfield

Quandela, 7 rue Léonard de Vinci, Massy, France

Paul.hilaire@quandela.com

A fault-tolerant quantum computer (FTQC) executes various quantum algorithms reliably despite minor yet significant noise. Achieving this requires careful arrangement of components for fault-tolerant quantum information processing without excessively large hardware. Photonic technology shows promise for large-scale quantum computing, but current efficient all-optical FTQC architectures [1] have a large resource footprint due to heavy reliance on resource state generators based on extensive hardware multiplexing. Quantum-emitter-based single-photon sources have recently outperformed traditional methods in single-photon quality, with their spin acting as a quantum memory, enhancing entanglement with emitted light. The current largest photonic entangled state was produced with this kind of sources [2-3]. We propose the spin-optical quantum computing (SPOQC) architecture, tailored for quantum emitter-based platforms, significantly reducing the resource footprint and hardware complexity without relying on multiplexing. It leverages spin-entangled photon emission and efficient repeat-until-success gates to fault-tolerantly process quantum information. SPOQC's performance matches that of all-photonic architectures. It assesses It is modular, scalable and can implement any stabilizer quantum error correcting (QEC) codes. Quantum information is encoded in quantum emitters' spin, with photons facilitating long-range two-spin gates, thus facilitating the implementation of advanced QEC codes (that are intrinsically nonlocal) and which can also significantly reduce the algorithm's runtime.

References

[1] S. Bartolucci et al., Nat. Comm. 14, 912 (2023)
[2] P. Thomas et al. Nature, 608, 677 (2022)
[3] N. Coste et al., Nat. Photon., 17, 582 (2023)

Figures

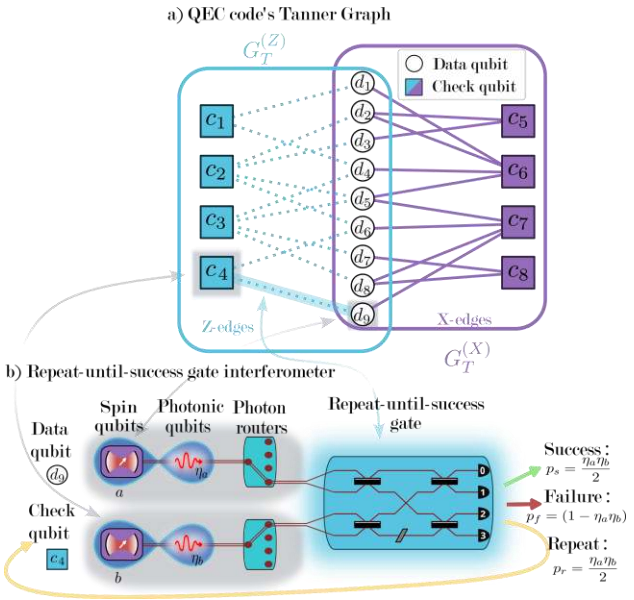


Figure 1: Overview of the SPOQC architecture. (a) a QEC code is characterized by its Tanner graph. (b) Each node of the Tanner graph is associated with a physical spin qubit and the edge connectivity physically represents a Repeat-Until-Success linear-optical gate that performs a CZ gates between each physical spins.

Optimized semiconductor single electron pumps for metrology and quantum technology

Hans Werner Schumacher[1]
Thomas Gerster[1], Frank Hohls[1], Vyacheslavs Kashcheyevs[2]

[1]*Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany*
[2]Departments of Physics, University of Latvia, Riga LV-1002, Latvia

hans.w.schumacher@ptb.de

Since the 2019 revision of the SI systems of units the international units are defined by fixed numerical values of a set of natural constants. With respect to electricity, the base unit of the electrical current, the Ampere, is defined by the value of the electrical charge of the electron of e = 1.602 176 634 x 10^{-19} As.

As a consequence, a primary quantum standard for the Ampere can be realized using so-called single electron pumps (SEPs) [1]. These are based on single electron transistors that are driven by an oscillating gate voltage with frequency f. During one oscillation cycle one electron is captured from source and later ejected to drain thereby generating a quantized current $I = ef$ only given by the applied frequency and the defined value e.

So far, the best demonstrated quantization accuracy of such an SEP has been obtained in gated quantum dots in a GaAs/AlGaAs heterostructures where a quantised current of about 100 pA has been found equal to ef within an uncertainty of 1.6 x 10^{-7} [2]. This extreme accuracy is not only relevant for metrology but also for spin qubits, where the clocked transport of electrons is discussed as a quantum link between neighbouring qubits [3].

In the talk I will first summarize the state of quantum current metrology based on single electron pumps. Then, I will discuss an optimized gate designs and a reliable fabrication process for these devices [4] and will show how single- and double gate operation during pumping allows to shift the single electron capturing process from the so-called back-tunneling (or decay cascade) regime to the thermal regime where the capturing error is determined by the fermi distribution of the source [5].

References

[1] H. Scherer, Hans W. Schumacher Ann. Phys. 531 (2019) 1800371.
[2] F. Stein et al., Appl. Phys. Lett. 107 (2015) 103501.
[3] A.M.J Zwerver et al., PRX Quantum 4 (2023) 030303.
[4] T. Gerster et al., in preparation.
[5] F. Hohls, et al., Phys. Rev. B 105 (2022) 205425.

Figures

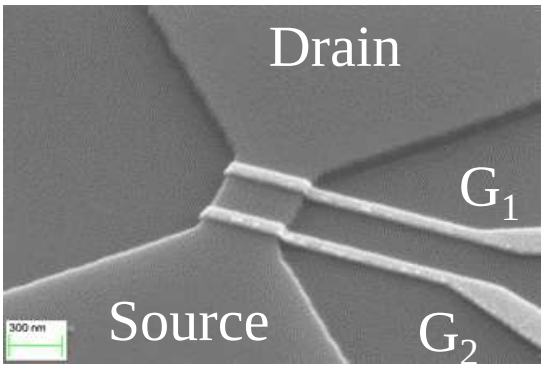


Figure 1: Single electron pump fabricated from an etched GaAs/AlGaAs heterostructure with top gates G defining a single electron transistor between source and drain. Operating the device with oscillating gate voltages with frequency f allows the generation of quantized currents $I = ef$ from source to drain.

Look-up table based fast tune-up of superconducting quantum processors.

Thijs Stavenga
Thijs Stavenga, Roald van den Boogaard, Floris Brullemans, Arno Bargerbos and Marten Arthers

Quantware, Electronicaweg 10, Delft, The netherlands

thijs@quantware.com

In recent years, the size and complexity of state-of-the-art quantum devices has increased significantly. The large number of qubits and peripherals demand the optimization and implementation of an ever growing number of parameters into circuit geometry. Additionally every qubit has several parameters that have to be implemented into a geometry to obtain the correct capacitance. However, simulating and optimizing the geometry using finite element methods is time prohibitive and does not scale to larger devices. Here, we present an alternative way of optimizing the circuit geometry using a pre-simulated look-up table to yield the desired circuit. Using the look-up table we get an optimization speedup of 3 orders of magnitude, bringing back the time from days to minutes, without significantly affecting parameter accuracy. This proves the look-up table to be a scalable way to implement the desired Hamiltonian parameters into circuit geometries.

Quantum Fourier Transform using Dynamic Circuits

Elisa Bäumer
Vinay Tripathi, Alireza Seif, Daniel Lidar, Derek Wang

IBM Quantum, IBM Research -- Zurich, 8803 Rüschlikon, Switzerland

eba@zurich.ibm.com

Abstract

In dynamic quantum circuits, classical information from mid-circuit measurements is fed forward during circuit execution. This emerging capability of quantum computers confers numerous advantages that can enable more efficient and powerful protocols by drastically reducing the resource requirements for certain core algorithmic primitives. In particular, in the case of the n-qubit quantum Fourier transform followed immediately by measurement, the scaling of resource requirements is reduced from $O(n^2)$ two-qubit gates in an all-to-all connectivity in the standard unitary formulation to O(n) mid-circuit measurements in its dynamic counterpart without any connectivity constraints (as first described in [1]). Here, we demonstrate the advantage of dynamic quantum circuits for the quantum Fourier transform on IBM's superconducting quantum hardware with certified process fidelities of >50\% on up to 16 qubits and >1\% on up to 37 qubits, exceeding previous reports across all quantum computing platforms. These results are enabled by our contribution of an efficient method for certifying the process fidelity, as well as of a dynamical decoupling protocol for error suppression during mid-circuit measurements and feed-forward within a dynamic quantum circuit that we call ``feed-forward-compensated dynamical decoupling'' (FC-DD). Our results demonstrate the advantages of leveraging dynamic circuits in optimizing the compilation of quantum algorithms.

References

[1] R. B. Griffiths and C.-S. Niu, Physical Review Letters 76, 3228–3231 (1996).

Figures

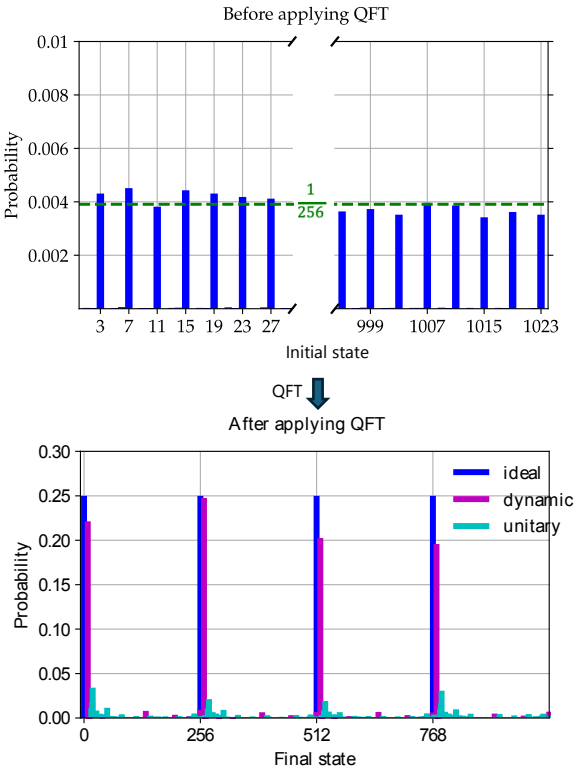


Figure 1: The quantum Fourier transform followed by measurement applied to a periodic state implemented with unitary vs. dynamic quantum circuits.

Error estimation in current noisy quantum computers

Presenting Author: Juan Borge
Co-Authors: Unai Aseguinolaza, Nahual Sobrino, Gabriel Sobrino, Joaquim Jornet-Somoza

Organization: Basic Sciences Department, Faculty of Engineering, Mondragon Unibertsitatea, 20500 Arrasate, Spain
Contact@E-mail: jborge@mondragon.edu

Abstract

One of the main important features of the noisy intermediate-scale quantum (NISQ) era is the correct evaluation and consideration of errors. In this paper, we analyze the main sources of errors in current (IBM) quantum computers and we present a useful tool (TED-qc) designed to facilitate the total error probability expected for any quantum circuit. We propose this total error probability as the best way to estimate a lower bound for the fidelity in the NISQ era, avoiding the necessity of comparing the quantum calculations with any classical one. In order to contrast the robustness of our tool we compute the total error probability that may occur in three different quantum models: 1) the Ising model, 2) the Quantum-Phase Estimation (QPE), and 3) the Grover's algorithm. For each model, the main quantities of interest are computed and benchmarked against the reference simulator's results as a function of the error probability for a representative and statistically significant sample size. The analysis is satisfactory in more than the 99% of the cases. In addition, we study how error mitigation techniques are able to eliminate the noise induced during the measurement.

Figures

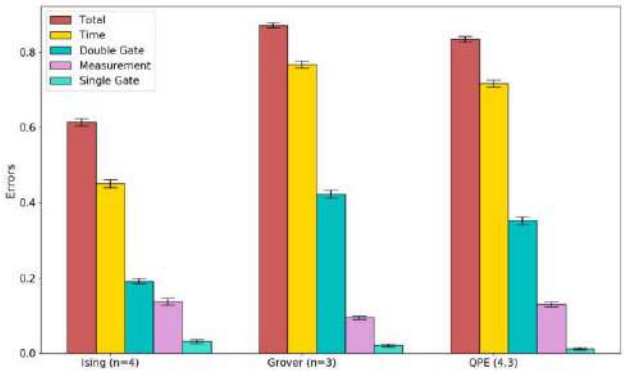


Figure 1 Error contributions in the three different studied quantum circuits. The error contributions are coming from three main sources: Time, measurement, and gate operations (single and double).

References

Unai Aseguinolaza, Nahual Sobrino, Gabriel Sobrino, Joaquim Jornet-Somoza, Juan Borge, arXiv:2302.06870

Physically motivated enhancements of variational quantum eigensolvers for quantum chemistry

David Casanova

Donostia International Physics Center (DIPC), 20018 Donostia, Euskadi, Spain

david.casanova@dipc.org

The Adaptive Derivative-Assembled Pseudo-Trotter Variational Quantum Eigensolver (ADAPT-VQE) [1] has emerged as a promising approach in quantum chemistry. Nevertheless, the application of ADAPT-VQE with noisy quantum devices requires to enhance its efficacy. Leveraging insights from electronic structure theory, we concentrate on optimizing state preparation without added computational burden and guiding ansatz expansion (Figure 1) to yield more concise wavefunctions with expedited convergence toward exact solutions. These advancements culminate in shallower circuits and reduced number of measurements. The performance of the new ADAPT-VQE variants will be assessed across mono, di, and tridimensional arrangements of H4 models, as well as in the ground state calculation of the water molecule. Ultimately, this work attests to the viability of physically-motivated strategies in fortifying ADAPT-VQE's efficiency, marking a significant stride in quantum chemistry simulations.

References

[1] Grimsley, H. R.; Economou, S. E.; Barnes, E.; Mayhall, N. J., Nat. Commun., 10 (2019) 3007.

Figures

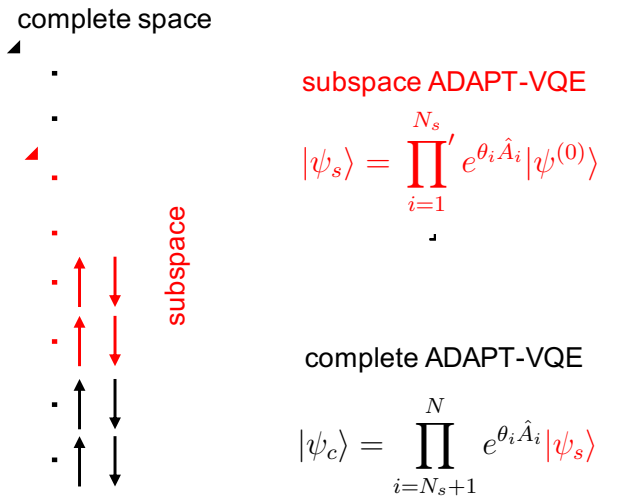


Figure 1: Representation of the orbital subspace strategy to guide ansatz growth in ADAPT-VQE.

Quantum Many-Body phase diagram characterization using Fidelity-based Kernels

Francesco Di Marcantonio[2,3]
Nicola Mariella[1], Enrique Rico[2], Sofia Vallecorsa[3], Sergiy Zhuk[1]

[1]*IBM Quantum, IBM Research Europe – Dublin*
[2]*Quantum Matter Group @ EHU Quantum Center, University of the Basque Country UPV/EHU*
[3]*Quantum Technology Initiative QTI @ CERN*

francesco.di.marcantonio@cern.ch

Abstract

The use of fidelities in Quantum Theory has a long history that has enhanced our understanding of quantum systems. In Quantum Many-body physics, detecting Quantum Phase Transitions (QTPs) without conventional order parameters is of particular interest, as these parameters may not work for some models. In such cases, Quantum Machine Learning (QML) comes into play, along with quantum fidelities. Our study of QPTs utilizes physics-inspired Quantum Kernels tailored to celebrated fidelities such as the Uhlmann and the Susceptibility fidelity. We leverage these Quantum Kernels for Anomaly Detection in an unsupervised setting - the anomalies being the quantum phase transition boundaries. In the Figure, we efficiently recognize the different phases of the Axial Next-Nearest-Neighbour Interaction (ANNNI) model already for spin chains of small sizes supporting the validity of our QML model.

References

[1] Richard Jozsa. Fidelity for mixed quantum states. Journal of Modern Optics, 41(12):2315–2323, 1994.
[2] John Shawe-Taylor and Nello Cristianini. Kernel Methods for Pattern Analysis. Cambridge University Press, 2004.
[3] Bernhard Schölkopf, Robert C. Williamson, Alex Smola, John Shawe-Taylor, and John Platt. Support vector machine for Novelty Detection. NeurIPS Proceedings, 12, 1999.
[4] Lei Wang, Ye-Hua Liu, Jakub Imriška, Ping Nang Ma and Matthias Troyer. Fidelity susceptibility made simple: A unified quantum Monte Carlo approach. Phys. Rev. X, 5, 2015.
[5] Maria Schuld, and Nathan Killoran. Quantum Machine Learning in Feature Hilbert Space. Phys. Rev. Lett. 122, 2019.

Figures

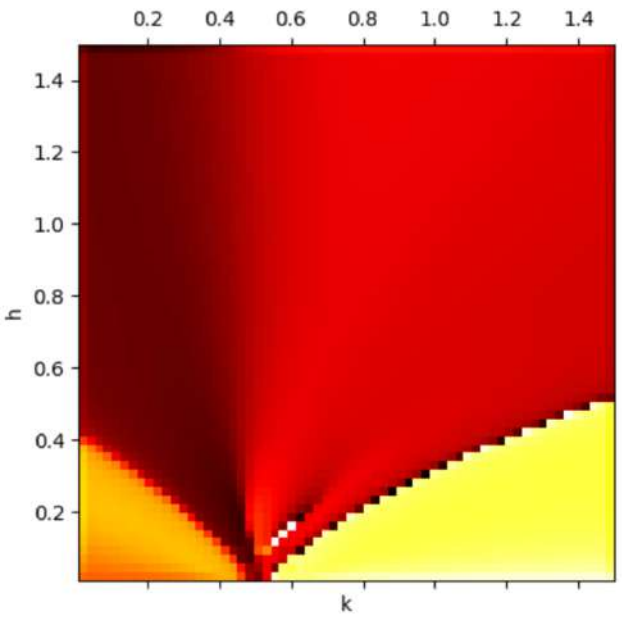


Figure 1: Phase Diagram of the ANNNI model realized using physics inspired feature mapping for our Quantum Kernel.

Quantum computation of the dynamics of the Jaynes-Cummings Hamiltonian for nanophotonics

Rubén Esteban[1,2]
Jonathan Sepúlveda[1], Niall Robertson[3], Sergiy Zhuk[3], Martin Mevissen[3], Javier Aizpurua[2,4,5]

[1]*Materials Physics Center, CSIC-UPV/EHU, E-20018, San Sebastián, Spain*
[2]*Donostia International Physics Center DIPC, E-20018, San Sebastián, Spain*
[3]*IBM Quantum, IBM Research Europe – Dublin, Mulhuddart, Dublin 15, Ireland*
[4]Ikerbasque, Basque Foundation for Science, E-48013 Bilbao, Spain
[5]Department of Electricity and Electronics, UPV/EHU, Leioa E-48940, Spain
ruben.esteban@ehu.eus

The strong coupling of excitons in quantum emitters with the modes of optical resonators leads to the emergence of hybrid excitations with novel properties that can be identified by Rabi oscillations in time domain. Usually, the realization of this effect requires cryogenic temperatures. However, this constraint can be overcome by confining the optical energy to an extremely small volume through metallic nanoresonators that support plasmonic resonances induced by the collective oscillations of the free electrons of the metal. A sketch of a such a configuration is shown in Figure 1.

We first describe the interest of the coupling between plasmonic nanoresonators and quantum emitters for molecular characterization and for the design of sources of quantum light. The physics of these systems can be modelled using the Jaynes-Cummings Hamiltonian for a single plasmonic mode coupled to a single quantum emitter treated as a two-level system.

We then implement the Jaynes-Cumming Hamiltonian in an IBM quantum computer after qubitization of the bosonic plasmonic excitation [1,2], and obtain the resulting time evolution of states population(Figure 2). We describe how, under adequate conditions, there is no trotterization error [3]. This work thus makes it possible to assess the possibilities of quantum computing to treat these systems, as a first step towards the study of more complex configurations involving many quantum emitters, for example, where the size of the Hilbert space makes classical calculations challenging.

References

[1] R. D. Somma arXiv: quant-ph/0512209 (2005).
[2] Xin-Yu Huang et al., arXiv:2105.12563, 2021
[3] Naomichi Hatano and Masuo Suzuki, arXiv:math-ph/0506007 (2005)

Figures

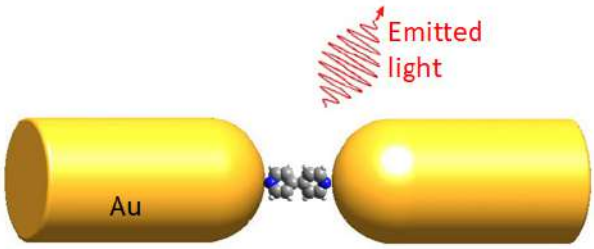


Figure 1: Sketch of a typical emitter-resonator system, where a quantum emitter (here, a molecule) is coupled with an optical nanoresonator.

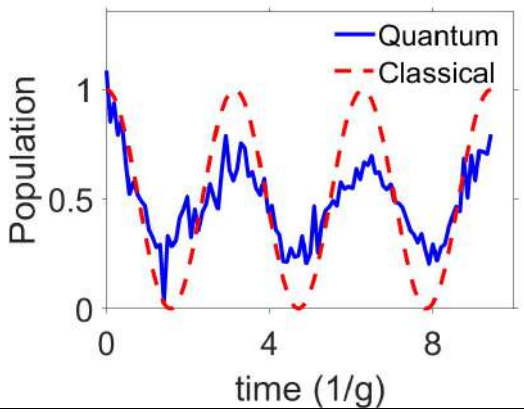


Figure 2: Population of a quantum emitter coupled to a plasmonic nanoresonator, obtained using classical (dashed red line) and quantum (solid blue line) simulations. The results show clear Rabi Oscillations in both cases. The time is given in units of 1/g, where g is the nanoresonator-emitter coupling strength.

Projected Lindblad dynamics via Hamiltonian symmetries for Quantum Error Mitigation

Josu Etxezarreta Martinez[1]
Javier Oliva del Moral[1], Dmytro Mishagli[2], Olatz Sanz[1], Reza Dastbasteh[1], Paul Schnabl[1], Robert B. Staszewski[3], Pedro M. Crespo[1], Sergiy Zhuk[4]

[1]Tecnun – Universidad de Navarra, Manuel Lardizabal Ibilbidea, 13, 20018 Donostia, Gipuzkoa
[2]IBM Quantum, IBM Research Europe – United Kingdom, IBM Hursley Park, Hursley, England, UK
[3]University College Dublin, Belfield, Dublin 4, Ireland
[4]IBM Quantum, IBM Research Europe – Dublin, IBM Technology Campus, Dublin 15, Ireland
jetxezarreta@unav.es

Quantum error mitigation (QEM) techniques have shown extremely good promise in order to extract accurate expectation values of observables of interest by means of noisy quantum processors in the NISQ-era [1,2]. Some widely-accepted QEM methods have converged into to the so-called Probabilistic Error Amplification (PEA) based zero-noise extrapolation (ZNE) [2]. This method assumes that the ideal (target) expectation value of operators are functions of noisy values of those measured at different noise rates. It should be noted that the PEA+ZNE methods require precise characterization of the noise in the quantum device. Moreover, it is not generally easy to make assumptions of the decay tendencies of the observables, especially when non-Clifford circuits are targeted [2,3]. Some methods attempt to learn those by substituting most of the gates of a circuit by Clifford gates (Clifford Data Regression, CDR) [4] or by small-scale tractable circuits [5]. However, changing the circuit changes the noise and, thus, what is learnt might not be always accurate for the target circuit.

In this work, we propose a method based on projecting the ideal expectation values onto a linear span of noisy measurements. The method does not require to know the amplification ratios in the system. In order to train the coefficients for the linear span, we make use of observables whose expectation values are conserved over the dynamics (Hamiltonian symmetries). Specifically, we probe the noisy processor to obtain noisy expectation values (at different noise rates) of quantities that are conserved and, therefore, known, for obtaining the projection weights. The obtained model is then used to mitigate the noise of the target observables of interest. In this way, the circuits for which the training is made are exactly the same as for the actual experiment.

We numerically analyse the proposed method for studying the magnetization in the transverse field Ising and Heisenberg models. We will also discuss the potential of the method for discerning which is the function that defines the decays of the observable. We will also present the future research on the topic.

References

[1] K. Temme et al. PRL 119, 0180509 (2017).
[2] Y. Kim et al. Nature 618, 500-505 (2023).
[3] Z. Cai. npj Quantum Information 7, 80 (2021).
[4] P. Czarnik et al. Quantum 5, 92 (2021).
[5] H. Liao et al. arXiv:2309.17368 (2023).

Evidence of Kardar-Parisi-Zhang scaling on a digital quantum simulator

Nathan Keenan[1,2]
Niall F. Robertson[1], Tara Murphy[1], Sergiy Zhuk[1], John Goold[2]

[1]*IBM Quantum, IBM Research Europe - Dublin, Mulhuddart, Dublin, Ireland*
[2]*Trinity College Dublin, Dublin, Ireland*

nathan.keenan@ibm.com

Abstract
Understanding how hydrodynamic behaviour emerges from the unitary evolution of the many-particle Schrodinger equation is a central goal of non-equilibrium statistical mechanics. In this work we implement a digital simulation of the discrete time quantum dynamics of a spin-1/2 XXZ spin chain on a noisy near-term quantum device, and we extract the high temperature transport exponent at the isotropic point. We simulate the temporal decay of the relevant spin correlation function at high temperature using a pseudo-random state generated by a random circuit that is specifically tailored to the ibmq-montreal 27 qubit device. The resulting output is a spin excitation on a homogenous background 21 qubit chain on the device. From the subsequent discrete time dynamics on the device we are able to extract an anomalous super-diffusive exponent consistent with the conjectured Kardar-Parisi-Zhang (KPZ) scaling at the isotropic point. Furthermore we simulate the restoration of spin diffusion with the application of an integrability breaking potential. [1]

Figures

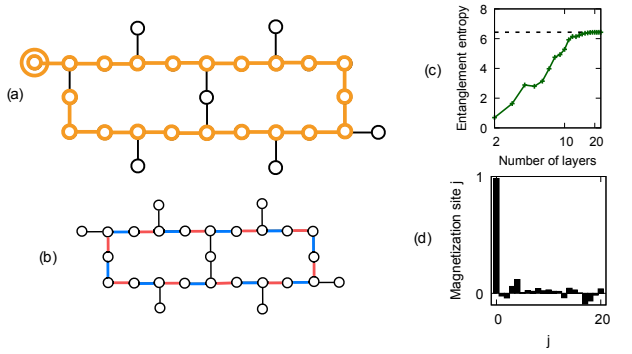


Figure 1: (a) The ibmq montreal qubit connectivity, with a 1-dimensional XXZ model (OBC) mapped onto a 21-qubit chain in the device. Site 0 is mapped to the encircled qubit, and is untouched by the randomisation procedure. (b) Red (blue) is CNOT pattern A (B) used in the random state preparation. These are alternated at each layer of the iterated random circuit. (c) The bipartite von Neumann entanglement entropy of the 20 qubit chain as a function of the number of layers in the random circuit. These results are from a clean simulation with connectivity matching that of ibmq montreal. The dashed line represents the maximum Page value (d) The spin density profile of the final state of one sampling of the random circuit.

References

[1] N.Keenan, N.Robertson, T.Murphy, S.Zhuk, J.Goold, npj Quantum Information, 9 (2023) 72

Diagonalizing large many-body systems on a quantum processor using quantum Krylov

William Kirby
Nobuyuki Yoshioka (University of Tokyo), Mirko Amico, Petar Jurcevic, Arkopal Dutt, Bryce Fuller, Shelly Garion, Holger Haas, Ikko Hamamura, Alexander Ivrii, Ritajit Majumdar, Zlatko Minev, Mario Motta, Bibek Pokharel, Pedro Rivero, Kunal Sharma, Chris Wood, Ali Javadi-Abhari, and Antonio Mezzacapo
IBM Quantum, IBM Research Cambridge, Cambridge, MA, USA

william.kirby@ibm.com

Abstract

In this talk, I will present experimental results on the simulation of ground state energies of Heisenberg XXZ models on a quantum computer. The method used is the quantum Krylov algorithm [1], a recently developed technique for approximating low-lying eigenenergies on near-term quantum computers without requiring a variationally-optimized quantum circuit. We show how symmetries of the model can be exploited to further simplify our circuits, and combined with the intrinsic noise resilience of the quantum Krylov algorithm and error mitigation techniques developed for large-scale simulations on superconducting quantum processors, we are able to show convergence to the ground state energy on two-dimensional systems of 50+ spins. The problem is parameterized such that one may seamlessly interpolate from the classically tractable regime to the classically intractable regime. Although effects of noise prevent us from reaching the latter in the current generation of experiments, this opens a clear and continuous path to demonstrating quantum advantage for ground state problems.

References

[1] Robert M. Parrish, Peter L. McMahon, "Quantum Filter Diagonalization: Quantum Eigendecomposition without Full Quantum Phase Estimation," arxiv:1909.08925 (2019).

Figures

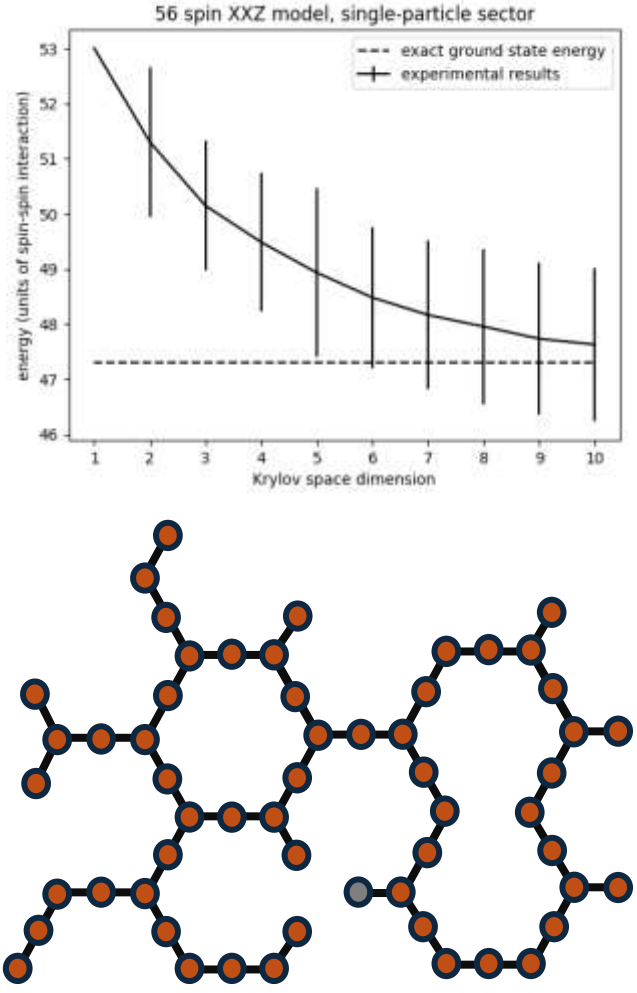


Figure 1: (top) results of quantum simulation of a 2D, 56-spin XXZ model in the single-particle sector using a quantum computer. (bottom) layout, including control qubit (gray).

Localisation, Thermalisation and Time Crystals: Quantum Simulations of Disorder

Eric D. Switzer[1], Ángel Rodríguez[2], **Nicolás Lorente[1,2],** Sergiy Zhuk[3], Niall Robertson[3], Oles Shtanko[3], Martin Mevissen[3], Nathan Keenan[3], Bibek Pokharel[3]

[1]*Donostia International Physics Center (DIPC)*
[2]*Centro de Fisica de Materiales (CFM/MPC)*
20018 Donostia, Euskadi, Spain

[3]*IBM Quantum*

nicolas.lorente@ehu.eus

Dynamical quantum systems provide a rich playground to study a number of fundamental questions in quantum mechanics regarding localisation, ergodicity and entanglement growth. Classical methods such as tensor networks can be used to study these phenomena but are restricted to certain paradigms such as short-time simulations or systems with weak entanglement growth. It is thus not always clear from numerical simulations whether an observed physical phenomenon is an artefact of the structure imposed on the Hilbert space by the tensor network algorithm or is indeed a true reflection of a quantum mechanical system. In this work, we use a quantum computer to address this issue. We consider a Hamiltonian with disordered couplings and implement its dynamics on a quantum computer. We ask the following questions: can we observe a low dimensional discrete time crystal in an *interacting* system on a real quantum device? Can we observe the localisation/thermalisation transition on a quantum computer? If the ergodic regime is difficult to study with classical numerics, can the quantum computer provide more accurate results?

Chemistry Beyond the Reach of Exact Solutions of the Schroedinger Equation on a Quantum-centric Supercomputer

Antonio Mezzacapo
Javier Robledo-Moreno, Mario Motta, Holger Haas, Ali Javadi-Abhari, Petar Jurcevic, William Kirby, Simon Martiel, Kunal Sharma, Sandeep Sharma, Tomonori Shirakawa, Iskandar Sitdikov, Rong-Yang Sun, Kevin J. Sung, Maika Takita, Minh C. Tran, Seiji Yunoki, Antonio Mezzacapo
IBM Quantum, IBM T. J. Watson Research Laboratory, Yorktown Heights, NY, USA

mezzacapo@ibm.com

Abstract

We present quantum computations of chemistry that go beyond problem sizes amenable to current state-of-the-art exact diagonalization methods. Our results are obtained in a quantum-centric supercomputing architecture, using 6400 nodes of the Fugaku supercomputer to assist an IBM Heron quantum processor. We simulate the N2 triple bond breaking in a correlation-consistent cc-pVDZ basis set, and the active-space electronic structure of [2Fe–2S] and [4Fe–4S] clusters, using 58, 45 and 77 qubits respectively, with quantum circuits of up to 10570 (3590 2-qubit) quantum gates.. The experiments performed establish an unconditional quality metric for quantum advantage, certifiable by classical computers at polynomial cost. We believe these results will redefine the exploration of quantum advantage for chemistry, and more broadly for applications of quantum computing in general.

News on Variational Quantum Machine Learning

Román Orús

DIPC, Paseo Manuel de Lardizabal 4, 20018 Donostia – San Sebastian
Multiverse Computing, Pasero de Miramon 170, 20014 Donostia – San Sebastian

roman.orus@dipc.org
roman.orus@multiversecomputing.com

In this short talk I will discuss recent developments to implement variational quantum machine learning algorithms using few-qubit NISQ quantum processors, including quantum clustering, quantum optimization with non-orthogonal states, quantum continuous optimization, and variational quantum attacks to symmetric-key cryptigraphy. I will also discuss recent developments on the implementation of quantum-SVMs and quantum kernels for classification problems.

References

[1] B. Aizpurua, P. Bermejo, J. Etxezarreta, R. Orus, arXiv:2311.02986
[2] P. Bermejo, R. Orus, SciRep 13, 9840 (2023)
[3] P. Bermejo, R. Orus, aXiv:2210.03136
[4] P. Bermejo, R. Orus, SciRep 13, 13284 (2023)

Approximate Quantum Compiling for Quantum Simulation: A Tensor network based approach

Niall Robertson[1]
Albert Akhriev[1]
Jiri Vala[2]
Sergiy Zhuk[1]

[1]*IBM Quantum, IBM Research Europe – Dublin*
[2]*Maynooth University, Maynooth, Ireland*

niall.robertson@ibm.com

Abstract

We introduce a framework to combine classical Tensor Network techniques with quantum computing for the purpose of quantum simulation. The method uses Tensor Network based methods to efficiently compile Trotterized time-evolution operators into short-depth quantum circuits and combines aspects of Approximate Quantum Compiling (AQC), Matrix Product States (MPS) and classical optimization techniques to achieve this. We demonstrate the effectiveness of this technique on simulations on a number of different models on up to 100 qubits and discuss the wide variety of quantum simulation problems that could benefit from this approach.

References

[1] Niall F. Robertson, Albert Akhriev, Jiri Vala, Sergiy Zhuk, arxiv: 2301:08609

Figures

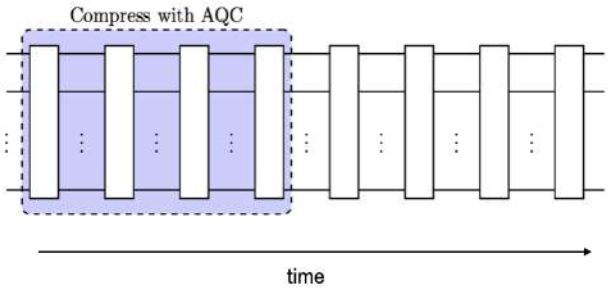


Figure 1: The AQCtensor workflow: the first part of the circuit (classically simulatable) is compressed to a shallow circuit. The remaining part (difficult to simulate classically) is simulated on the quantum device.

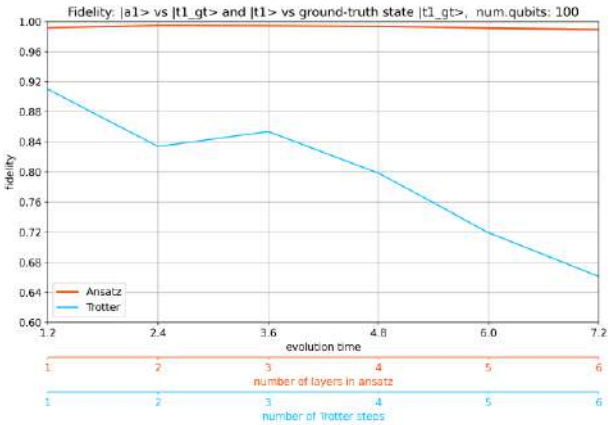


Figure 2: Blue line: the fidelity of the Trotterized circuit with the quasi-exact state. Red line: the fidelity of the optimised circuit with the quasi-exact state.

Quasi-2D Time Crystals on NISQ Hardware: Challenges & Opportunities

Eric D. Switzer[1], Ángel Rodríguez[2], Nicolás Lorente[1,2], Sergiy Zhuk[3], Niall Robertson[3], Oles Shtanko[3], Martin Mevissen[3], Nathan Keenan[3], Bibek Pokharel[3]

[1]*Donostia International Physics Center (DIPC)*
[2]*Centro de Fisica de Materiales (CFM/MPC)*
20018 Donostia, Euskadi, Spain
[3]*IBM Quantum*

eric.switzer@dipc.org

Recent advancements have showcased the capability of noisy intermediate-scale quantum (NISQ) hardware to create many-body localization using a one-dimensional chain of spins, subjected to periodic driving [1-5]. These implementations reveal several useful features, including period multiplicity under periodic driving, retention of initial state information amidst noise, and other characteristics indicative of a phase of matter known as a discrete time crystal (DTC). However, these demonstrations have primarily been confined to one-dimensional systems. It has been suggested that the distinctive traits of a DTC might extend to two-dimensional and quasi-two-dimensional lattice structures [6]. In this study, we leverage cutting-edge NISQ hardware (IBM Torino) to simulate the dynamics of a quasi-two-dimensional heavy-hexagonal spin ½ lattice. Our investigation unveils approximate period doubling phenomena and robustness of dynamics against noise interference. Additionally, we address the intricacies associated with implementation of these lattices on NISQ devices and outline avenues for further exploration into the characteristic signatures of many-body localization.

References

[1] M. Ippoliti *et al.*, PRX Quantum 2 (2021), 030346.
[2] X. Mi *et al.*, Nature 601 (2022), 531.
[3] A. Smith *et al.*, npj Quantum Inf 5 (2019), 1.
[4] P. Frey and S. Rachel, Science Advances 8 (2022), eabm7652.
[5] V. Zhang and P. D. Nation, arXiv: 2301.07625 (2023).
[6] C. Sims, Crystals 13 (2023), 1188.

Figures

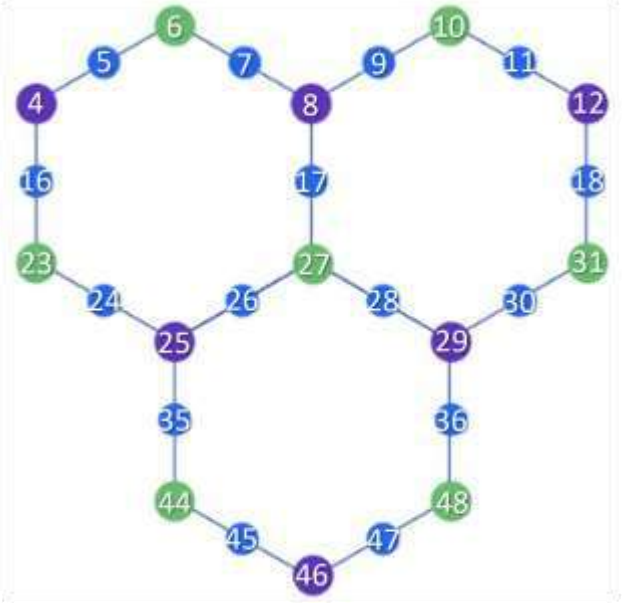


Figure 1: Subset of 28 qubits in a heavy-hex lattice (quasi-2D) geometry, with the corresponding physical qubit index label. A total of 125 qubits (18 hexagons) is used on IBM Torino.

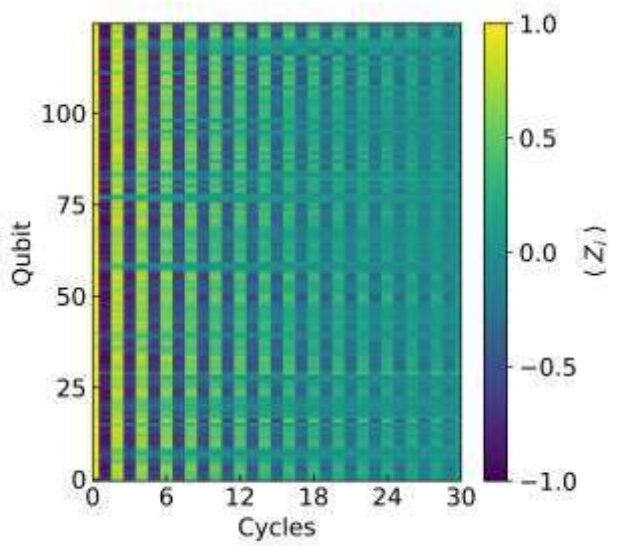


Figure 2: Polarization per qubit as a function of time (Floquet cycles) for the geometry described in Figure 1, for a single realization of disorder. The polarization exhibits approximate period doubling, a necessary component for a discrete time crystal.

Trotter error bounds and dynamic multi-product formulas for Hamiltonian simulation

Sergiy Zhuk[1]
Niall Robertson[1], Sergey Bravyi[2]

[1]*IBM Quantum, IBM Research Europe -Dublin, Ireland*
[2]*IBM Quantum, New York, US*
sergiy.zhuk@ie.ibm.com

Multi-product formulas (MPF) are linear combinations of Trotter circuits offering high-quality simulation of Hamiltonian time evolution with fewer Trotter steps. Here we report two contributions aimed at making multi-product formulas more viable for near-term quantum simulations. First, we extend the theory of Trotter error with commutator scaling developed by Childs, Su, Tran et al. to multi-product formulas. Our result implies that multi-product formulas can achieve a quadratic reduction of Trotter error in 1-norm (nuclear norm) on arbitrary time intervals compared with the regular product formulas without increasing the required circuit depth or qubit connectivity. The number of circuit repetitions grows only by a constant factor. Second, we introduce dynamic multi-product formulas with time-dependent coefficients chosen to minimize a certain efficiently computable proxy for the Trotter error. We use a minimax estimation method to make dynamic multi-product formulas robust to uncertainty from algorithmic errors, sampling and hardware noise. We call this method Minimax MPF and we provide a rigorous bound on its error.

References

[1] Zhuk,S., Robertson, N, Bravyi, S. arXiv:2306, (2023)

Figures

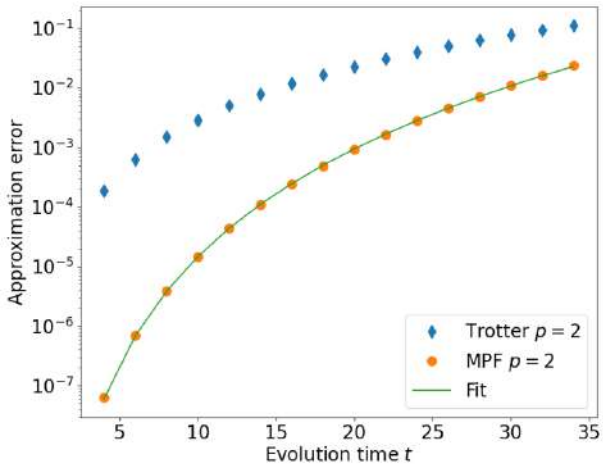


Figure 1: Approximation error achieved by the second-order Trotter circuit with k3 = 850 time steps (blue) and MPF with (k1, k2, k3) = (200, 650, 850) (orange) for the Heisenberg spin chain Hamiltonian with n = 14 qubits. Green line shows the fitting formula.

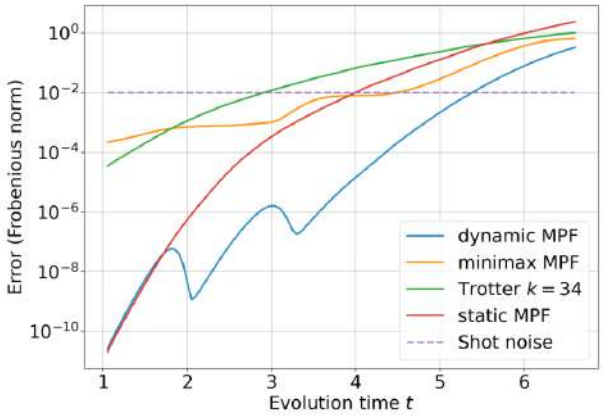


Figure 2: Approximation error for MPFs: well-conditioned static MPF with ρ8,26,34 (red), best Trotter formula ρ34(green), dynamic MPF with exact data (blue) and mini-max MPF with noisy/approximated data (orange) both using ρ8,20,26,30,34, for the Heisenberg spin chain Hamiltonian Eq. (30) with n = 10 qubits. The shot noise magnitude is depicted as a dashed line for reference.

Coherent Manipulation of a Binary Atomic System with Gain

Presenting Author (Lorena Acevedo)
Co-Authors (Manuel Donaire)

University of Valladolid, Paseo Belén 7, 47011, Valladolid, Spain

Contact@E-mail
(cindylorena.acevedo@uva.es)

Abstract

We analytically study the optical response of a binary atomic system with one of them excited by an incoherent pump and continuous illumination provided by a quasi-resonant beam [1]. This study allows us to analyze and eventually optimize the coherent manipulation of the system while preserving the fundamental quantum properties, i.e., entanglement, superposition and coherence by executing operations by applying lasers on atoms trapped in optical tweezers [2]. Using a schematic representation, we identify all radiative processes to describe those configurations in which incoherent effects, such as absorption and spontaneous emission processes, can be neglected in the middle and far-field regime. On the other hand, we identify those processes that, by breaking the parity symmetry, imply the directionality of the emission and determine the asymmetric transfer of the excitation. In subsequent work, this study will be extended to chains of neutral atoms through numerical simulations, with the aim of optimizing the scalability of multi-atom qubits [3].

References

[1] Donaire, M., Phys. Rev. A, 4 (2021) 043704
[2] Lukin, M. D. and Fleischhauer, M. and Cote, R. and Duan, L. M. and Jaksch, D. and Cirac, J. I. and Zoller, P., Phys. Rev. Lett, 3 (2001) 037901
[3] Henriet, L., Beguin, L., Signoles, A., Lahaye, T., Browaeys, A., Reymond, G.-O., & Jurczak, C., Quantum (Online), 4 (2020) 347

Acknowledgments

Project: European Union.-Next Generation UE/MICIU/Recovery, Transformation and Resilience Plan /Junta of Castilla y León

Q-CAYLE Group: Secure Quantum Communications in Castilla y León

Learning QAOA landscapes: Monte Carlo Tree Search with Iterative Search-space Restriction for Parameter Optimization

Andoni Agirre Arabolaza[1,2],
Evert van Nieuwenburg[3] & Matteo M. Wauters[1,4].

[1]*Niels Bohr Institute and Qdev, University of Copenhagen, 2100 Copenhagen, Denmark.*
[2]*Donostia International Physics Center (DIPC), 20018 Donostia, Basque Country, Spain.*
[3]*Lorentz Institute and LIACS, Leiden University, 2300 Leiden, The Netherlands.*
[4]*Pitaevskii BEC Center, University of Trento, 38123 Trento, Italy.*

andoni.agirre@dipc.org

Variational Quantum Algorithms (VQA) are the leading class of hybrid quantum-classical methods to cope with the limitations of near-term quantum hardware [1]. However, their effectiveness is hampered by the complexity of the classical parameter optimization, making the design of efficient optimization methods fundamental for leveraging the potential of VQAs. In this work, we propose a gradient-free parameter optimization strategy based on a modified version of the Monte-Carlo tree search (MCTS) algorithm [2] for the Quantum Approximate Optimization Algorithm (QAOA) [3], one of the most relevant algorithms in the VQA family. Our modifications allow MCTS to iteratively restrict the action space to exploit the parameter regularity inherent in optimal schedules and efficiently explore complex search domains [4]. The algorithm performs well in hard instances of 3-SAT and MaxCut problems, and exhibits remarkable robustness against noise. Our results shed light on the interplay of artificial intelligence and quantum information and provide a valuable step towards robust quantum computation with existing hardware.

Figures

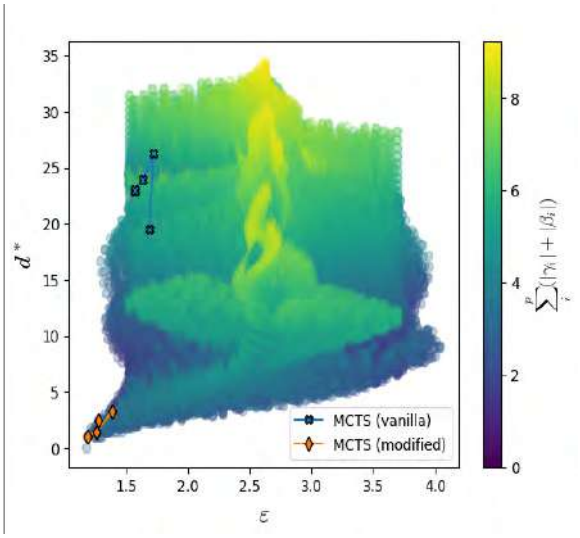


Figure 1: Distribution of leaf nodes in *P*=2 QAOA for a 3-SAT instance according to the distance from the optimal parameters and the final energy. Performance comparison of standard and modified MCTS.

References

[1] M. Cerezo *et al.*, Nat Rev Phys **3**, 625–644 (2021).
[2] M. Świechowski *et al.* Artif. Intell. Rev **56**, 2497–2562 (2023).
[3] E. Farhi, arXiv:1411.4028 (2014).
[4] A. Agirre, E. van Nieuwenburg, M. Wauters in preparation.

Use of harmless NADES for modulating luminescent properties of N-doped graphene quantum dots

Francisco Borja Aguirre Yagüe[1]
Marina Sanmiguel Gutierrez[1]
Ignacio Hernández Campo[2]
Ángel Yedra Martinez[1]
[1]*Centro Tecnológico de Componentes (CTC). Scientific and Technological Park of Cantabria (PCTCAN), 39011 Santander, Spain.*
[2]*DCITIMAC, Facultad de Ciencias, University of Cantabria, 39005 Santander, Spain*
faguirre@centrotecnologicoctc.com

Solvents are capable to control the dehydration and carbonization of organic molecules in solvothermal processes. They also determine the size of sp2-conjugated domains related to the emission range of fluorescence for carbon-based quantum dots and are involved in the addition of doping agents as nitrogen in graphitic positions responsible of an increase of Photoluminescence Quantum Yield (PLQY) [1]. Modulating luminescence is required for several applications of Quantum Dots (QDs). Current strategies for red shifting are associated to the use of complex precursors, reducing solvents like dimethylformamide (DMF) or concentrated sulfuric acid solutions [2]. However, these approaches limit their applicability for large scale applications in synthesis of functional materials due to their toxicity and effect in environment. Deep eutectic solvents (DES) achieved a large interest recently due to their high ionic charge, their high polarity, and their supramolecular structure [3]. Moreover, natural sourced eutectic solvents (NADES) have been studied due to their low toxicity, low production cost and high chemical stability that makes them promising candidate to be employed in different processes as catalysts o even reactor medium [4]. For example, some studies have reported their use as solvents or precursors for carbonized nanostructures with desired electronic properties [5]. In this work, different proportions of NADES have been employed as reaction medium to modify the emission wavelength of solvothermal synthesized luminescent graphene quantum dots. According to the results obtained, the use of different compounds like *choline and polyols*, as well as their mixture proportions are capable to tune the reductive character of solvothermal medium. Thus, an inhibition of oxidized moieties and an increase of conjugated domains and nitrogen doped in graphitic positions are observed compared to water-based assays. This allowed to obtain highly luminescent materials with tuned emission properties for several applications (as cell labelling, led lighting, etc) avoiding the use of harmful reactants at the same time.

References

[1] Z. Zhu, Y. Zhai, Z. Li, P. Zhu, S. Mao, C. Zhu, D. Du, L. A. Belfiore, J.Tang, Y. Lin, *Materials Today*, *Volume 30* (**2019**), pages 52-79.
[2] H. Ding, J. S. Wei, P. Zhang, Z. Y. Zhou, Q. Y. Gao, H. M. Xiong, *Small* 14 (22), No. 1800612, (**2018**).
[3] T. El Achkar, H. Greige-Gerges, S. Fourmentin, *Environ Chem Lett 19,* (**2021**), pages 3397–3408.
[4] M. Pätzold, S. Siebenhaller, S. Kara, A. Liese, C. Syldatk, D. Holtmann, *Trends in Biotechnology*, Volume 37, Issue 9, (**2019**), pages 943-959,
[5] M. H. Mruthunjayappa, N. S. Kotrappanavar, D. Mondal, *Progress in Materials Science,Volume 126,* (**2022**), 100932

Figures

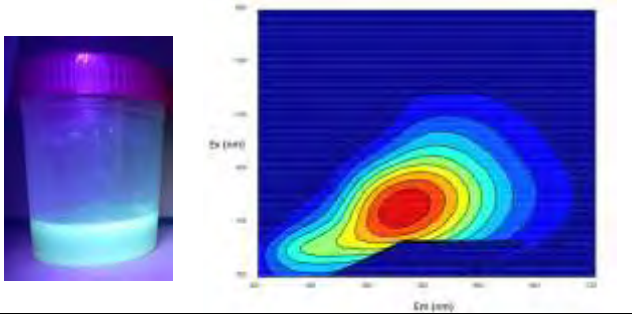


Figure 1: Synthesized graphene quantum dots in NADES (left picture) and excitation-emission spectroscopy wavelength profiles of synthesized quantum dots (right picture).

From Classical via Hybrid to Quantum model: Quantum Machine Learning Applications for Fake Art Identification

Digvijaysinh Ajarekar
Suhaib Al-Rousan
Shraddha Thanki
Prof. Helena Liebelt
Prof. Rui Li

Institute of Future Technologies, Deggendorf Institute of Technology, Veilchengasse 2, Deggendorf D-94469, Germany

E-Mail: helena.liebelt@th-deg.de

Abstract

Artificial Intelligence has been used for the real and fake art identification and different machine learning (ML) models are being trained then employed with acceptable accuracy in classifying artworks. Fake art can distort the understanding and appreciation of an artist's true work and style. Accurate identification of genuine pieces ensures the preservation of artistic heritage and prevents the spread of misinformation. As the future revolutionary technology, quantum computing opens a grand new perspective in the art area. Using Quantum Machine Learning(QML), the current work explores the utilization of fully quantum models, hybrid models along with classical model implementation. The study utilizes Normal Arbitrary Superposition state (NAQSS) for encoding image into quantum circuit. The learning of trainable parameters for image classification Quantum Neural Networks (QNN) for a fully quantum models. With a Hybrid approach, Hybrid Quantum Neural Network with parallel quantum dense layers (HQNN-Parallel). ResNet model is being used for classical model. The study addresses the quantum speed up in training time of models, accuracy and computational complexity of the models. Starting with a simplest example of 4 * 4 images up to 32 * 32, the accuracy has been improved for full quantum model with the increasing size of the images as the circuit depth increases linearly with the image size namely $(2^{n+1}-1)$.
The three models are discussed and the potential of QML and parameters influencing accuracy are extensively investigated. The implementations have been carried out using Qiskit and Torch for training the models.

Figures

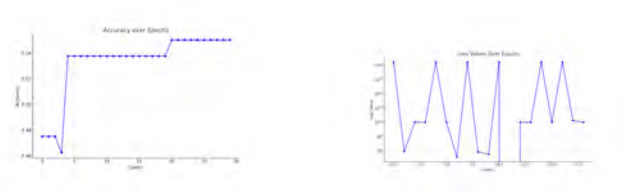


Figure 1: . Training accuracy for 2*2 image classification of Quantum Neural Network with NAQSS Image Encoding.

References

[1] H. S. Li, Q. Zhu, R. G. Zhou, L. Song and X. j. Yang, "Multi-dimensional colour image storage and retrieval for a normal arbitrary superposition state", Quantum Information Processing, Vol. 13, pp. 991-1011, 2014

[2] Arsenii Senokosov, Alexander Sedykh, Asel Sagingalieva, Alexey Melnikov, "Quantum Machine Learning Image Classification", arXiv preprint arXiv: 2304.09224, 2023

[3] H.-S. Li, Z. Qingxin, S. Lan, C.-Y. Shen, R. Zhou, and J. Mo, "Image storage, re-trieval, compression and segmentation in a quantum system," Quantum information processing, vol. 12, no. 6, pp. 2269–2290, 2013.

Topological superconductivity with mixed singlet-triplet symmetry in twisted bilayer WSe_2

W. Akbar,[1]

A. Biborski,[1] L. Rademaker,[2] and M. Zegrodnik[1,*]

[1]*Academic Centre for materials and Nanotechnology, AGH University of Krakow, Al. Mickiewecza 30, 30-059 Krakow, Poland.*

[2]*Department of Theoretical Physics, University of Geneva, CH-1211 Geneva, Switzerland.*

michal.zegrodnik@agh.edu.pl

Abstract

We study the electronic properties of twisted WSe_2 within a single-band t-J model supplemented with Dzyaloshinskii-Moriya term. In order to take into account the effects of electron-electron correlations the Gutzwiller approach is applied. The calculated phase diagram contains stability regions of the topologically nontrivial superconducting state characterized by a mixed d+id-wave (singlet) and p-ip-wave (triplet) gap symmetry. We also report on the appearance of an additional extedned s-wave and f -wave pairings which reside in the low and high electron concentration regimes. As we show, by changing the displacement field, one can tune the balance between the singlet and triplet contributions to the pairing. We analyze the physical origin of the reported effects and discuss it briefly in the view of new possibilities for designing quantum phases in moiré systems with high degree of tunability.

This research was founded by National Science Centre, Poland (NCN) according to decision 2021/42/E/ST3/00128.

References

[1] Y. Cao et al., Nature 556 (2018) 80
[2] Y. Tang et al., Nature 579 (2020) 353
[3] L. Wang et al., Nature Materials 19 (2020) 861
[4] M. Zegrodnik et al., Phys. Rev. B 108 (2023) 064506

Figures

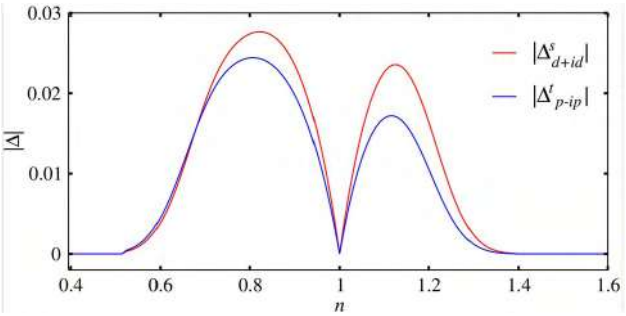


Figure 1: Superconducting gap amplitudes for the spin-singlet d + id and spin-triplet p − ip symmetries as a function of band filling n for selected values of exchange interaction energy J = 2.62 meV and displacement field D = 0.4 V/nm

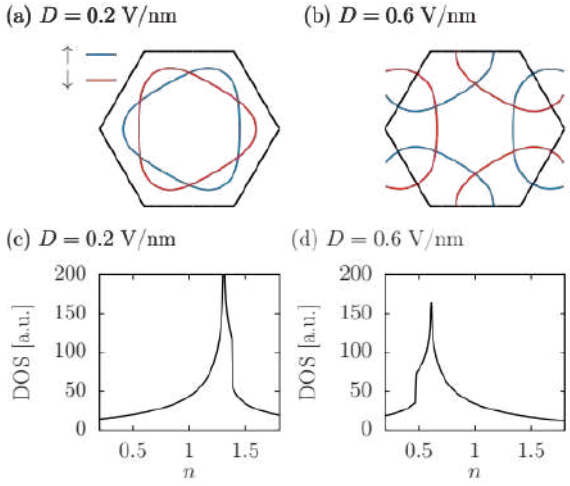


Figure 2: The spin dependant Fermi surfaces at half filling (a,b) and the density of states (c,d) for two selected values of the displacement field, D.

Quantum Hall and Light Responses in a 2D Topological Semimetal

Sariah Al Saati
Karyn Le Hur

CPHT, CNRS, Institut Polytechnique de Paris, Route de Saclay, 91120 Palaiseau, Franc

sariah.al-saati@polytechnique.edu

We investigate the topological characteristics of a recently discovered class of semimetals in two dimensions on the honeycomb lattice. These semimetals reside at the transition between two distinct topological insulators, each existing in a nontrivial topological phase. As a result, these semimetals exhibit specific topological properties, including the presence of edge modes. In a preceding work [1], we demonstrated the topological robustness of this semimetal phase against disorder and interactions. In this work [2], we delve deeper into the semimetal's.

References

[1] Karyn Le Hur and Sariah Al Saati. Topological nodal ring semimetal in graphene. Physical Review B, 107(16) (2023).

[2] Sariah Al Saati and Karyn Le Hur. Quantum hall and light responses in a 2d topological semimetal, arXiv:2311.13922 (2023).

Figures

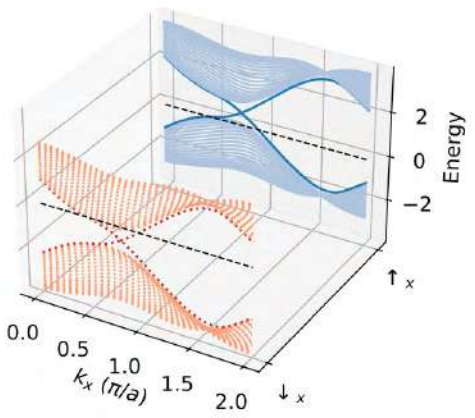


Figure 1: One-dimensional energy bands of the topological semimetal showing the two underlying band structures of opposite spin polarization, with the spin polarization shown in the third direction.

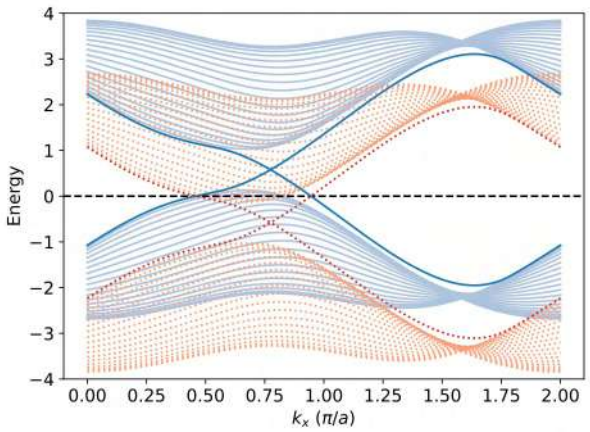


Figure 2: Resulting energy bands in the momentum-Energy axis.

Symmetry-protected gates on superconducting circuits

Jesús Matías Alcaine Cuervo[1,2,3]
Enrique Rico[1,3,4], Juan José García-Ripoll[5]

[1]EHU Quantum Center, University of the Basque Country UPV/EHU, Barrio Sarriena s/n, 48940 Leioa, Biscay, Spain
[2]BCMaterials, Basque Center for Science, Applications and Nanostructures, UPV/EHU Science Park, 48940 Leioa, Biscay, Spain
[3]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, 48080 Bilbao, Biscay, Spain
[4]IKERBASKE, Basque Foundation for Science, Plaza Euskadi 5, 48009 Bilbao, Biscay, Spain
[5]Institute of Fundamental Physics, IFF-CSIC, Calle Serrano 113b, 28006 Madrid, Spain

jesusmatias.alcaine@ehu.eus
jesusmatias.alcaine@bcmaterials.net

Abstract

The study of qubit architectures with intrinsic protection against noise has been an ever-growing field of research. The 0 - π qubit is an exciting case, owing to its multimode nature and resilience against noise. Here we deeply study the 0 - π qubit phenomenology and propose a novel perspective on single-qubit gates realization, based on adiabatic time evolution by taking advantage of its remarkable symmetry properties.

References

[1] Iñigo L. Eguskiza, Ainhoa Iñiguez, Enrique Rico et al., Physical Review B 105, L201104 (May 2022)
[2] András Gyenis, Agustin Di Paolo, Jens Koch et al., PRX Quantum 2, 030101 (September 2021)
[3] Peter Groszkowski, Agustin Di Paolo, Arne L. Grimsmo et al., New Journal of Physics 20, 043053 (April 2018)
[4] Peter Brooks, Alexei Kitaev and John Preskill, Physical Review A 87, 052306 (May 2013)

Figures

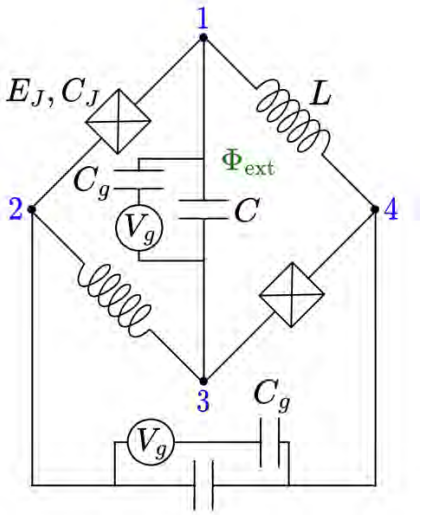


Figure 1: Circuit diagram of the 0-π qubit

Figure 2: Schematic view of the logical qubit gate trajectory in the ground state surface for the 0-π qubit Hamiltonian

Disorder induced delocalization in magic-angle twisted bilayer graphene [1]

Pedro Alcázar Guerrero[12]
Viet-Hung Nguyen[3], Aron W. Cummings[1], José-Hugo García[1], Jean-Christophe Charlier[3], Stephan Roche[14]

[1] ICN2, ICN2Building(UAB Campus), Bellaterra, Spain
[2] Departament of Physics (UAB Campus), Bellaterra, Spain
[3] ICMN, Université Catholique de Louvain(Chemin des étoiles 8 B-1348), Louvain la Neuve, Belgium
[4] ICREA, Barcelona, Spain
pedro.alcazar@icn2.cat

Flat bands in Moiré systems, and their localization in real space, have been connected with exotic correlated physics, such as the superconducting and Mott insulating phases of Magic-Angle Twisted Bilayer Graphene (MATBLG) [2-4]. This happens because the vanishing kinetic energy and the real-space localization trigger a dominant Coulomb interaction.

The role of the Moiré superlattice potential in this phenomenon is well known, but the roles of structural (twist-angle) and electrostatic disorder remain unclear.

In this presentation we will discuss what is known about the effect of disorder on MATBLG, and present simulation results showing that the inclusion of electrostatic disorder in MATBLG can lead to delocalization in the flat bands, increasing the electronic mean free path. This suggests that even weak disorder can have a strong impact on the Coulomb interactions that drive the exotic physics of these systems.

References

[1] PA Guerrero, VH Nguyen, AW Cummings, JH García, JC Charlier, S Roche, arXiv:2401.08265
[2] Y Cao, V Fatemi, S Fang, K Watanabe T Taniguchi, E Kaxiras, PJ Herrero, Nature, 566 (2018) 43
[3] P Stepanov et al, Nature, 583 (2020) 375
[4] R Bistritzer, AH McDonald, PNAS, 108 (2011) 12233

Figures

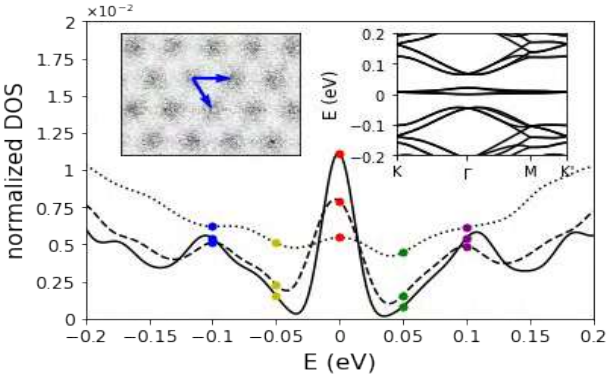


Figure 1: Density of states of MATBLG for increasing disorder strengths (solid → dashed → dotted). The left inset shows the localization pattern in the clean case. The right inset shows the band structure of the clean system.

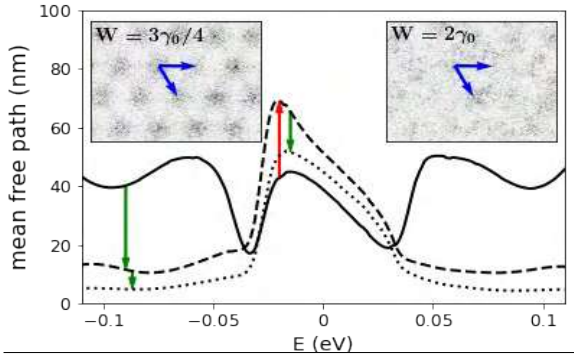


Figure 2: Mean free path of electrons for increasing values of disorder (solid → dashed → dotted) An increase in disorder initially leads to an increase in the mean free path in the flat bands, with the usual trend recovered once its contribution dominates the Moiré potential. Insets show local densities of states for intermediate (left) and strong (right) disorder.

Polarization-tuneable excitonic spectral features of atomically thin ReS_2

Pedro Luis Alcázar Ruano
Juan Salvador-Sánchez, Olga Arroyo-Gascón, Daniel Vaquero-Monte, Enrique Díez, Ana Pérez-Rodríguez, Leonor Chico, Francisco Domínguez-Adame, Jorge Quereda

Universidad Complutense de Madrid, Avenida Complutense s/n, Madrid, Spain

pedrolua@ucm.es

Most studies on ReS2 spectroscopy have primarily focused on optical characterization, such as photoluminescence, absorbance, or reflectance spectroscopy. However, to fully understand the material's properties, a comprehensive investigation into its optoelectronic behaviour is necessary. In this study, we have conducted polarization-resolved photocurrent spectra measurements on few-layer ReS2 photodetectors at both room temperature and cryogenic conditions (14 K). Our findings reveal an exciton-like spectral feature with comparable photoresponse intensity to the main exciton lines reported in previous literature. Interestingly, this phenomenon was not observed in earlier photoluminescence measurements. Furthermore, we observed changes in the intensities of the three exciton features under linear polarized light, with each reaching maximum intensity at different polarization angles. The results from first-principles exciton calculations using the Bethe-Salpeter formalism support our experimental observations. These findings offer new insights into the study and utilization of exotic optoelectronic phenomena in ReS2-based devices.

References

[1] Vaquero, D., Arroyo-Gascón, O., Salvador-Sánchez, J., Alcázar-Ruano, P.L., Diez, E., Perez-Rodríguez, A., Correa, J.D., Domínguez-Adame, F., Chico, L., & Quereda, J. (2023). Polarization-tuneable excitonic spectral features in the optoelectronic response of atomically thin ReS2. *2D Materials, 11*.

Figures

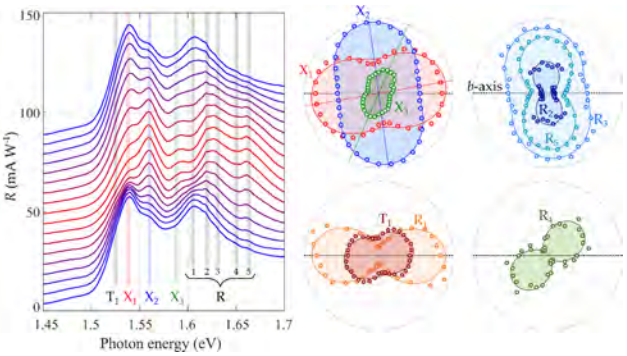


Figure 1: On the left, photocurrent spectra acquired for different angles of light polarization, from 0 to 170° relative to the b crystalline axis with Vsd = 5 V, Vgate = 45 V and a power density of 500 W m-2 . Consecutive spectra have been shifted vertically in steps of 5 mA W -1 for easier visualization. On the right, polar plots showing the modulation of the different spectral features as a function of the polarization direction, extracted from fittings to multi-Lorentzian curves

J-coupling NMR Spectroscopy with Nitrogen Vacancy Centers at High Fields [1]

P. Alsina-Bolívar
A. Biteri-Uribarren, C. MUnuera-Javaloy, and J. Casanova

Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, 48080 Bilbao, Spain

polalsinabolivar@gmail.com

A diamond-based sensor utilizing nitrogen-vacancy (NV) center ensembles permits the analysis of micron- sized samples through NMR techniques at room temperature [2]. Current efforts are directed towards extending the operating range of NV centers into high magnetic fields, driven by the potential for larger nuclear spin polarization of the target sample and the presence of enhanced chemical shifts. Especially interesting is the access to J-couplings as they carry information of chemical connectivity inside molecules [3]. In this work, we present a protocol to access J-couplings in both homonuclear and heteronuclear cases with NV centers at high magnetic fields. Our protocol leads to a clear spectrum exclusively containing J-coupling features with high resolution. This resolution is limited primarily by the decoherence of the target sample, which is mitigated by the noise filtering capacities of our method.

References

[1] P. Alsina-Bolívar, A. Biteri-Uribarren, C. Munuera-Javaloy, and J. Casanova, *arXiv preprint arXiv:2311.11880*.

[2] D. R. Glenn, D. B. Bucher, J. Lee, M. D. Lukin, H. Park, and R. L. Walsworth Nature, **555** (2018) 351

[3] M. H. Levitt, *Spin Dynamics: basics of Nuclear Magnetic Resonance, 2nd ed.* (Wiley, Chichester, 2008)

[4] C. Munuera-Javaloy, A. Tobalina, and J. Casanova, Physical Review Letters, **130** (2023) 13360

Figures

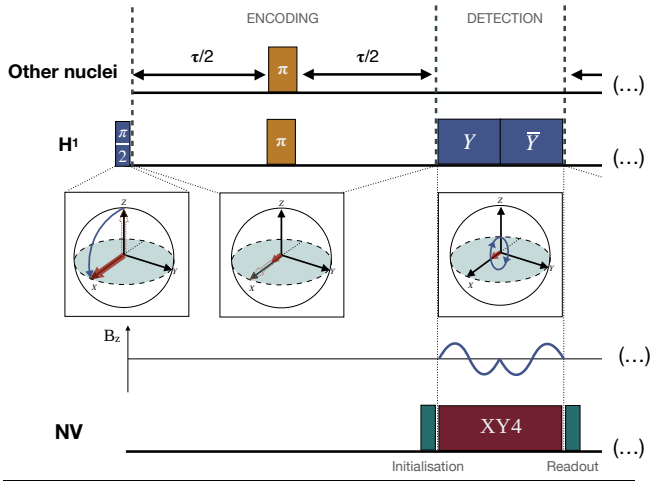


Figure 1: Scheme of one step of the protocol. The sequence begins by driving the hydrogen nuclei to the |+> state. By employing a free evolution interval τ, with by a π-pulse at its midpoint, we selectively isolate the desired J-couplings while simultaneously mitigating the impact of magnetic field inhomogeneities. This approach effectively extends the coherence time of the sample from T2* to T2. Then, the signal emitted by the sample (proportional to the magnetisation, depicted bellow the sequence) is read via an heterodyne read-out protocol [4] with the nitrogen vacancy center ensemble.

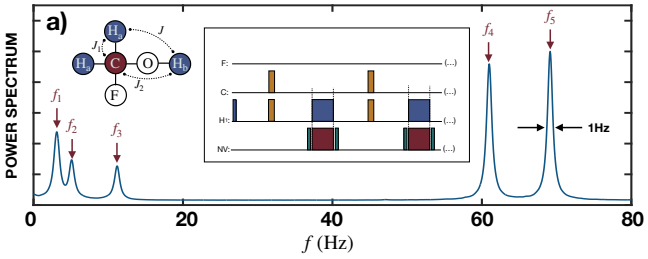


Figure 2: Simulation of the protocol using fluoromethanol as the target molecule. The obtained peaks in the Fourier space are directly related to the couplings depicted in the scheme of the molecule. In this case, only the coupling among hydrogens and carbons are targeted (as well as those between non-equivalent hydrogens). The frequency resolution is estimated to be approximately 1Hz, which is about 3 times better than when working with T2*.

Hybridisation of Andreev bound states in a hybrid four terminal Josephson junction

Tommaso Antonelli[1,2] *

M.Coraiola[2*], E.Cheah[1], F.Krizek[1,2], R.Schott[3] W.Wegscheider[1], F. Nichele[2].

[1] Laboratory for Solid StatePhysics, ETH Zurich, 8093Zurich, Switzerland
[2] *IBM Research Europe—Zurich, 8803 Ruschlikon, Switzerland*

tantonell@phys.ethz.ch

Abstract

Multi terminal Josephson junctions are emergent platform where Andreev bound states (ABSs) are predicted to exhibit non-trivial topological phases [1-6]. Particularly, in four terminal devices, the ABSs should hybridise forming Weyl nodes in their energy spectrum when the phase differences between the four terminals are tuned within a finite region of parameter space. Therefore, independent phase control is essential to experimentally investigate the properties of such devices. Here, we fabricate a four terminal device (Fig.1(a,b)) in an hybrid Al/InAs QW heterostructure, where the three phase differences are independently controlled via flux biasing. Using tunnelling spectroscopy, we explore how the ABS energy spectrum evolves across the entire three-dimensional phase space identifying different phase-regions where the hybridisation between two and three ABSs occurs as shown in Fig2(a,b). Our results pave the way for future investigations on new topological ABS in multiterminal devices.

References

[1] van Heck, B. et al., Phys. Rev. B 90, 155450 (2014).
[2] Yokoyama, T. et al., Phys. Rev. B 92, 155437 (2015).
[3] Riwar, R.-P. et al., Nat. Commun. 7, 11167 (2016).
[4] Eriksson, E. et al., Phys. Rev. B 95, 075417 (2017).
[5] Meyer, J. S. et al. Phys. Rev. Lett. 119, 136807 (2017).
[6] Klees, R. L. et al. Phys. Rev. Lett. 124, 197002 (2020).

Figures

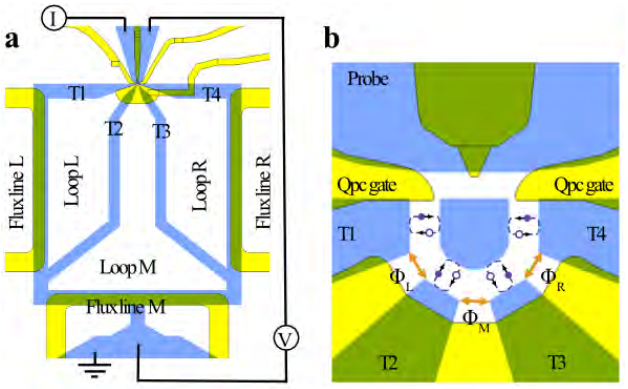


Figure 1: (a) Schematics of our four terminal device where the three phase differences (ϕ_L, ϕ_M, ϕ_R) in (b) are tuned via flux biasing. Tunnelling spectroscopy is performed on the superconductive island at the center of the scattering area (b).

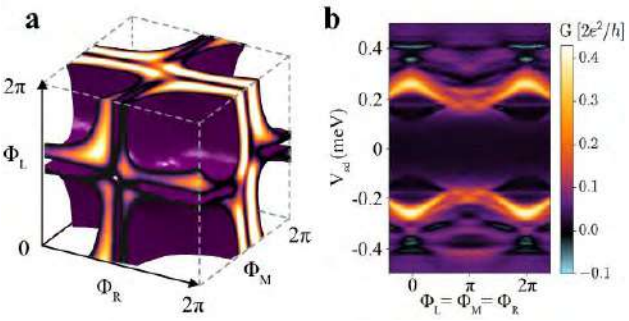


Figure 2: (a) Conductance isosurface measured at Vsd = -0.25 meV showing characteristic signatures of hybridisation between two ABSs along the cube's faces. (b) Energy spectrum of a tri-ABS molecule when the three phases are simultaneously tuned to (π, π, π).

Chiral adiabatic transmission protected by Fermi surface topology

Isidora Araya Day
Kostas Vilkelis, Antonio L. R. Manesco, A. Mert Bozkurt, Valla Fatemi, Anton R. Akhmerov

TU Delft, Lorentzweg 1, Delft, The Netherlands

iarayaday@gmail.com

Multiple mechanisms can protect two modes from scattering into one another: topology and symmetry in a quantum spin Hall effect, adiabaticity in a point contact, and spatial separation in quantum Hall effect.
Up to now, however, only spatial separation was known to protect chiral transport of modes in a three terminal device.
I will share our discovery of higher-dimensional adiabaticity that allows three modes to pass through each other without scattering in a multiterminal superconducting device [1].
This protection relies on the recently discovered link between the Fermi surface topology and the structure of propagating quasiparticle modes in Josephson junctions [2-3].

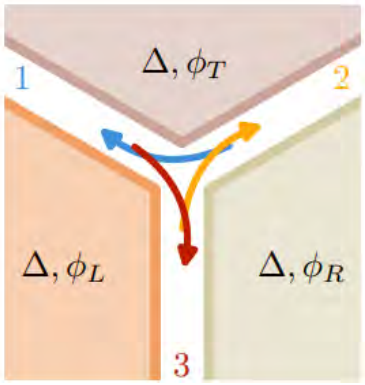


Figure 1: Three terminal Josephson junction.

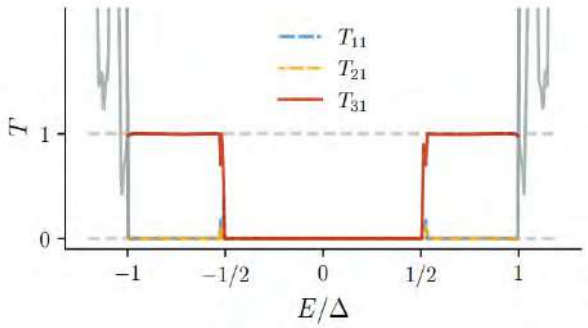


Figure 2: Quantized transmission of Andreev modes through the superconducting trijunction.

References

[1] I. Araya Day et al. ArXiv preprint 2311.17160, 2023.
[2] P. M. Tam et al. Physical Review Letters, 2023.
[3] P. M. Tam et al. Physical Review B, 2023.

Figures

Novel 3D circuit QED architecture for quantum information processing

Desislava G. Atanasova[1,2]
Ian Yang[1,2], Teresa Hönigl-Decrinis[1,2], Daria Gusenkova[3]*, Ioan Pop[3], Gerhard Kirchmair[1,2]

1. Institute for Quantum Optics and Quantum Information, A-6020 Innsbruck, Austria
2. Institute for Experimental Physics, University of Innsbruck, A-6020 Innsbruck, Austria
3. Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

desislava.atanasova@uibk.ac.at
* Current address: IQM, Munich, Germany

Superconducting circuits based on 3D architectures offer a way for hardware-efficient quantum information processing. Combined with nonlinearity, a single bosonic mode can replace a multi-qubit register, thus significantly reducing the required control electronics. Compared to their purely planar counterpart, 3D circuits possess longer lifetimes and a straightforward design that eases engineering the interactions in composite systems.
In this work, a superconducting coaxial cavity[1] is coupled to a fluxonium qubit[2] via a readout resonator. The tunability of the qubit, provided by a magnetic flux hose[3], is used to adjust the cavity-qubit interaction in situ. Combined with an element for two-photon dissipation, this setup could be utilized as an improved building block for a fully protected logical qubit.

References

[1] P. Heidler, C. Schneider et al, *Phys. Rev. Applied 16* (2021) 034024
[2] D. Gusenkova, M. Spiecker et al, *Phys. Rev. Appl. 15* (2021) 064030
[3] O. Gargiulo, S. Oleschko et al, *Appl. Phys. Lett.* 118 (2021) 012601
[4] P. Groszkowski, J. Koch, *Quantum 5* (2021) 583

Figures

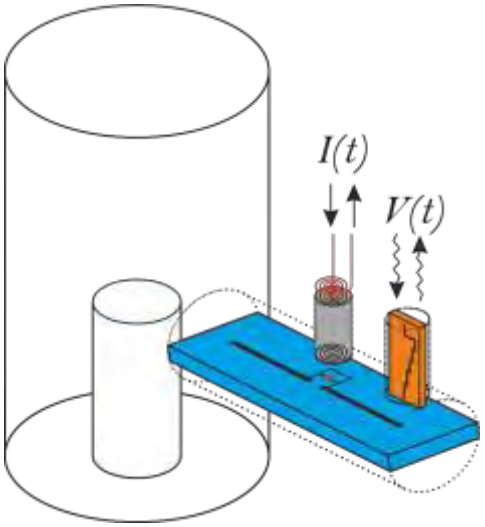


Figure 1: Setup schematic. The system consists of a coaxial cavity (white), fluxonium chip (blue), magnetic flux hose[4] (grey) and a Purcell filter[5] (orange).

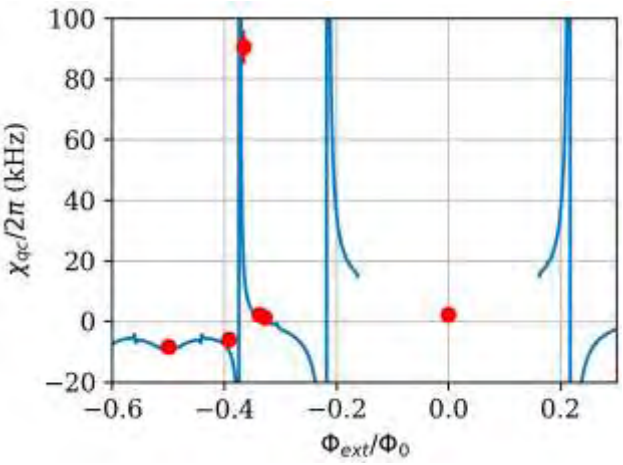


Figure 2: Simulated[4] dispersive shift between the cavity and the qubit as a function of the normalised trapped flux (blue) together with the measured datapoints (red).

Interplay Between Topological and Defect States: Periodic One-Dimensional Patterns in Bilayer Graphene

A. Ayuela[1], R. Guerrero-Avilés[1], L. Chico[2], W. Jaskólski[3], and M. Pelc[3]

[1]*Material Physics Center CFM-MPC, Donostia International Physics Center (DIPC), Paseo Manuel Lardizabal 4-5, 20018 Donostia-San Sebastián, Spain.*
[2]*GISC, Departamento de Física de Materiales, Facultad de Ciencias Físicas, Universidad Complutense de Madrid, 28040 Madrid, Spain*
[3]*Institute of Physics, Nicolaus Copernicus University in Toruń, Grudziadzka 5, 87-100 Toruń, Poland*

a.ayuela@csic.es

Gating Bernal bilayer graphene breaks the inversion symmetry so that the stacking AB/BA boundaries reveal topologically protected states within the gap [1]. Here, we theoretically investigate arrays where the AB and BA domains are periodically patterned with experimentally identified defect lines [2,3]. In the calculations we consider electron-electron interaction effects using density functional theory. Our findings reveal the existence of topological states within a gap induced by the patterning even without an applied gate voltage. Furthermore, with an applied gate potential, the defect lines introduce spin-polarized states pinned within the gap and exhibit ferromagnetically coupled states. Importantly, we observe a hybridization of magnetic and topological states near the valleys that form conducting channels characterized by spin-momentum locking. The effect persists even with slight n-doping and gate voltage; however, the progressively pinned n-doped defect states induce spin polarization in the topological and valley states. Additionally, the two-dimensional bands under doping conditions exhibit nesting across the Fermi surface, allowing for modulation of charge densities along the lines which are nearly commensurate with the underlying graphene-defect lines. These quasi-one-dimensional patterns in bilayer graphene show a new kind of spin conducting channels with novel characteristics common to both spintronics and valleytronics [4].

References

[1] AS. Huang, et al , Phys. Rev. Lett. 121, 037702 (2018).
[2] W. Jaskólski, M. Pelc, G. W. Bryant, L. Chico, and A. Ayuela, 2D Materials 5, 025006 (2018).
[3] W. Jaskólski, M. Pelc, L. Chico, and A. Ayuela, Nanoscale 8, 6079 (2016).
[4] R. Guerrero-Avilés, A. Ayuela, L. Chico, W. Jaskólski, M. Pelc, (to be submitted).

Figures

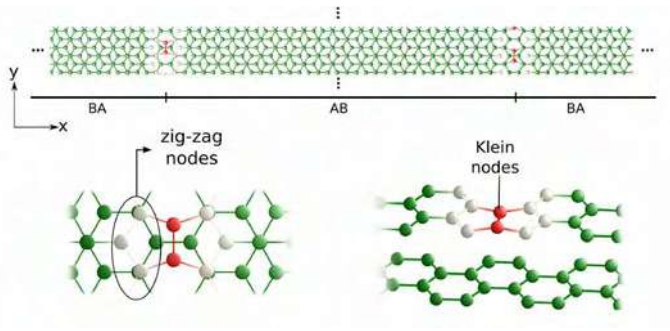


Figure 1: (Upper panel) Schematic view of an array of defect lines in bilayer graphene separating AB and BA stacking domains. (Lower panels) Zoom views of defect nodes. Gray and red carbon atoms correspond to zigzag- and Klein-like nodes, respectively.

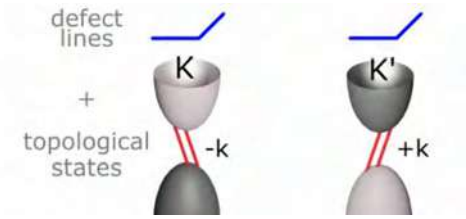


Figure 2: Interplay of defect states and topological states around valleys, to be discussed for domain walls in bilayer graphene, as shown in Fig 1.

Atomic-Scale Quantum Sensing of Electric and Magnetic Fields in a Scanning Tunneling Microscope

Yujeong Bae[3,4,7]
Taner Esat[1,2], Dmitriy Borodin[3,4], Jeongmin Oh[3,4], Andreas J. Heinrich[3,4], F. Stefan Tautz[1,2,5], Ruslan Temirov[1,2,6]

[1]*Peter Grünberg Institute (PGI-3), Forschungszentrum Jülich; Jülich, Germany.*
[2]*Jülich Aachen Research Alliance (JARA), Fundamentals of Future Information Technology; Jülich, Germany.*
[3]*Center for Quantum Nanoscience (QNS), Institute for Basic Science (IBS); Seoul 03760, South Korea.*
[4]*Department of Physics, Ewha Womans University; Seoul 03760, South Korea.*
[5]*Experimentalphysik IV A, RWTH Aachen University; Aachen, Germany.*
[6]*Faculty of Mathematics and Natural Sciences, Institute of Physics II, University of Cologne; Cologne, Germany.*
[7]*Empa, Swiss Federal Laboratories for Materials Science and Technology, nanotech@surfaces Laboratory, 8600, Dübendorf, Switzerland.*

yujeong.bae@empa.ch

Abstract

Quantum sensing harnesses the innate sensitivity of quantum systems to external perturbations, enabling precise measurements of physical quantities. The most prevalent platforms like color centers in insulators and superconducting circuits excel in detecting magnetic or electric fields but the spatial resolution of existing techniques remains elusive as a consequence of retaining the sensor location and size. In contrast, conventional probe techniques, such as scanning tunneling microscopy (STM), achieve atomic-scale resolution routinely. Recent advances integrating electron spin resonance (ESR) with STM [1,2] have paved the way for quantum sensing while the studies have focused on quantum sensors located on a surface, which prevents tunable couplings and three dimensional characterization. This work presents a fully integrated, mobile quantum sensor positioned at the STM tip. The quantum sensor is composed of a magnetic atom cluster for readout and a free radical for ESR-based quantum sensing. By measuring the magnetic and electric dipole moments of an iron atom and a silver dimer on Ag(111), we demonstrate the functionality of our quantum sensor, providing sub-microvolt energy resolution and simultaneous atomic-scale spatial resolution for magnetic and electric field measurements. We anticipate that our fully integrated sensing and read-out unit can further facilitate the characterization of spin ordering in newly emerging materials, thereby advancing the application of quantum sensing technologies to the realm of quantum materials.

References

[1] S. Baumann, W. Paul, T. Choi, C. P. Lutz, A. Ardavan, and A. J. Heinrich, Science, 350 (2015) 417-420.
[2] Y. Chen, Y. Bae, and A. J. Heinrich, Adv. Mater., 35 (2023) 2107534.

Figures

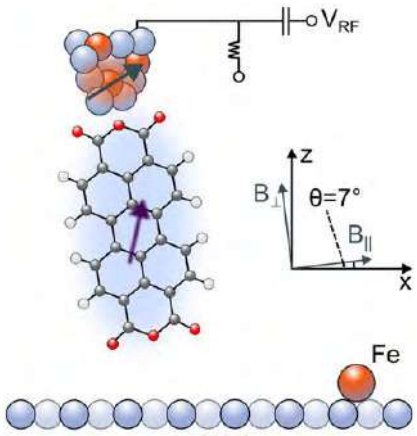


Figure 1: Molecular quantum sensor attached to the STM tip, which can be electrically detected by ESR and deliver atomic resolution to read out magnetic and electric fields.

Passive Protection of Quantum Information in Mixed-Range Interacting Quantum Spin Chains

Anthony Balchin
Dr. Eran Ginossar

University of Surrey, Advanced Technology Institute, Guildford, United Kingdom.

a.balchin@surrey.ac.uk

Quantum error-correction schemes are designed to actively remove errors from large scale quantum processors and are predicted to require a significant number of physical resources. A different 'passive' approach to this problem encodes quantum information in the ground state space of a quantum phase that is protected by symmetry and topology [1].

Our 'passive' approach involves the engineering of a spin chain model Hamiltonian with both short-range nearest-neighbour (NN) interactions and longer-range interactions, beyond next-NN. This model exhibits a high degree of entanglement across the chain and possesses protected degenerate ground states. These robust states energetically suppress errors and can be viable for quantum computation due to their non-local properties [2,3]. We use a density matrix renormalisation group (DMRG) approach to study the entanglement structure with quantum information measures, in order to classify the quantum phases and detect signatures of topologically non-trivial phases. This work can be used to offer further insight into the engineering of qubits for exploiting protection properties of topologically ordered phases of matter.

References

[1] B. Terhal, Rev. Mod. Phys., **87**, 307, (2015)
[2] A. Callison, E. Grosfeld, E. Ginossar, Phys. Rev. B, **96**, 085121 (2017)
[3] P. Brookes *et al.*, Phys. Rev. Applied, **17**, 024057 (2022)

Figures

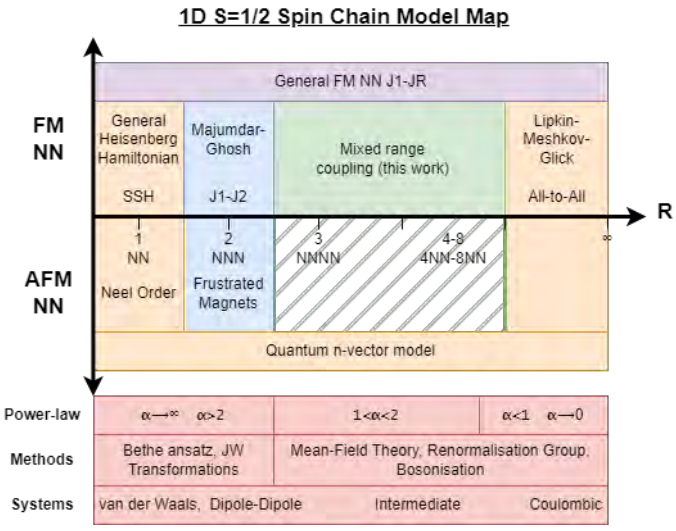


Figure 1: A map of different spin chain models with some example systems placed in terms of their longest interaction, where R is an integer corresponding to the distance between the site numbers in the two-body interactions. Vertical axis represents the sign of the interaction between the NN pairs, ferromagnetic (FM) or antiferromagnetic (AFM). Below represents regimes of power-law models, validity of some analytical methods, and examples of physical systems.

Topological Phase Transition from 1D Edge States to 0D End States in Germanene Nanoribbons

Dennis J. Klaassen[1], Lumen A.G. Eek[2], Alexander N. Rudenko[3], Esra D. van 't Westende[1], Carolien Castenmiller[1], Zhiguo Zhang[1,4], Bene Poelsema[1], Arie van Houselt[1], Motohiko Ezawa[5], Cristiane M. Smith[2], Harold J.W. Zandvliet[1] and **Pantelis Bampoulis[1]**

[1]*University of Twente, Drienerlolaan 5, Enschede, The Netherlands*

[2]*Utrecht University, The Netherlands*

[3]*Radboud University Nijmegen, The Netherlands*

[4]*Fudan University, China*

[5]*University of Tokio, Japan*

p.bampoulis@utwente.nl

Investigating topological phases and their transitions is crucial for discovering new quantum states and advancing topological device technology. The transitions between distinct topological phases, especially from two-dimensional (2D) to one-dimensional (1D) systems, remain largely unexplored and poorly understood. In this study, we synthesized germanene nanoribbons, which are 2D topological insulators [1], featuring zigzag terminations, large topological gaps (100-150 meV), and metallic edge states. These nanoribbons enable the packing of a dense array of parallel 1D topological edge states. By systematically varying the nanoribbon width, we monitored the evolution of their topological characteristics, pinpointing a transition to a 1D topological insulator phase below a critical width of about 2 nm. This transition is marked by the vanishing of the 1D edge states and the emergence of distinct zero-dimensional (0D) end states. We obtain theoretically and experimentally that the 0D topological behavior of (thin) Germanene nanoribbons is rich and complex. The topological phase depends in a non-monotonic way on ribbon width, spin-orbit coupling, staggered mass, and termination.

References

[1] P. Bampoulis et al. Phys. Rev. Lett. 130, (2023) 196401

Figures

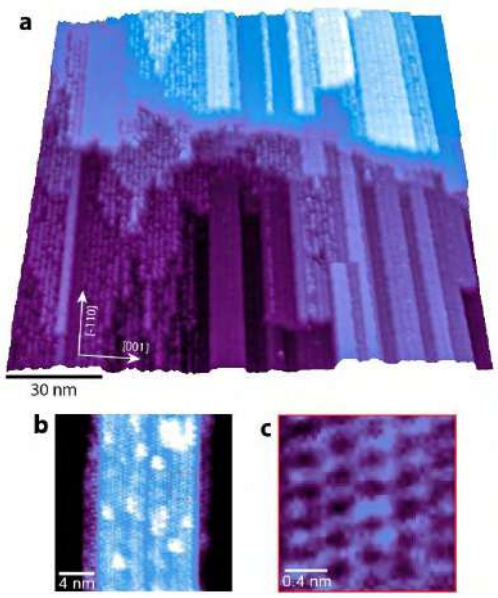


Figure 1: (a) Large-scale STM image of germanene nanoribbons grown on the Ge_3Pt substrate. **(b)** Detailed view of a germanene nanoribbon. **(c)** Close-up of the area marked by the red square in (b), highlighting the honeycomb lattice structure of germanene.

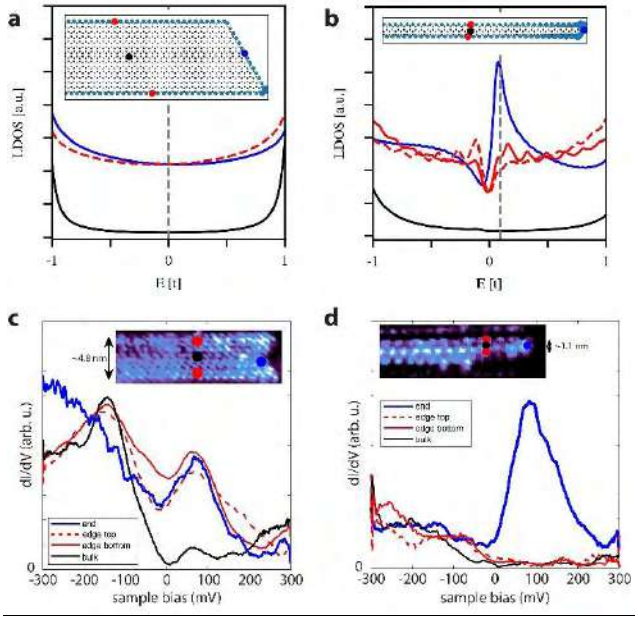


Figure 2: LDOS calculations for a wide **(a)** and a narrow **(b)** nanoribbon showing a transition to 0D end states. Experimental dI(V)/dV spectra comparing a wide **(c)** and narrow **(d)** nanoribbon, showing the vanishing of edge states and emergence of pronounced end states as the nanoribbon width decreases.

Engineering Transport Orbitals in Single Molecule Junctions

Pablo Bastante
Nicolás Agraït

Departamento de Física de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain

pablo.bastante@uam.es

Single-molecule devices provide an ideal platform to study quantum transport for a new generation of electronic components, as molecular design enables the integration of electronic functions at the smallest level [1]. Charge transport can be tuned using electron-donating substituents, just like traditional semiconductors [2]. In this work, single-molecule devices based on compounds in Figure 1a, including either electron withdrawing or donating side groups into a tolane molecular structure, are fabricated and characterized using the STM-break junction technique at ambient conditions. Measuring the electrical conductance and the thermopower we find that the electron withdrawing side groups can be used to tune the energy levels of transport orbitals and create additional charge transport channels due to quantum interference effects for the enhancement of charge transport properties.

Figures

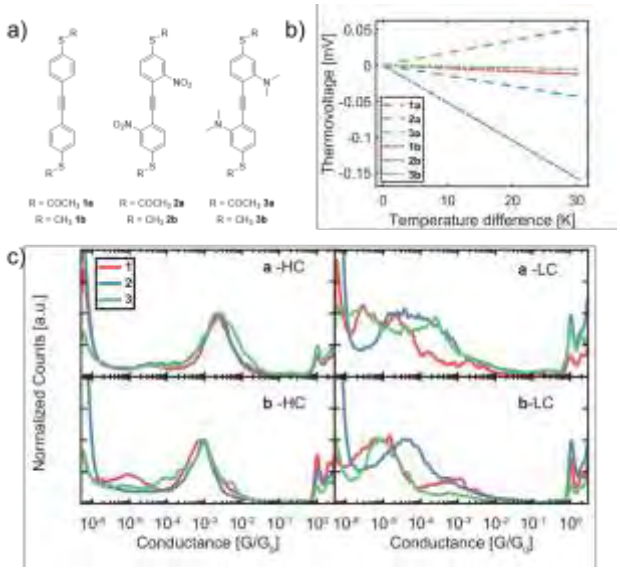


Figure 1: (a) Schematic view of tolane **1** with either electron withdrawing **2** or donating **3** side groups, decorated with either –SAc **a** or –SMe **b** anchor groups. (b) Linear fit of all the temperature difference dependent thermovoltage values for all the compounds to obtain the themopower, combined for comparison. (c) 1D-conductance histograms of the HC (left) and LC (right) peaks as obtained from clustering, separated by anchoring group (top: -SAc, bottom: -SMe). Measurements have been normalized by peak height to make the peak position and shape directly comparable across the different molecules

References

[1] D. Xiang et al., Chem. Rev. Lett., 116 (2016) 4318
[2] L. Venkataraman et al., Nano Lett., 7 (2007) 502
[3] A. Daaoub et al., J. Phys. Chem. Lett., 13 (2022) 9156

Testing dimension by a null witness

Adam Bednorz
Tomasz Białecki, Tomasz Rybotycki, Josep Batle, Jakub Tworzydło

Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland

abednorz@fuw.edu.pl

Abstract

Certified qubits are critical for reliable quantum error correction. A diagnostic test of the qubit dimension should be robust against nonideal quantum operations. We developed a dimension witness, a function of measurement probability matrix, which is zero up to statistical error if the tested system is of expected dimension. The witness is tailored to important cases: simple parametric rotation [1]; single qubit and random operations [2,3]; single qubit and a sequence of identical gates [4]; single multi-outcome measurement [5]; entangled qubits[6]. We applied of the test to various IBM Quantum qubits. Collecting large statistics, we conclude that most cases pass the test, which is robust against decoherence and incoherent leakage. However, some cases show failure, Figs. 1,2, with the nonzero witness beyond 5 standard deviations. Our method is therefore a very accurate diagnostic tool to check the extra dimension, invisible for superficial benchmarking. The failures have no simple and consistent causes and need urgent technical or fundamental explanations.

References

[1] T. Białecki, T. Rybotycki, J. Tworzydło, A. Bednorz, arXiv:2112.07567, Frontiers in Physics (in press)
[2] J. Batle, A. Bednorz, Phys. Rev. A 104, 042433 (2022)
[3] T.Białecki, T. Rybotycki, J. Batle, J. Tworzydło, A. Bednorz, arXiv:2301.03296
[4] T. Białecki, T. Rybotycki, J. Batle, J. Tworzydło, A. Bednorz, arXiv:2308.11246, Phys Rev. A (in press)
[5] J. Batle, A. Bednorz, Phys. Rev. A 108,062202 (2023)
[6] J. Batle, T. Białecki. T. Rybotycki, J. Tworzydło, A. Bednorz, arXiv:2312.13996

Figures

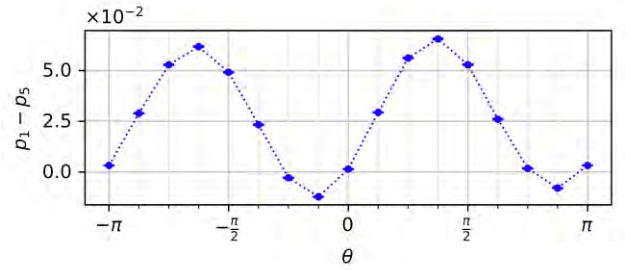


Figure 1: Failure of the rotation test on IBM lagos qubit 0. The difference between probabilities for 1 and 5 gates at the angle θ is not zero [1]

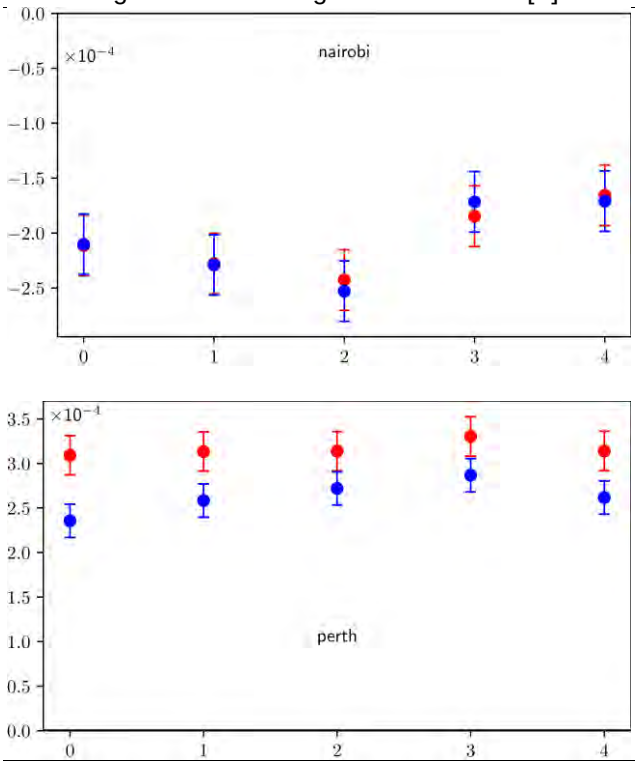


Figure 2: Failure of the parametric random operation test of the qubit dimension on IBM qubits (nairobi 0 and perth 0) [3], with the witness calculated from averaged probabilities (blue) and averaged over individual runs (red)

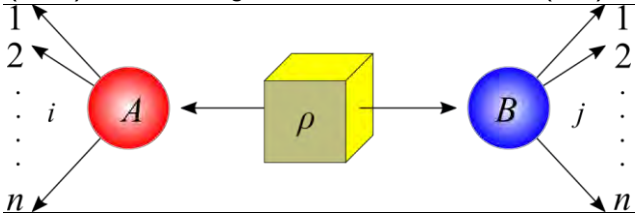


Figure 3: Test of dimension of entangled qubits with *n* measurements at each party [6]

Si/SiGe based quantum dot devices for memory and micron-scale connectivity with more than 200 gate electrodes

Max Beer
Ran Xue, Tom Struck, Mats Volmer, Lino Visser, Tobias Offermann, Hendrik Bluhm and Lars R. Schreiber

JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany

max.beer@rwth-aachen.de

Abstract

Si/SiGe based gate-defined spin qubits have been matured to such a degree over recent years that high density, high quantum dot count devices are technologically feasible. We recently demonstrated the capability of our Quantum Bus (QuBus) device [1] to initialize a register of 34 quantum dots (Fig. 1), with a per-dot filling of a single or no electrons at will (Fig. 2) [2]. All the while the entire "electron pattern" can be shifted along the register using conveyor-mode shuttling and electrons can be loaded and detected at the end of the shuttle [2, 3]. Despite more than 100 gate electrodes along the shuttle lane, only six control terminals are required. We demonstrated the shuttling of a single electron across the entire device back and forth (19 µm) with 99.8 % fidelity. In a related work [4], we show coherent separation and rejoining of an entangled spin-pair up to an accumulated shuttling distance of 3.36 µm using a similar QuBus device.

In this talk, I will discuss our fabrication processes at the Helmholz-Nanofacility at Research Center Jülich. They enable, in general, a large gate-electrode count beyond the 200 gate mark and specifically a T-junction connecting shuttle device featuring three single electron transistors as proximate charge sensors. I will also elaborate on a pre-screening process we developed to validate our devices electrically at an intermediate temperature of 4 K.

References

[1] Langrock et al., PRX Quantum **4**, 020305 (2023)
[2] Xue *et al.*, preprint, arXiv:2306.16375 (accepted for Nat. Commun.)
[3] Seidler *et al.*, npj Quantum Inf. **8**, 100 (2022)
[4] Struck *et al.*, preprint, arXiv:2307.04897 (accepted for Nat. Commun.)

Figures

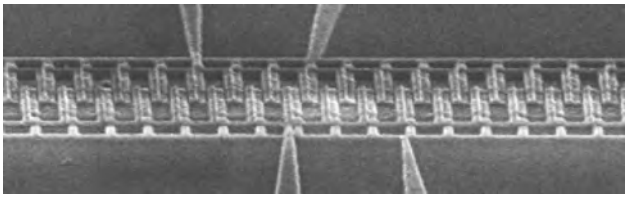


Figure 1: Scanning electron micrograph of the center section of a QuBus device. The width of the image covers approximately 4.3 µm.

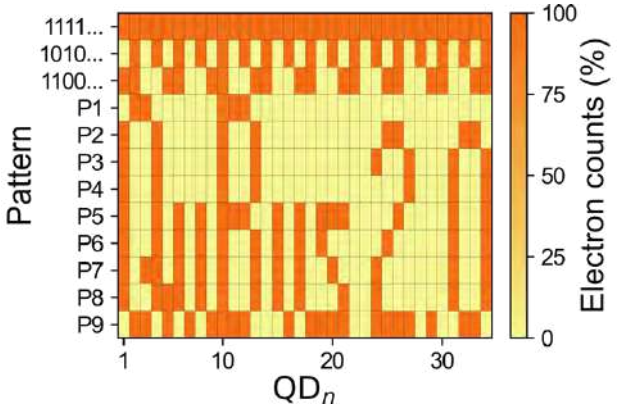


Figure 2: Fidelity analysis of the encoding of several "electron patterns" given by the quantum dot filling (either 0 or 1 at will). Each line represents one filling pattern for the full device containing 34 QDs. Adapted from [2].

Towards reduced dielectric losses in superconducting quantum circuits

María Benito-Gomes [1,2]
Gemma Rius [1]

[1] *Instituto de Microelectrónica de Barcelona – Centro Nacional de Microelectrónica (IMB-CNM), CSIC. Carrer dels Til.lers s/n, Cerdanyola del Vallès, 08193, Spain*
[2] *Departament de Física, Universitat Autònoma de Barcelona, Bellaterra 08193, Spain*

maria.benito@imb-cnm.csic.es, gemma.rius@csic.es

Superconducting circuits is one of the most popular platforms used for prospective quantum computers. However, e.g. state-of-the-art resonators still report losses at least one order of magnitude higher than predicted for pure bulk dielectric losses, which has been commonly attributed to Two-Level-Systems (TLS) of amorphous materials, such as native oxides.
Indeed, despite having been studied for decades, materials-induced decoherence is still one of the major challenges to overcome.
Most of the bibliography has focused so far on reducing TLS in terms of metal growth procedures, surface preparation methods, and other fabrication-related characterization [1]. We aim to tackle the issue by benchmarkable *metal/substrate combinations, i.e.* using the same fabrication procedures and resonator's geometry, in order to make informed analyses of the substrate-related dielectric losses. It is aimed to fill the gap of current comparisons from meta-analysis [2], where differences in chip design and fabrication steps can limit comparisons validity.

Here, I will present some of the recent results obtained for *Aluminium Superconducting Resonators, which have been patterned on substrates such as Sapphire, Silicon, and Silicon Carbide*. Transfer measurements as a function of applied microwave power and operating temperature are employed to extract the internal quality factor of each resonator, while a dedicated design, "tapered" resonators with equivalent coupling to feed line, is used for estimating the TLS surface density.

References

[1] Oliver, William D., and Paul B. Welander. "Materials in superconducting quantum bits." MRS bulletin 38.10 (2013): 816-825.
[2] McRae, Corey Rae Harrington, et al. "Materials loss measurements using superconducting microwave resonators." Review of Scientific Instruments 91.9 (2020).

Figures

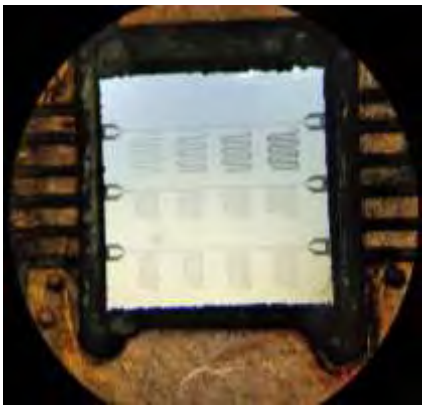


Figure 1: SC Al/Sapphire resonators designed with different surface participation ratios

A study on the effect of ring exchange interaction in a two-leg Bose-Hubbard ladder

Sourav Biswas[1]
Enrique Rico Ortega[1,2,3], and Tobias Grass[1,2]

[1] *Donostia International PhysicsCenter, Donostia - San Sebastian, 20018, Spain.*

[2] *IKERBASQUE, Basque Foundation for Science, Plaza Euskadi 5, 48009 Bilbao, Spain.*

[3] *EHU Quantum Center, University of the Basque Country UPV/EHU, P.O. Box 644, 48080 Bilbao, Spain.*

sourav.biswas@dipc.org

In this work, we study the effect of ring exchange interaction in a two-leg Bose-Hubbard ladder using the DMRG (Density matrix renormalization group) technique. In realistic setups, a two-leg system is expected to be influenced by ring exchange [1, 2] mechanism apart from extended density-density interaction. In this regard, one can think of a two-band system and investigate different phases of matter emerging due to such interactions. The significance of such exchange terms has been known for a while [1, 2, 3]. In light of recent experimental observation [4] of the bose-metal phase, the study of such exchange interaction has become crucial for gaining more understanding of interacting bosonic systems.

References

[1] D. N. Sheng, Olexei I. Motrunich, Simon Trebst, Emanuel Gull, and Matthew P. A. Fisher, Phys. Rev. B 78, 054520 (2008).

[2] A. Paramekanti, L. Balents, M. P. A. Fisher, Phys. Rev. B 66, 054526 (2002).

[3] P. Phillips and D. Dalidovich, Science 302, 243 (2003).

[4] A. Hegg, J. Hou, and W. Ku, Proc. Natl. Acad. Sci.118(46), 2100545118 (2021).

Amplified Nanoscale Detection of Labelled Molecules via Surface Electrons on Diamond[1]

A. Biteri-Uribarren
P. Alsina-Bilívar, C. Munuera-Javaloy, R. Puebla, and J. Casanova

University of the Basque Country UPV/EHU, Leioa, Spain

ainitzebiteriuribarren@gmail.com

The detection of individual molecules and their dynamics has been a long-standing challenge in the field of nanotechnology. In this work, we present a method that utilizes a nitrogen vacancy (NV) center and a dangling bond (DB) on the diamond surface to measure the coupling between two electronic targets (L1 and L2) tagged on a macromolecule. To achieve this, we design a multi-tone dynamical decoupling sequence that leverages the strong interaction between the nitrogen vacancy center and the dangling bond. In addition, this sequence minimizes the impact of decoherence finally resulting in an increased signal-to-noise ratio. This proposal has the potential to open up new avenues for fundamental research and technological innovation in distinct areas such as biophysics and biochemistry.

References

[1] A. Biteri-Uribarren, P. Alsina-Bolívar, C. Munuera-Javaloy, R. Puebla and J. Casanova, Communication Physics, 6 (2023) 359.

Figures

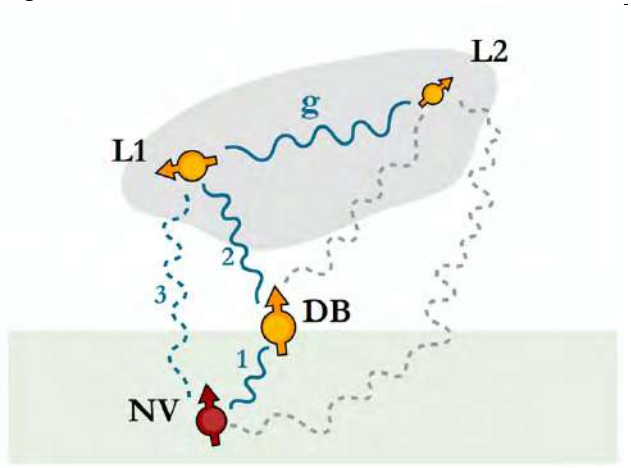


Figure 1: Illustration of the system. The dipolar coupling g between L1 and L2 is the target parameter of the protocol.

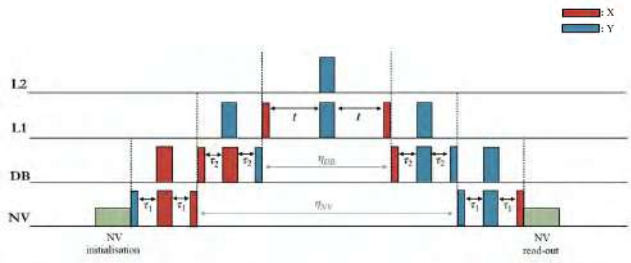


Figure 2: Scheme of the multi-tone dynamical decoupling sequence, where each channel is associated to an element of the system (NV, DB and labels). The blue and red boxes represent the pulses to be delivered, the wider ones indicate π pulses while the others π/2 pulses, and the color encodes the axis of the pulse. To extract the dipolar coupling, the protocol needs to be applied for different values of t.

Control of a qubit by means of a Classical field: The Driven Jaynes-Cummings model

Ivan A. Bocanegra Garay*, L. Hernández-Sánchez**, I. Ramos-Prieto**, F. Soto-Eguibar** and H. M. Moya-Cessa

**Departamento de Física Teórica, Atómica y Óptica and Laboratory for Disruptive Interdisciplinary Science, Universidad de Valladolid, 47011, Valladolid, Spain.*
***Instituto Nacional de Astrofísica, Óptica y Electrónica, Calle Luis Enrique Erro No. 1, Santa María Tonanzintla, Puebla, 72840, México.*

Contact: ivanalejandro.bocanegra@uva.es

The Jaynes-Cummings model (JCM) is one of the most important models in quantum optics. It sketches out the interaction of a two-level system (qubit) with a single mode of the quantized electromagnetic field (cavity field) in the so-called *rotating wave approximation* (RWA) [1,2]. We present a exatly-solvable modification of the JCM, where both the qubit and the quantized field are driven by an external classical field: the driven JCM (DJCM) [3,4] (Figure 1), and show that the classical driving field can be used as a control for the qubit. Particularly, it is shown that, by properly adjusting the external classical driving field, it is possiible to finely manipulate the atomic transitions of the qubit (see Figure 2), as well as the quantum properties of the cavity field. This, in turn, is of interest in many active areas of research encompassing basic science as well as applied physics. To mention a few, we can list the theory of quantum information and quantum communications, quantum optics, quantum control, quantum computation, etc (see for instance [5,6]).

References

[1] E. T. Jaynes and F. W. Cummings, Proc. IEEE 51 (1963) 89.
[2] B. W. Shore and P. L. Knight, J. Mod. Opt. 40 (1993) 1195.
[3] P. Alsing, D. -S. Guo and H. J. Carmichael, Phys. Rev. A. 45 (1992) 5135.
[4] I. A. Bocanegra-Garay, L. Hernández-Sánchez, I. Ramos-Prieto, F. Soto-Eguibar and H. M. Moya-Cessa, SciPost Phys. 16 007 (2024).
[5] M. Brune, F. Schmidt-Kaler, A. Maali, J. Dreyer, E. Hagley, J. M. Raimond and S. Haroche, Phys. Rev. Lett. 76 (1996) 1800.
[6] H. J. Kimble, Nature 453 (2008) 1023.

Figures

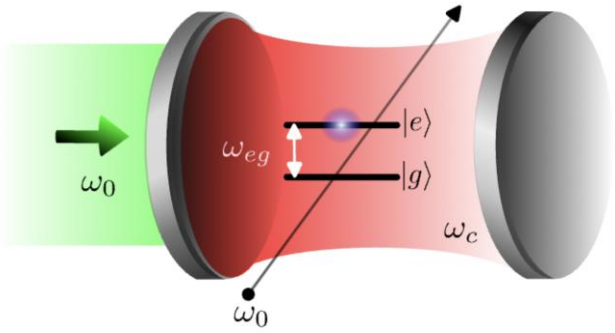


Figure 1: Schematic setup for the DJCM.

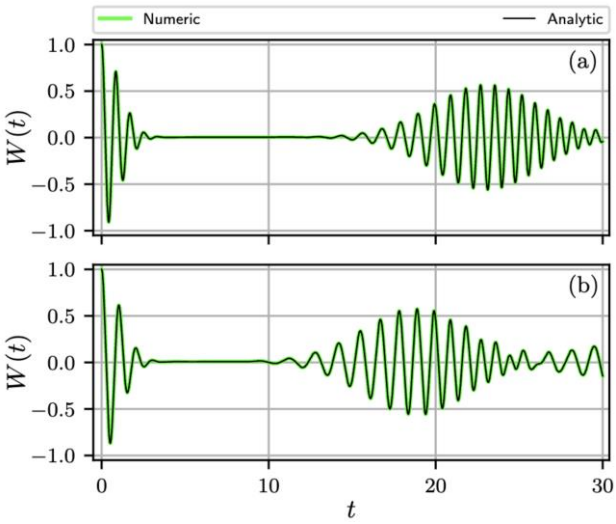


Figure 2: Atomic inversion W(t) corresponding to the DJCM (up) and the JCM (down).

Tailoring arbitrary energy-phase relationships using Josephson tunnel junctions

A. Mert Bozkurt[1,2]
J. Brookman[1], V. Fatemi[3], and A. Akhmerov[1]

[1] Kavli Institute of Nanoscience, Delft University of Technology, 2600 GA Delft, The Netherlands
[2] QuTech, Delft University of Technology, Delft 2600 GA, The Netherlands
[3] School of Applied and Engineering Physics, Cornell University, Ithaca, NY 14853 USA

a.mertbozkurt@gmail.com

Abstract

Josephson tunnel junctions exhibit a simple current-phase relation, characterized by single harmonics. Conversely, high-transparency Josephson junctions feature multiple harmonics, with the specific harmonics depend on microscopic details of the junction, presenting a challenge for precise control.

In this talk, I will illustrate that two Josephson tunnel junctions are connected in series, their energy-phase relationship is identical to a high-transparency Josephson junction (see Fig.1 (a)).
Based on this, I will demonstrate that by connecting multiple arms in parallel and introducing a magnetic flux (see Fig.1(b)), we can systematically engineer specific current-phase relationships.

As an example, I will showcase a superconducting diode implementation with a high efficiency, a two-terminal device that controls supercurrent flow in one direction differently from the other.
The resulting superconducting diode efficiency is robust against the imperfections in the design parameters, making it practical for real-world implementations.
Beyond superconducting diodes, I will also showcase various other energy-phase relationships to demonstrate the versatility of the approach.

This technique can be useful for engineering sophisticated energy-phase landscapes for advanced quantum computing systems.

References

[1] A. Mert Bozkurt, Jasper Brookman, Valla Fatemi, Anton R. Akhmerov, SciPost Phys. 15, 204 (2023).

Figures

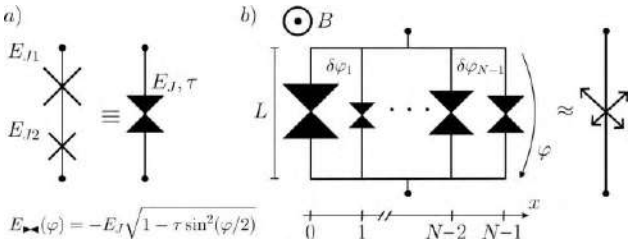


Figure 1: a) Two Josephson tunnel junctions in series is equivalent to a high transparency Josephson junction. (b) The layout of the Josephson junction array with N arms connected in parallel. Magnetic field B points out of the plane of the Josephson junction array, giving rise to phase difference between arms. We denote the resulting EPR of the Josephson junction array as a two-terminal circuit element.

Towards Andreev molecules in semiconducting nanowires

[1]Vittorio Buccheri
[1]Ivo Cools, [2]Thomas Kanne, [2]Jesper Nygård, [1]Simone Gasparinetti, [1]Attila Geresdi.

[1]Department of Microtechnology and Nanoscience. Chalmers University of Technology, SE, 41296, Göteborg, Sweden.

[2]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark.

buccheri@chalmers.se

Semiconducting Josephson junctions have recently attracted attention due to the interesting physics they present as a combination of superconducting and semiconducting properties [1] and, particularly, for their suitability in Quantum Information [2, 3, 4]. The main role in this kind of devices is played by the Andreev bound states, which are fermionic modes created in the weak link as a consequence of electron-hole Andreev reflections at the semiconductor-superconductor interfaces. It has been experimentally proven that Andreev bound states in a single semiconductor Josephson junction can be coherently addressed and used to realize a quantum bit [5, 6, 7]. Such a result pushes towards the investigation of devices with two or more weak links hosting coupled Andreev bound states, the so-called Andreev molecules [8, 9].
In this talk, I present characterization measurements on a device in which a semiconducting nanowire hosting two junctions is coupled to a superconducting resonator in a rf-SQUID configuration.
We control the chemical potential in the weak link and the superconducting phase across the nanowire via electrostatic gates and external magnetic field, respectively. We demonstrate strong coupling between the resonator and an Andreev bound state by single-tone and two-tone spectroscopy measurements. I conclude by presenting preliminary results towards independent control of individual Andreev bound states in a 2-junction device.

References

[1] E. Prada, P. San-Jose, M.W.A. de Moor et al. From Andreev to Majorana bound states in hybrid superconductor–semiconductor nanowires. Nat Rev Phys 2, 575–594 (2020).
[2] M.A. Desposito and A. Levy Yeyati, Controlled dephasing of Andreev states in superconducting quantum point contact. Phys. Rev. B, 64, 140511(R) (2001).
[3] G. Wendin and V.S. Shumeiko, Quantum bits with Josephson junctions (Review Article). Low Temp. Phys. 33(9), 724-744 (2007).
[4] C. Padurariu and Yu. V. Nazarov. Theoretical proposal for superconducting spin qubits. Phys. Rev. B 81, 144519 (2010).
[5] C. Metzger, S. Park, L. Tosi, et al., Circuit-QED with phase-biased Josephson weak links. Phys Rev. Res. 3, 013036 (2021).
[6] M. Hays, V. Fatemi, D. Bouman, et al. Coherent manipulation of an Andreev spin qubit. Science, 373, 430 (2021).
[7] M Hays, G. de Lange, K. Serniak et al., Direct Microwave Measurement of Andreev-Bound-State Dynamics in a Semiconductor-Nanowire Josephson Junction. Phys. Rev. Lett. 121, 047001 (2018).
[8] O. Kürtössy, Z. Scherübl, G. Fülöp et al., Andreev Molecule in Parallel InAs Nanowires. Nano Lett., 21, 7929-7937 (2021).
[9] D.Z. Haxell, M.Coraiola, M. Hinderling et al., Demonstration of the Nonlocal Josephson Effect in Andreev Molecules. Nano Lett., 23, 7532-7538 (2023).

Growth of AlOx tunnelling barriers via oxidation of Al in thermalized atomic oxygen atmosphere

David Caldevilla-Asenjo[1].
Sara Catalano[1], Elia Strambini[2], F. Sebastian Bergeret[1], Celia Rogero[1], Maxim Ilyn[1]

[1]*Centro de Física de Materiales CSIC-UPV/EHU, Paseo Manuel Lardizabal 5, 20018 Donostia, Spain*
[2]*NEST Istituto Nanoscienze-CNR and Scuola Normale Superiore, I-56127, Pisa, Italy*

david.caldevilla@estudiante.uam.es

Thin insulating *AlOx* layers have become important parts of the devices like magnetic or superconducting tunnelling junctions, state of art transistors and radiation sensors. Widespread implementation of Aluminium Oxide *AlOx* is concerned with easy fabrication procedure that consists in exposure of metallic Al to oxygen atmosphere. Nevertheless, the oxidation in near ambient O_2 conditions is known to be a self-limited process, which gives rise to the *AlOx* layers of ~ 2nm and dispersion of the thicknesses of ~50% [1]. The lack of tuneability in this method motivates the usage of an oxygen-plasma atmosphere to induce the oxidation. Accelerated oxygen ions produced via electrical discharge or due to application of the radio-frequency electromagnetic fields were found to be capable of creating homogeneous *AlOx* layers of variable thicknesses despite the effect of granularity of the metallic Al films [2]. But using of oxygen plasma has the counter part of generating some stoichiometric problems along the process, like a presence of oxygen-rich layers, which can oxidize the upper electrode or provoking appearance of metastable two-state systems, which is a source of noise in the radio-frequency circuits [3]. In this talk I will report on the alternative growth technique of the *AlOx* layers that consists in exposure of thin Al films to thermalized atomic oxygen atmosphere of 3-4 mbars. I will present the results of combined spectroscopic photoemission characterization of the continuous *AlOx* layers and transport measurements of Al-*AlOx*-Al Josephson Junctions performed in a dilution refrigerator at a base T of 8mK. These data will demonstrate the advantages of using atomic oxygen in comparison to oxidation in molecular O2 or by means of the accelerated O ions.

References

[1] L.J. Zeng et al, J. Phys. D: Appl. Phys (2015) 395308
[2] Y. Ando et al, J. Phys. D: Appl. Phys. 35, (2002), 2415-2421
[3] M.F. Gillies et al, J. Appl. Phys. 88, (2000), 429-434

Figures

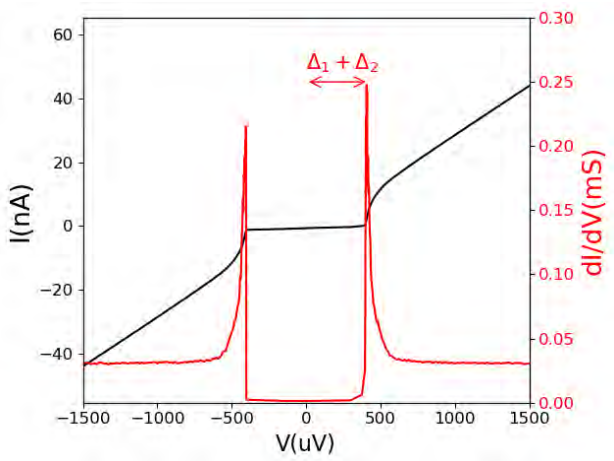


Figure 1: Tunnel spectroscopy of a Al-AlOx-Al tunnel barrier at 8mK.

Polarization Characterization of BBO and ppKTP SPDC-based Entanglement Light Sources

John Campbell
John Dooley, Bryan Hennelly

Maynooth University, Dept of Electronic Engineering, Maynooth Couny Kildare, Republic of Ireland
John.Campbell.2023@mumail.ie

Abstract

This article explores the polarization control and characterization of established experimental generation and characterization of polarization entangled photons using type-II spontaneous parametric down conversion (SPDC) with nonlinear optics[1]. The study investigates the use of different nonlinear optical crystals, such as BBO and ppKTP, to generate polarization-entangled single photon pairs at 810 nm.

The focus of our work is the application of using SPDC photons in quantum networks with the entanglement source as a node optimized based on the mapped network's Fiedler vector, allowing for optimal distribution as quantum networks grow in complexity using continuous variable entanglement light sources based on ppKTP [2].

The Poincaré sphere is used to map the state from the entanglement source (Figure 1), and the Wigner function of the entangled photons is constructed (Figure 2) from standard polarization measures. Quantum state tomography is employed to generate the Wigner function, providing phase-space representations of polarization-entangled states [2].

The experimental results demonstrate the potential of non-linear optical SPDC-sourced polarization states of quantum entanglement distributed as a resource in fibered networks [3].

Figures

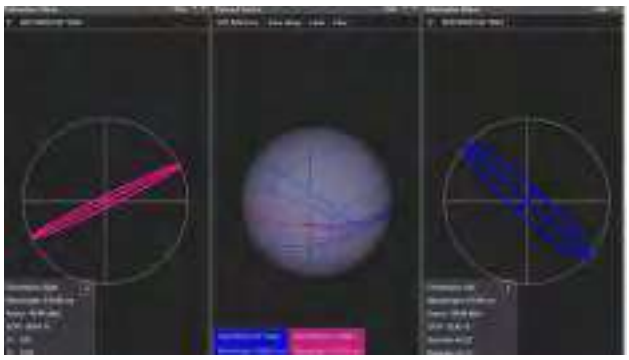


Figure 1: Polarizations of the signal and Idler from an entanglement source mapped to the Poincaré sphere

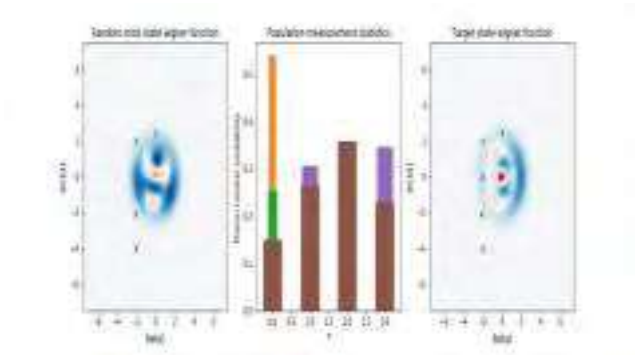


Figure 2: Wigner functions of the entanglement source in the initial basis vs the target Bell-state basis for measurement

References

[1] Kwiat, P. G., Mattle, K., Weinfurter, H., Zeilinger, A., Sergienko, A. V., & Shih, Y. (1995). New high-intensity source of polarization-entangled photon pairs. Physical Review Letters, 75(24), 4337-4341.

[2] Valentina Parigi, "Continuous variables quantum complex networks," Laboratoire Kastler Brossel – Sorbonne Université, Paris, 2023.

[3] . Xavier GB, De Faria GV, Temporão GP, Von der Weid JP. Full polarization control for fiber optical quantum communication systems using polarization encoding. Opt. Express. 2008

Quantum AI for Alzheimer's disease early screening

Giacomo Cappiello[1]
Prof. Filippo Caruso[2]

[1] *DiMaI "U. Dini", Università di Firenze, Viale Morgagni 67/A, Firenze, 50134, Italy*
[2] *Department of Physics and Astronomy, Università di Firenze, Via Sansone 1, Sesto Fiorentino 50019, Italy*

giacomo.cappiello@unifi.it

Alzheimer's disease is a neurodegenerative brain disorder that mostly affects elderly people, causing important cognitive impairments [1]. The analysis of handwriting can be effective for diagnosing [2]. The DARWIN (Diagnosis AlzheimeR WIth haNdwriting) dataset contains handwriting samples from people affected by Alzheimer's disease and a group of healthy people [3]. Here we use this dataset to test kernel methods for classification task and compare their performances with the ones obtained via quantum machine learning methods. We find that quantum and classical algorithms achieve similar performances and in some cases quantum methods perform even better.

References

[1] Honig, L.S., Mayeux, R.: Natural history of alzheimer's disease. Aging Clinical and Experimental Research 13(3), 171–182 (2001)
[2] Cilia, N.D., Stefano, C.D., Fontanella, F., Di Freca, A.S.: An experimental protocol to support cognitive impairment diagnosis by using handwriting analysis. Procedia Computer Science 141, 466–471 (2018)
[3] Cilia, N.D., De Gregorio, G., De Stefano, C., Fontanella, F., Marcelli, A., Parziale, A.: Diagnosing alzheimer's disease from on-line handwriting: A novel dataset and performance benchmarking. Engineering Applications of Artificial Intelligence 111, 104822 (2022)

Figures

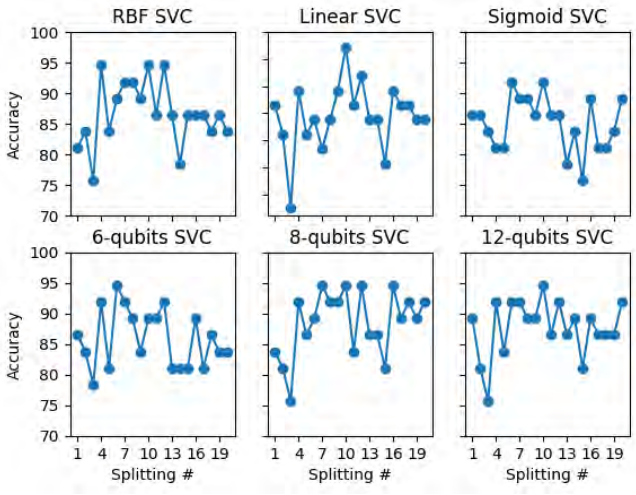


Figure 1: Accuracies (in percentage) vs. splittings of the dataset in training and test set in classical and quantum SVC models.

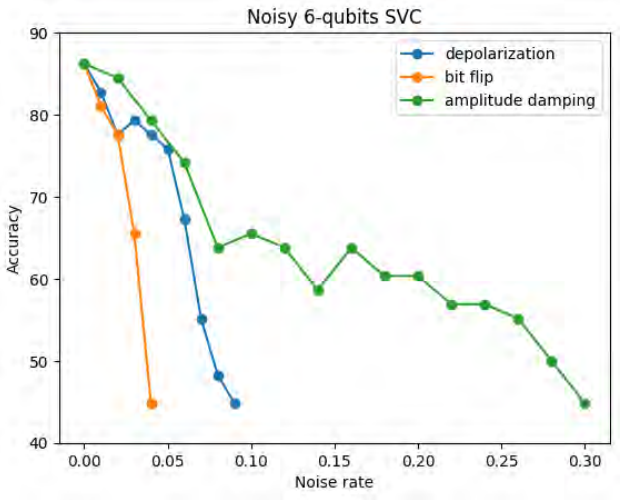


Figure 2: Accuracies (in percentage) of 6-qubits SVC as noise rate increases in the depolarizing, bit-flip and amplitude damping noise models.

Classical and Quantum devices to train Learning Models

Mariano Caruso[1,2,3]
Clara Stampa Guilarte[4], Luis Miguel Nieto Calzada[4]

[1] FIDESOL, 18016, Granada, Spain.
[2] UGR, Universidad de Granada, 18071, Granada, Spain.
[3] UNIR, Universidad Internacional de La Rioja, Logroño, Spain.
[4] UVA, Universidad de Valladolid, 47011, Valladolid, Spain

mcaruso@fidesol.org

Abstract

The increasing number of parameters in machine learning models poses a substantial bottleneck in their efficient training, leading to a disproportionate utilisation of resources, including energy and computational time. We propose an approach to tackle this problem in the context of supervised machine learning, based on the construction of purpose-built computing machines that address this task. We outline two solutions for this approach based on classical circuits and another based on quantum circuits.

References

[1] Mariano Caruso & Cecilia Jarne, Lecture Notes in Networks and Systems 585 (2023), 105-114.

[2] Tao Xin, Shijie Wei, Jianlian Cui, Junxiang Xiao, Iñigo Arrazola, Lucas Lamata, Xiangyu Kong, Dawei Lu, Enrique Solano, and Guilu Long, Phys. Rev. A 101 (2020), 032307.

Figures

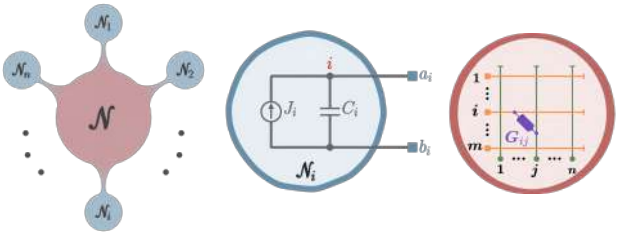


Figure 1: Classical circuit implementation for training.

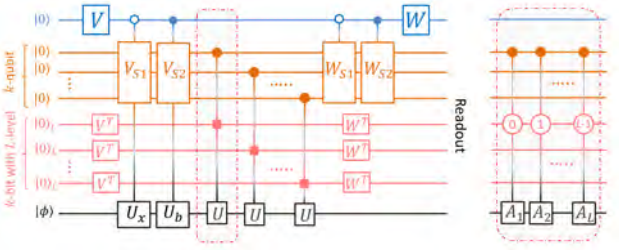


Figure 2: Quantum circuit implementation for training (extracted from [2]).

Quantum sensing of RF fields with 10 Hz spectral resolution using NV centers in Silicon Carbide

Robert Cernansky[1]
Zhengzhi Jiang[2,3], Hongbing Cai[4,5], Xiaogang Liu[2,3,6], Weibo Gao[4,5,7]

1 Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, D-89081 Ulm, Germany
2 Joint School of NUS and Tianjin University, International Campus of Tianjin University, Binhai New City, Fuzhou 350207, P. R. China.
3 Department of Chemistry, NUS, Singapore 117543, Singapore.
4 Division of Physics and Applied Physics, SPMS, NTU, Singapore 637371, Singapore.
5 The Photonics Institute and Centre for Disruptive Photonic Technologies, NTU, Singapore 637371, Singapore.
6 Institute of Materials Research and Engineering, Agency for Science, Technology and Research, Singapore 138634, Singapore
7 Centre for Quantum Technologies, NUS, 117543 Singapore, Singapore.

robert.cernansky@uni-ulm.de

Nuclear Magnetic Resonance (NMR) spectroscopy is an important analytical tool commonly used in life sciences. Its advantages come from its nature to be a non-invasive method to detect molecular structure of biological samples required for applications in diagnostics and fundamental science. However, the limited magnetic sensitivity restricts its utility to study only macroscopic sample sizes on the order of few hundred μm[3]. Diamond has shown to be very promising candidate to overcome the current limitations of bulky NMR machines by using Nitrogen Vacancy (NV^-) defects that are able to reach comparable sub-Hz spectral resolution while reaching nano[1] and few micrometer[2] spatial resolution. However, diamond is an expensive material that is not compatible with standard CMOS fabrication which makes developing scalable and low-cost magnetometers difficult to achieve. On the other hand, Silicon Carbide (SiC) is a technology friendly material with large scale production of high-temperature electronics that host high quality defects useful for quantum sensing applications, like ones present in diamond.

Here we discuss our results to detect a 900 kHz radio-frequency field generated via a test coil. By utilizing the advantages of "Synchronized readout" technique[2] we were able to reach a 10 Hz spectral resolution using ensemble of NV^- centers in SiC[3] while simultaneously achieving the record room temperature coherence time of 28.1 μs. These results pave a way of using SiC defects for future practical sensing applications.

References

[1] S. Schmitt et. al., "Submillihertz magnetic spectroscopy performed with a nanoscale quantum sensor", Science, 356, 832-837, May 2017

[2] D. R. Glenn et. al., "High-resolution magnetic resonance spectroscopy using a solid-state spin sensor", Nature, 555, 351-354, March 2018

[3] Z. Jiang et. al, "Quantum sensing of radio-frequency signal with NV centers in SiC", Science Advances, 9, 20, May 2023

Figures

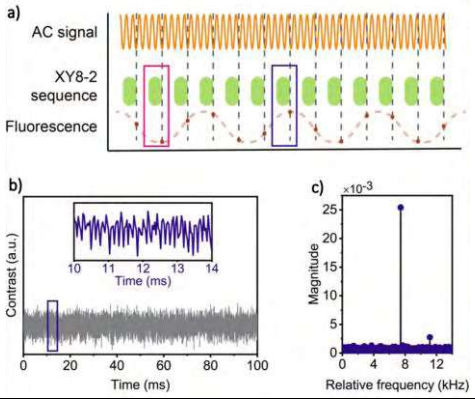


Figure 1: a) Measurement of AC signal with Synchronized readout technique. b) Recorded florescence in time domain and its c) Fourier Transform demonstrating a 900 kHz AC signal measured with 10 Hz spectral resolution

Disordered Topological Crystalline Phases

Adam Yanis Chaou [1]
Mateo Moreno-Gonzalez [2], Alexander Altland [2], Piet W Brouwer [1].

[1] Dahlem Center for Complex Quantum Systems and Institut für Physik, Freie Universität Berlin
[2] Institute for Theoretical Physics, University of Cologne

a.chaou@fu-berlin.de

Abstract

The myriad manifestations of topological crystalline phases (TCP), from anomalous higher-order boundary states to obstructed atomic limits, are well understood. A comprehensive understanding of their stability to disorder however remains an open question. We classify such disordered phases (with order-two symmetries) with disorder that breaks the crystalline symmetry, while preserving it on average. We uncover novel disordered phases; statistical higher-order phases whose hinge states are subject to disorder-induced backscattering but remain protected from Anderson localization at zero-energy and a novel superconducting phase which concurrently host the aforementioned critical zero-energy hinge state along with a disorder stable chiral Majorana hinge mode. We also discover that obstructed atomic limits are stable to disorder if and only if they have a filling anomaly: An observation that results, in contrast to clean TCPs, in disordered TCPs satisfying a complete bulk-boundary correspondence.

Exploring indefinite causal order in the development of quantum batteries

Yuanbo Chen
Yoshihiko Hasegawa

The University of Tokyo, Japan

chen@biom.t.u-tokyo.ac.jp

In the conventional setting of quantum physics, any pair of events are strictly related by a fixed causal order. However, the seminal work by the authors in [1] extended the notion causality by considering quantum correlations without causal order. As a result, a broader class of processes can be described in the framework they developed. This has led to the discovery of indefinite causal order (ICO), where scenarios like event A happens in the causal past of event B and event B locates in the causal past of A becomes in superposition is allowed. Indefinite causal order is of great interest due to its potential to offering practical advantages besides foundational significance [2-5].

In this talk, we will explore the role of ICO in quantum thermodynamics, specifically focusing on the advancement of protocols for charging quantum batteries [6]. Based on quantum collision models, we construct an ICO charging protocol for quantum batteries. Contrary to the intuitive expectation that stronger interactions result in higher energy charging, we unveil a novel phenomenon of inverse interaction. This discovery leads to a reversal of this relationship, enhancing thermal efficiency at the same time. These findings mark the first evidence showcasing the unique influence of ICO on quantum dynamics, and we anticipate its continued significance in shaping the landscape of future quantum technologies.

References

[1] O. Oreshkov, et al., Nat. Commun. 3, 1092 (2012)

[2] D. Ebler, et al., Phys. Rev. Lett. 120, 120502 (2018)

[3] M. J. Renner and r and C. Brukner Phys. Rev. Lett. 128, 230503 (2022)

[4] X. Zhao, et al., Phys. Rev. Lett. 124, 190503 (2020)

[5] P. Yin, et al., Nat. Phys. 19, 1122 (2023)

[6] G. Zhu*, Y. Chen*, et al., Phys. Rev. Lett. 131, 240401(2023)

Figures

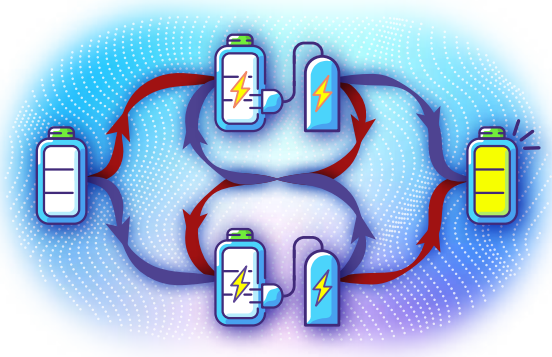


Figure 1: Quantum battery charging with indefinite causal order: a quantum battery experiences a quantum superposition of charging dynamics in the two causal orders.

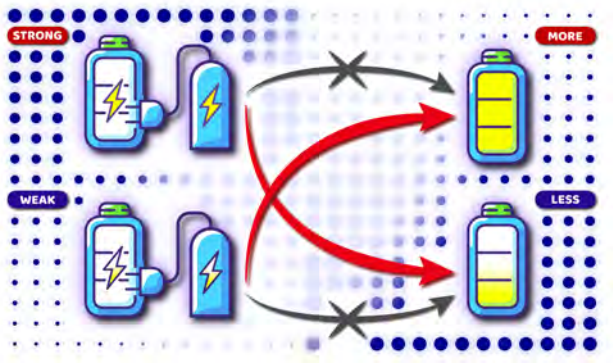


Figure 2: Common intuition suggests that a more powerful charger results in a battery with a stronger charge. However, the discovery of an inverse interaction effect stemming from ICO introduces a remarkable reversal in this relationship.

Cos(2phi) Josephson Junction and Gate Controlled Josephson Diode in Proximitized InAs Supercurrent Interferometers*

Christian Schönenberger[1,2]
C. Ciaccia[1], R. Haller[1], A. C. C. Drachmann[2], C. Schrade[2], T. Lindemann[3], M. J. Manfra[3,4]

[1] *Quantum- and Nanoelectronics Lab, Department of Physics and Swiss Nanoscience Institute, University of Basel, Switzerland.*
[2] *Centre for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Denmark.*
[3] *Department of Physics and Astronomy, School of Electrical and Computer Engineering, and School of Materials Engineering, Purdue University, West Lafayette, Indiana, USA.*
[4] *Birck Nanotechnology Centre, Purdue University, West Lafayette, Indiana, USA.*

christian.schoenenberger@unibas.ch

Superconducting qubits with intrinsic noise protection offer a promising approach to improve the coherence of quantum information. Crucial to such protected qubits is the encoding of the logical quantum states into wavefunctions with disjoint support. Such encoding can be achieved by a Josephson element with an unusual charge-4e supercurrent emerging from the coherent transfer of pairs of Cooper-pairs. We demonstrate the controlled conversion of a conventional charge-2e dominated supercurrent to a charge-4e dominated one in a superconducting quantum interference device (SQUID) consisting of gate-tuneable planar Josephson junctions realized in a InAs two-dimensional electron gas proximitized by a nearby superconducting Al film evaporated in-situ. We investigate the ac Josephson effect of the SQUID and measure a dominant photon emission at twice the fundamental Josephson frequency together with a doubling of the number of Shapiro steps, both consistent with the appearance of charge-4e supercurrent [1]. Our results present a step towards protected superconducting qubits based on superconductor-semiconductor hybrid materials.

Using the same material system, we also demonstrate that by tuning the higher harmonics of Josephson junctions allows to engineer the superconducting diode effect [2]. The Josephson Diode (JD) is a non-reciprocal circuit element that supports a larger critical current in one direction than in the other. This effect has been gaining a growing interest because of promising applications in superconducting electronic circuits with low power consumption. The effect can only appear if time-reversal symmetry and inversion symmetry is broken together. In a DC-SQUID geometry the former is achieved by applying a phase bias induced by the flux in the loop and the latter by tuning the two junctions in an asymmetric regime. While in earlier work the asymmetry was created through asymmetric loop inductances, this is realized here by tuning the transparency of the two Josephson junctions asymmetrically.

References

[1] C. Ciaccia et al., Phys. Rev. Research 5 (2023) 033131.
[2] C. Ciaccia et al., Comm. Phys. 7 (2024) 41.

*This research was supported by the Swiss Nanoscience Institute (SNI), the Swiss National Science Foundation through grants Nos. 172638 and 192027, and the QuantEra project SuperTop. We further acknowledge funding from the European Union's Horizon 2020 research and innovation program, specifically (a) from the European Research Council (ERC) grant agreement No. 787414, ERC-Adv TopSupra, (b) grant agreement No. 828948, FET-open project AndQC, and (c) grant agreement 847471, project CO-FUND-QUSTEC. C. Schrade acknowledges support from the Microsoft Corporation.

Coplanar stripline resonators for superconductor-semiconductor hybrid devices

Ivo Cools
R.M. López Báez, V. Buccheri, N. Trnjanin, O. Shvetsov, A. Geresdi, S. Dash

Quantum device physics laboratory,
Department of Microtechnology and Nanoscience,
Chalmers University of Technology, Sweden
Cools@chalmers.se

High impedance resonators, often fabricated by using a high kinetic inductance material, enhance the coupling of microwave photons to charges in semiconductor structures as desired for example in spin qubit research. In this study, we characterize quarter wavelength differentially driven coplanar stripline (CPS) resonators made of sputtered niobium titanium nitride (NbTiN). By varying geometrical and material parameters (width, gap distance, kinetic inductance), changes in the internal quality factor are observed. The CPS geometry is particularly well suited to be coupled to semiconductor nanostructures, whose gate-tunable properties influence the resonance frequency. This research continues by building a Josephson parametric amplifier using the nanowire-resonator structure.

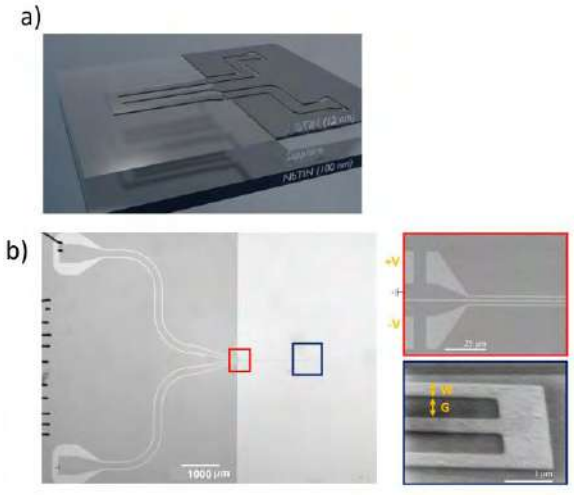


Figure 1:
Coplanar stripling geometry and geometrical parameters under investigation (*W, G)*

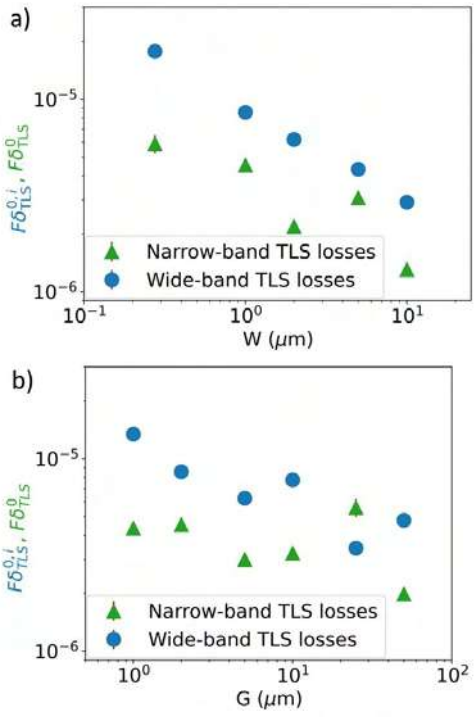


Figure 2:
Measured losses by variation of the width (*W*) and gap (*G*) geometric parameters

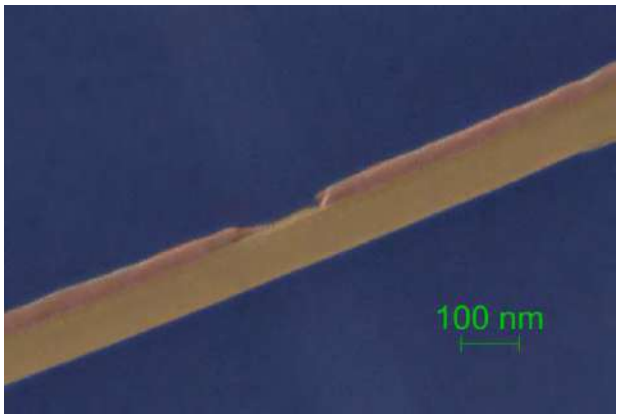


Figure 3:
Etched nanowire (blue: Si - orange: Al - yellow: InAs), to be used in a nanowire-resonator structure

Exponential optimization of quantum state preparation via adiabatic thermalization

Davide Cugini[1]
Davide Nigro[1]
Mattia Bruno[2]
Dario Gerace[1]

1)Dipartimento di Fisica, Università di Pavia, via Bassi 6, 27100 Pavia, Italy

2)Dipartimento di Fisica, Università di Milano Bicocca, Piazza della scienza 3, 20126 Milano, Italy

davide.cugini01@universitadipavia.it

The preparation of a given quantum state on a quantum computing register is a typically demanding operation, requiring a number of elementary gates that scales exponentially with the size of the problem. In view of performing quantum simulations of manybody models, this limitation might severely hinder the actual application of the noisy quantum processors that are currently available [1,2]. We present an original method to prepare a generic quantum state exploiting the concept of adiabatic thermalization [3]. In particular, we apply a procedure introduced in [4], and theoretically derive an exponential scaling law for the simulation error of the quantum state preparation as a function of the thermalization time. Here, the characteristic time dependence of such error on the thermalization process is explicitly formulated. We then design a preconditioning term that modifies the adiabatic preparation, reducing its characteristic time and hence giving an exponential advantage. We perform extensive numerical experiments to test our mathematical result on typical spin-models, such as the one- and two-dimensional Ising and Heisenberg Hamiltonians, confirming that the exponential bound is indeed realized and observing an exponential advantage for the preconditioned adiabatic processes. Our results provide a promising strategy to perform quantum simulations of manybody models via Trotter evolution on near term quantum processors.

References

[1] Y. Kim, et al., Nature, 618.7965 (2023) 500-505.
[2] F. Tacchino, et al., Advanced Quantum Technologies 3 (2020) 1900052.
[3] S. Jansen, M.-B. Ruskai, and R. Seiler, Journal of Mathematical Physics 48 (2007) 102111.
[4] G. Nenciu, Communications in mathematical physics 152 (1993) 479-496.

Figures

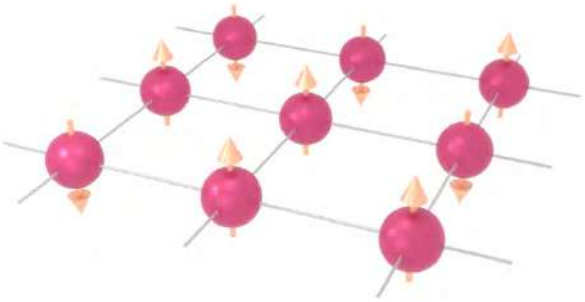


Figure 1: Lattice structure for 2D XZ Heisenberg model with periodic boundary conditions.

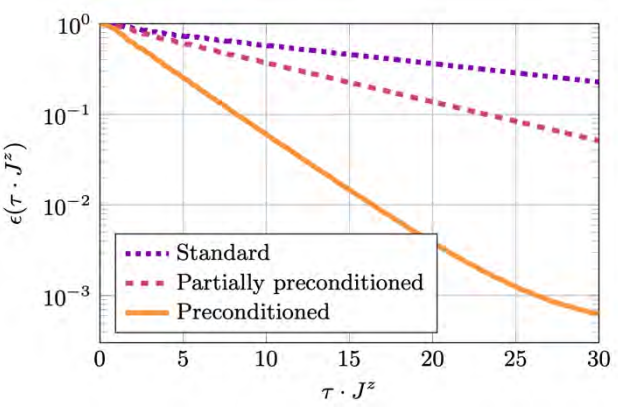


Figure 2: Dependence of the adiabatic thermalization error, plotted as a function of the thermalization time, for the ground state preparation of the 2D Heisenberg model with coupling constants $J^x = 5J^z$.

Hot electron dynamics in graphene – a linear-scaling atomistic approach

Aron W. Cummings[1]
Luis M. Canonico Armas[1] and Stephan Roche[1,2]

[1]*Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC & BIST, Campus UAB, Bellaterra, 08193 Barcelona, Spain*
[2]*ICREA–Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain*

aron.cummings@icn2.cat

Graphene holds significant promise for a variety of applications. In particular, graphene photodetectors have been shown to be very fast, highly sensitive, and consume minimal power, making them extremely promising for next-generation optical communications [1].

Hot electrons – electrons whose temperature is higher than the surrounding lattice – play a fundamental role in such graphene photodetectors. A variety of theories and measurements have been developed and conducted to understand the main factors controlling the dynamics and relaxation of hot carriers in graphene, but fundamental questions remain to be examined [2].

Here, we present our development of a numerical simulation tool that can capture the dynamics of hot carriers in graphene with arbitrary lattice vibrations, defects, and disorder. Our methods are linear-scaling, meaning we can simulate systems with millions of atoms – this permits an atomic description of the system while allowing for system sizes that approach the experimental scale. Such a tool will allow for a deeper understanding of hot carrier dynamics in graphene and other 2D materials, as well as reveal strategies for the control of such dynamics, with an eye toward future applications in photodetection, optical communications, and energy conversion.

We acknowledge funding from project ECONWHET, PID2019-106684GB-I00, financed by MCIN / AEI / 10.13039 / 501100011033.

References

[1] M Romagnoli et al, *Nat Rev Mater* **3**, 392 (2018)
[2] M Massicotte, G Soavi, A Principi, K-J Tielrooij, *Nanoscale* **13**, 8376 (2021)

Figures

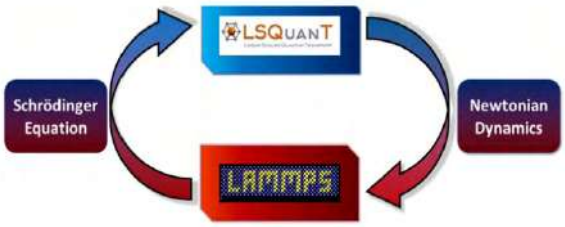


Figure 1. Schematic of the self-consistency cycle for the atomistic simulation of coupled charge and ion dynamics.

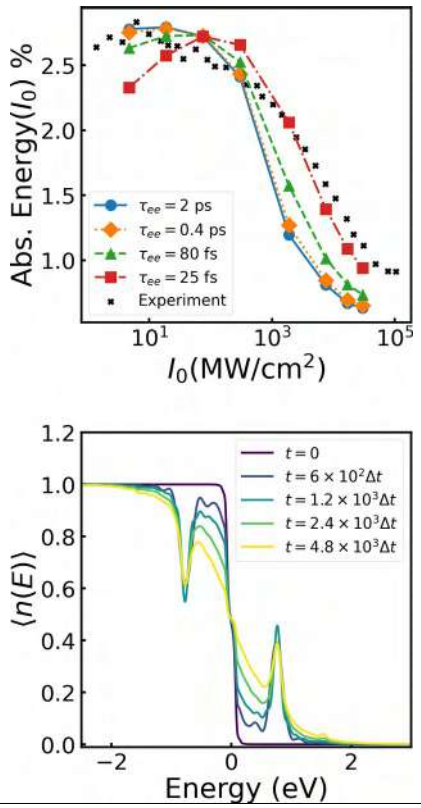


Figure 2. *Top*: absorption efficiency of a finite optical pulse in graphene, as a function of optical power. Colored curves are simulation results and black symbols are from experiments. *Bottom*: time evolution of the electronic carrier distribution under the optical pulse, with competing vertical absorption and thermalization effects.

Simulating the Dynamics of Open Quantum Systems with Quantum Monte Carlo Methods

Jacopo D'Alberto[1]
C. Apostoli[1], G. Bertaina[2], and D. E. Galli[1]

[1]*Dipartimento di Fisica, Università degli Studi di Milano, via Celoria 16, I-20133 Milano, Italy*
[2]*Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, I-10135 Torino, Italy*

jacopo.dalberto@unimi.it

Abstract

The interest in quantum technologies has grown dramatically in recent years. In particular, the attempt to achieve the supremacy of quantum simulators over the classical counterpart, is one of the most challenging tasks nowadays. In this context, understanding properly the features of open quantum systems could be the key to the development of increasingly large and powerful quantum computers. Several approximate approaches were developed in recent years to simulate the dynamics of open quantum systems [1], however the results obtained so far are generally limited to small size systems. Our novel approach is based on the time-dependent Variational Monte Carlo method, used in [2], but it exploits the so-called unravelling of the master equations to obtain a set of quantum trajectories evolving with Stochastic Schrödinger Equations (SSE). By finding the solution for several independent trajectories, we will then be able to reconstruct time-dependent observables equivalent to those coming from the master equations.

References

[1] H. Weimer, A. Kshetrimayum and R. Orús, Rev. Mod. Phys. 93 (2021) 1.
[2] M. J. Hartmann and G. Carleo, Phys. Rev. Lett. 122 (2019) 25

Figures

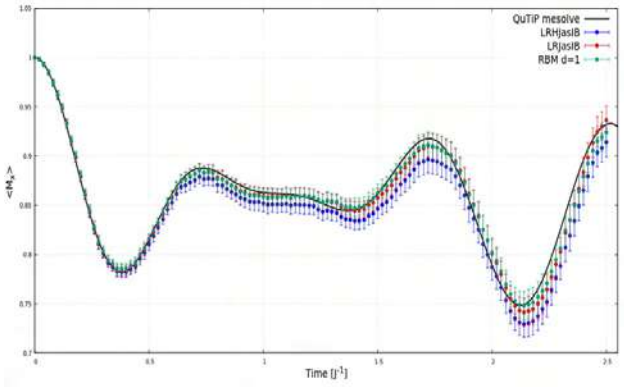


Figure 1: Time-evolution of the total x-magnetization for a 8-spin dissipative TFI model. Different variational ansatze (from the typical Jastrow wavefunction to the more sophisticated RBM) are proposed and compared to the exact solution.

Curriculum reinforcement learning for quantum architecture search under hardware errors

Yash Patel[1], **Akash Kundu**[2,3], **Mateusz Ostazewski**[4], **Xavi Bonet-Monroig**[1], **Vedran Dunjko**[1], **Onur Danaci**[1]

[1] *$\langle aQa^L \rangle$ Applied Quantum Algorithms, Leiden University*

[2] *Institute of Theoretical and Applied Informatics, Polish Academy of Sciences*

[3] *Joint Doctoral School, Silesian University of Technology*

[4] *Warsaw University of Technology, Institute of Computer Science*

The key challenge in the noisy intermediate-scale quantum era is finding useful circuits compatible with current device limitations. Variational quantum algorithms (VQAs) offer a potential solution by fixing the circuit architecture and optimizing individual gate parameters in an external loop. However, parameter optimization can become intractable, and the overall performance of the algorithm depends heavily on the initially chosen circuit architecture. Several quantum architecture search (QAS) algorithms have been developed to design useful circuit architectures automatically. In the case of parameter optimization alone, noise effects have been observed to dramatically influence the performance of the optimizer and final outcomes, which is a key line of study. However, the effects of noise on the architecture search, which could be just as critical, are poorly understood. This work addresses this gap by introducing a curriculum-based reinforcement learning QAS (CRLQAS) algorithm designed to tackle challenges in realistic VQA deployment. The algorithm incorporates (i) a 3D architecture encoding and restrictions on environment dynamics to explore the search space of possible circuits efficiently, (ii) an episode halting scheme to steer the agent to find shorter circuits, and (iii) a novel variant of simultaneous perturbation stochastic approximation as an optimizer for faster convergence. To facilitate studies, we developed an optimized simulator for our algorithm, significantly improving computational efficiency in simulating noisy quantum circuits by employing the Pauli-transfer matrix formalism in the Pauli-Liouville basis. Numerical experiments focusing on quantum chemistry tasks demonstrate that CRLQAS outperforms existing QAS algorithms across several metrics in both noiseless and noisy environments.

Control of Collective Dark States in Waveguide QED

Julian Daser,
Filip Hudek, **Teresa Hönigl-Decrinis**, Gerhard Kirchmair

Institute for Experimental Physics, University of Innsbruck, 6020 Innsbruck, Austria

Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, 6020 Innsbruck, Austria

Julian.daser@uibk.ac.at,

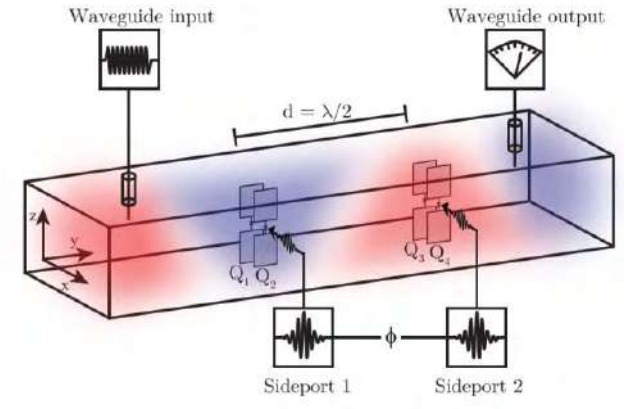
Propagating microwave photons in waveguides couple extremely well to superconducting qubits due to their large dipole moment and mediate long-range interactions between distant qubits causing the emergence of collective states due to interference effects [1]. Of particular interest are dark or subradiant states, which are protected from decoherence as they decouple from the waveguide environment and thus exhibit long lifetimes. This makes them promising candidates for photon storage, excitation transfer and photon-photon gates [2].
However, the protection from decoherence comes with a caveat that the control of such states is challenging. Only recently, a global dark state formed by two transmon pairs, each exhibiting local dark and bright states, was probed experimentally by exciting the local dark states selectively through individual drive ports in a rectangular waveguide [3].
To extend the system to larger arrays of transmon qubits [2,4], we are working on a planar implementation.

References

[1] Sheremet, A. S., et al. Rev. Mod. Phys. 95, 015002 (2023)
[2] Holzinger, R., et al., Phys. Rev. Let. 129, 253601 (2022)
[3] Zanner, M., et al., Nature Physics 18, 538-543 (2022)
[4] Orell, T., et al. Phys. Rev. A 105.6, 063701 (2022)

Figures

a)



b)

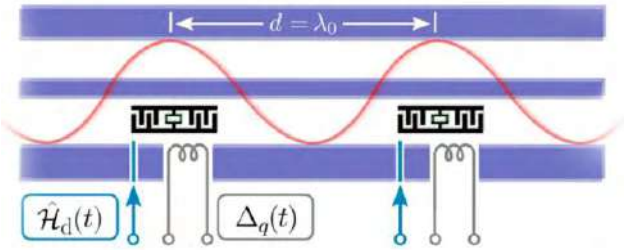


Figure 1: Waveguide QED setups.
a) 3D [3] and b) planar [2].

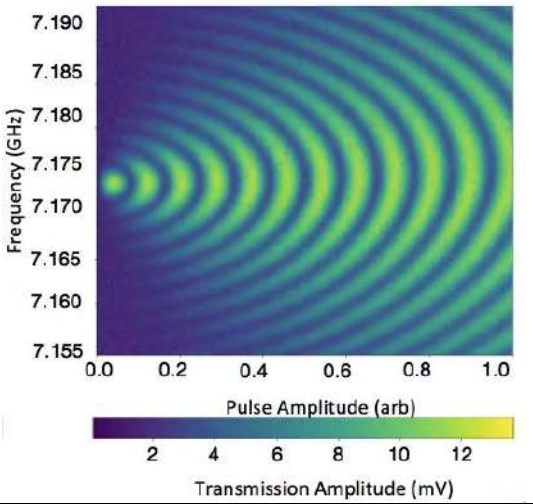


Figure 2:
Rabi oscillations of a dark state formed by a local transmon qubit pair as seen in Fig. 1a)

Additive twisted codes: new distance bounds and infinite families of quantum codes

Reza Dastbasteh[1]
Petr Lisonek[2]

[1]*Tecnun – University of Navarra, Donostia, Gipuzkoa, Spain*

[2]*Department of Mathematics, Simon Fraser University, Burnaby, BC, Canada*

rdastbasteh@unav.es

Quantum error-correcting codes, or simply quantum codes, are used to protect quantum information from corruption by noise (decoherence) on the quantum channel, much like classical error-correcting codes. The most common approach to constructing quantum codes is through the stabilizer formalism, which establishes a connection between certain dual-containing additive codes and quantum (stabilizer) codes [1, 2].

One of the main challenges in designing quantum stabilizer codes is the dual-containment (commuting) condition, which restricts the use of classical codes in constructing good quantum codes. In this talk, we first present a construction method for binary stabilizer quantum codes that allows the utilization of additive codes that are not dual-containing (equivalently, containing a non-commuting set of generators).

Next, we focus on a family of classical codes called additive twisted codes for constructing binary quantum codes. We establish a stronger connection between twisted codes and linear cyclic codes, enabling us to derive novel minimum distance lower and upper bounds for twisted codes and identify new similarities between twisted codes and linear cyclic codes. In particular, we prove that the Hartmann-Tzeng bound holds for twisted codes.

Finally, we present five infinite families of record-breaking and sometimes optimal binary quantum codes that can be constructed from twisted codes using these bounds. To determine whether a quantum code is record-breaking and/or optimal, we refer to the tables maintained by Markus Grassl [3]. A more detailed explanation of the material covered in this talk can be found in [4, Chapter 3].

References

[1] A. R. Calderbank, E. M. Rains, P. Shor, and N. J. Sloane, "Quantum error correction via codes over GF(4)," IEEE Transactions on Information Theory, 1998.

[2] D. Gottesman, "Class of quantum error-correcting codes saturating the quantum Hamming bound," Physical Review A, 1996.

[3] M. Grassl, "Code Tables: Bounds on the parameters of various types of codes," Website: http://www.codetables.de/.

[4] R. Dastbasteh, "New quantum codes, minimum distance bounds, and equivalence of codes," PhD Thesis, Simon Fraser University, 2023. Available online: https://summit.sfu.ca/item/36338.

The closed-branch decoder for quantum LDPC codes

Antonio de Marti I Olius
Josu Etxezarreta Martinez

Tecnun – University of Navarra, Manuel Lardizabal Ibilbidea, 13, 20018 Donostia, Gipuzkoa
ademartio@unav.es

Quantum computers promise an advantage over classical computers for certain tasks, which may provide groundbreaking computation capabilities of use for several research fields. Unfortunately, quantum decoherence prevents us from reaching their full potential. Qubits, which are the most fundamental constituents of quantum processors, tend to interact in non-trivial ways that we cannot predict nor control, thus there is a pressing necessity for correcting the non-desired errors qubits may experience because of their interaction with the environment. The field within quantum computing which aims to tackle this unfortunate phenomenon is named quantum error correction [1]. Quantum error correcting codes consist in protecting the information of a number of clean (logical) qubits by means a much larger set of noisy qubits, referred as physical qubits. If a number of the constituent qubits undergoes a non-trivial Pauli error, we receive partial information of it through a vector commonly named as syndrome. The algorithm that receives a syndrome as input and returns an estimate of the error is named the decoder, and it is of pivotal importance in quantum error correction [1,2].

The decoder of choice for general quantum error correcting codes (QLDPC) is the belief propagation order statistics decoder (BPOSD) [3], an algorithm with good accuracy but too slow. Real-time decoding in superconducting quantum processors would require decoding algorithms to be executed in an order of microseconds. Achieving a decoder that is fast at enough accuracy is necessary if we want to reach quantum fault-tolerance.
Given the introduced context, we propose a new decoder named the closed-branch decoder [4] which scales as O(n*m), where n is the number of qubits within the code and m is a tuneable parameter. Its accuracy is good enough requiring much less complexity than BPOSD. In the presentation, I will cover the structure and intricacies of this new decoder.

References

[1] Stabilizer Codes and Quantum Error Correction, Gottesman, PhD manuscript, (1997).
[2] Decoding algorithms for surface codes, deMarti iOlius, Fuentes, Orús, Crespo & Etxezarreta Martinez, arXiv preprint (2023).
[3] Degenerate quantum LDPC codes with good finite length performance, Panteleev & Kalachev, Quantum, 2521-327X (2021).
[4] The closed-branch decoder for quantum LDPC codes, deMarti iOlius & Etxezarreta Martinez, arXiv preprint (2024).

Figures

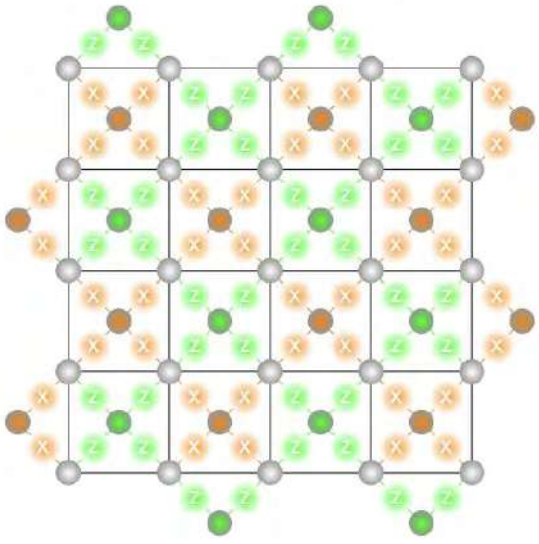


Figure 1: Surface code, a type of quantum error correcting code.

Theoretical study of GdW_{10} and GdW_{30} molecules energy transitions and experimental fitting.

Xavier del Arco
David García Pons, Jorge Pérez Bailón, María José Martínez Pérez y David Zueco.

Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, Zaragoza, Spain

Departamento de Física de la Materia Condensada, Universidad de Zaragoza

xavierr@unizar.es

Single Ion Magnets (SIM) are appealing for theoretical research given their simple Hamiltonian. A very promising family of SIM involves lanthanide atoms encapsulated by polyoxometalates (POMs), which represent a class of mononuclear lanthanoid complexes known for their intriguing single-molecule magnetic properties[1]. In this study, we investigated the Hamiltonian characteristics of two specific POMs, GdW_{10} and GdW_{30} [2], and examined the underlying physical phenomena governing their energy transitions. Our analysis aimed to provide accurate predictions and enhance the theoretical-experimental consistency in the understanding of these systems. Our final goal is to combine lanthanide SIM with superconducting and magnonic circuits for quantum computing and sensing applications.

References

[1] Cardona-Serra S, Clemente-Juan JM, Coronado E, Gaita-Ariño A, Camón A, Evangelisti M, Luis F, Martínez-Pérez MJ, Sesé J. Lanthanoid single-ion magnets based on polyoxometalates with a 5-fold symmetry: the series [LnP5W30O110]12- (Ln3+ = Tb, Dy, Ho, Er, Tm, and Yb). J Am Chem Soc. 2012 Sep 12;134(36):14982-90. doi: 10.1021/ja305163t. Epub 2012 Aug 30. PMID: 22894703.

[2] Jenkins, Duan, Diosdado, García-Ripoll, Gaita-Ariño, Giménez-Saiz, Alonso, Coronado, & Luis. (2017). Coherent manipulation of three-qubit states in a molecular single-ion magnet. Physical Review B, 95(6). https://doi.org/10.1103/PHYSREVB.95.064423

Figures

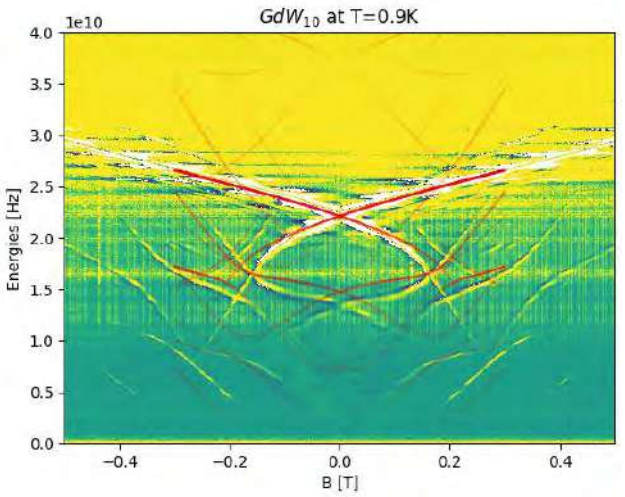


Figure 1: Plot of the theoretical energy levels transition on the experimental measure.

Non-uniform and anisotropic polarizability resulting in pronounced local repulsion minima in high-T_c superconductors

Nassim Derriche
George Sawatzky

The University of British Columbia (Stewart Blusson Quantum Matter Institute), 2355 E. Mall, Vancouver, Canada

nderriche@phas.ubc.ca

Tremendous research effort, both on the experimental and theoretical sides, is being invested by the scientific community to understand the underlying physics of high-T_C superconductors in the hope of using that knowledge to design and produce them at ambient conditions. We demonstrate here the dramatic effect of non-uniform, discrete electric polarizability in high-T_C superconductors on the spatial fluctuations of the short to medium range Coulomb interactions through a real-space semiclassical model. Although this is a general property, we focus on the cuprates as parent compounds, in which the charge carriers are primarily concentrated on the O sublattice. The anisotropic effective Cu-O bond polarization caused by charge transfer energy modulation and the O^{2-} atomic polarizability together generate a non-monotonic screened hole-hole Coulomb interaction at short distances that displays a local minimum at the in-plane second nearest neighbor O-O distance solely along the Cu-O bond direction. This is in accordance with the pseudogap phase anisotropy [1] and the short coherence length [2] observed in many high-T_C superconductors.

References

[1] V. Aji, A. Shekhter, and C. M. Varma, Physical Review B 81 (2010) 064515
[2] J. Hwang, Scientific Reports 11 (2021) 11668

Figures

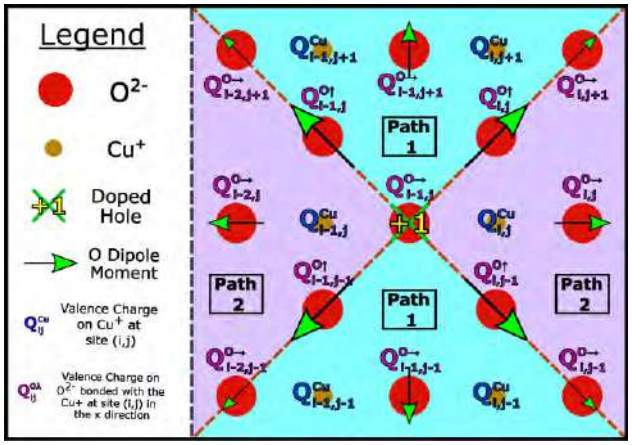


Figure 1: Diagram of the polarization effects induced by a doped hole on an O site of a CuO_2 cluster. The two regions in which placing a second hole results in distinct interaction behaviour are highlighted.

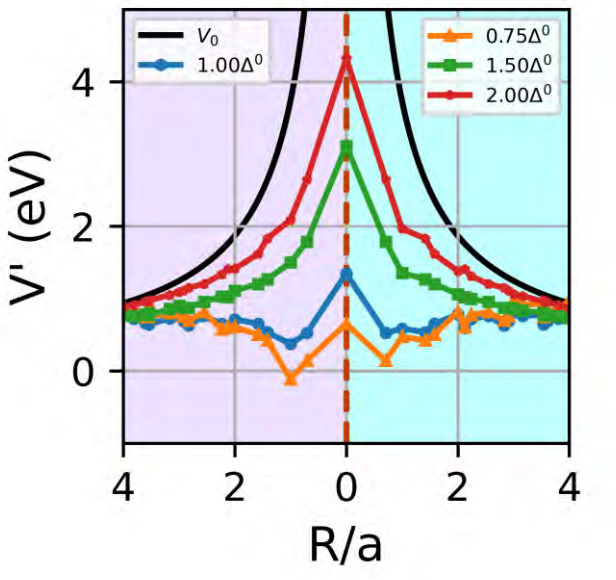


Figure 2: Screened Coulomb interaction V' between two holes hosted by oxygen ions in a cuprate plane for different Cu-O charge transfer energies (Δ^0 = 6.00 eV).

Studying the relationship of the quantum software and the energy consumption and success ratio

Elena Desdentado[1]
Coral Calero[1,2]
Mª Ángeles Moraga[1]
Félix Óscar García[1]

[1]*Instituto de Tecnologías y Sistemas de Información, Universidad de Castilla-La Mancha*
[2]*aQuantum. Green Quantum Algorithms & Software Research*

{Elena.DFernandez,Coral.Calero,
Mariaangeles.Moraga, Felix.Garcia}@uclm.es

Quantum computing is growing a lot in recent years as it is expected to be able to solve problems for which classical computing needs too much time or is not able to solve.

However, this technology is energy-intensive, so if we want to use it to solve highly complex problems, it is essential to implement energy-efficient solutions. This preliminary study examines correlations between energy consumption and the success rate of quantum circuits with respect to some static measures of quantum code. Moreover, we have studied the correlation for 4 IBM quantum computers.

The measures used, proposed by [1] are: M2.2: Lines of Code, M3.3; Number of operations, M3.5: Percentage of operations that increase the cyclomatic complexity, HM1.1: Number of used qubits and HM6.1: Quantum cyclomatic complexity; that have been applied to five algorithms.

The energy consumption and success rate are taken from a previous study developed by the authors [2].

The results (Figures 1 and 2) indicate that there exist significant moderate to high correlations between the energy consumption and the total number of operations, the number of qubits used and the quantum cyclomatic complexity of the algorithm. We can also observe that there are negative high correlations between the success rate and the number of lines of code, operations and qubits employed. These findings underscore the importance of efficiently managing complexity and size to decrease the energy consumption of quantum circuits.

References

[1] Díaz, A., Rodríguez, M., Piattini, M.: Towards a set of metrics for hybrid (quantum/classical) systems maintainability. Journal of Universal Computer Science (J.UCS) 30(1), 25–48 (2024). https://doi.org/10.3897/jucs.99348

[2] Fernández, E.D., de la Rubia, M.M., Martín, M.S.: Studying the consumption of IBM quantum computers (08 2021), https://aisel.aisnet.org/isd2014/proceedings2021/sustainable/3

[3] Quantum-and-Classical-Computing-Study, https://github.com/elenaDesdentado/Quantum-and-Classical-Computing-Study

Figures

Energy consumption

	M2.2	M3.3	M3.5	HM1.1	HM6.1
ibmq_lima	+	+	+	+	+
ibmq_quito	+	+	+	+	+
ibmq_santiago	+	+	-		
ibmq_manila				+	+

Figure 1: Energy consumption correlations to the static measures for all quantum algorithms.

Success rate

	M2.2	M3.3	M3.5	HM1.1	HM6.1
ibmq_lima	-	-	-	-	-
ibmq_quito	-	-	-	-	-
ibmq_santiago	-	-	-	-	
ibmq_manila	-	-	-	-	

Figure 2: Success rate correlations to the static measures for all quantum algorithms.

Using Entangled Generalized Coherent States for Photonic Quantum Metrology

Aprameyan Desikan[1],
Madhura Ghosh Dastidar[2], Vidya Praveen Bhallamudi[2]

[1]*Department of Physical Sciences, Indian Institute of Science Education and Research Mohali, Sector 81 SAS Nagar, Manauli PO 140306, India*
[2]*Department of Physics, Indian Institute of Technology Madras, Chennai 600036, Tamil Nadu, India*

ms20175@iisermohali.ac.in

Quantum metrology involves estimating unknown parameters in quantum systems, utilizing techniques like entanglement and squeezing to surpass classical measurement limits [1, 2]. Classical protocols for parameter estimation with N probes are restricted by the shot-noise limit of $1/\sqrt{N}$, but quantum protocols can achieve the Heisenberg limit of 1/N, enhancing estimation sensitivity. Such quantum-enhanced sensitivity finds application in fields ranging from gravitational wave detection [3] to quantum imaging and quantum frequency standards [4]. Photonic quantum metrology is based on using an interferometric setup with non-classical light state as the input. Numerous studies have explored the advantages of certain entangled states of light such as the NOON state [5] and entangled coherent state [6]. However, their experimental realisations through various strategies remain a problem in terms of scalability.

Our work introduces entangled generalised coherent state (EGCS) and its potential for photonic quantum metrology.
We have theoretically shown that such states achieve the Heisenberg limit for phase sensitivity, and under certain conditions, even surpass that limit. This proves it to be more advantageous compared to the NOON and entangled coherent states, even at smaller mean photon numbers. We further propose a simple scheme to experimentally generate these entangled generalised coherent states with current technology [7].

References

[1] V. Giovannetti, S. Lloyd, and L. Maccone, Nat. Photon. **5**, 222 (2011)
[2] G. Tóth and I. Apellaniz, J. Phys. A Math. Theor. **47**, 424006 (2014)
[3] R. Schnabel, N. Mavalvala, D. E. McClelland, and P. K. Lam, Nat. Commun. **1**, 121 (2010)
[4] V. Giovannetti, S. Lloyd, and L. Maccone, Science **306**, 1330 (2004)
[5] J. Cooper, D. Hallwood, and J. Dunningham, Phys. Rev. A **81**, 043624 (2010)
[6] J. Joo, W. J. Munro, and T. P. Spiller, Phys. Rev. Lett. **107**, 083601 (2011)
[7] Madhura Ghosh Dastidar, Aprameyan Desikan, and Vidya Praveen Bhallamudi, arXiv: 2305.10377v1 [quant-ph] (2023)

Figures

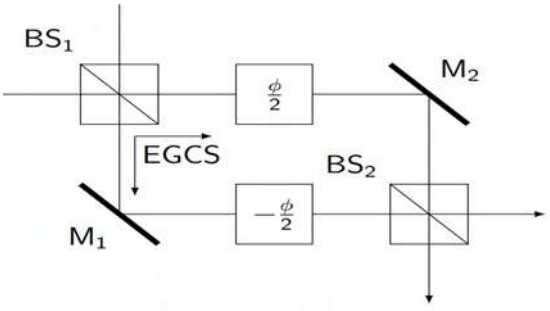


Figure 1: Mach-Zehnder interferometric set-up used to analyse the phase sensitivity in photonic quantum metrology schemes

Hybrid light-matter states in topological superconductors coupled to cavity photons

Olesia Dmytruk[1]
Marco Schirò[2]

[1]*CPHT, CNRS, École polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France*
[2]*JEIP, UAR 3573 CNRS, Collège de France, PSL Research University, 11 Place Marcelin Berthelot, 75321 Paris Cedex 05, France*

olesia.dmytruk@cnrs.fr

Using photonic cavities to control properties of the materials is a novel research direction of condensed matter physics. Topological materials play particularly important role in this direction due to their robustness and their possible application in quantum technologies. Among topological materials, topological superconductors hosting zero-energy Majorana bound states hold a specially interesting place for their potential of being used as building blocks for a fault-tolerant topological quantum computer. The prototype system for topological superconductivity is the Kitaev chain model describing a one-dimensional p-wave superconductor with Majorana bound states emerging at its opposite ends, while semiconducting-superconducting nanowire is one of the most promising platforms for implementing Majorana bound states in the lab. However, their observation caused much controversy since one of their key signatures – the zero-bias peaks in differential conductance measurements – can be attributed to non-Majorana physics. Previous theoretical works conducted in the weak light-matter coupling regime have explored the idea of using cavities to probe Majorana bound states. However, in these works the cavity played a role of non-invasive spectroscopic tool to probe the signatures of these modes. A different scenario arises in the strong or ultrastrong light-matter coupling regime where electronic and photonic degrees of freedom hybridize resulting in formation of polaritons, which in the case of a topological superconductor could take the form of the Majorana polaritons. In [1], we study a topological superconductor that hosts Majorana bound states strongly coupled to cavity photons. We consider two models for topological behaviour: a Kitaev chain and semiconducting - superconducting nanowire. We find that the cavity photonic spectral function (Figure 1) directly related to polariton spectrum of the hybrid system depends on the parity of the Majorana bound states in the topological phase. Moreover, we demonstrate that the peaks in cavity spectral function appear at different energy scales for the electronic chain in the trivial and topological phases. Therefore, cavity spectral function could be used to probe Majorana bound states in topological superconductors.

References

[1] Olesia Dmytruk and Marco Schirò, arXiv: 2310.01296.

Figures

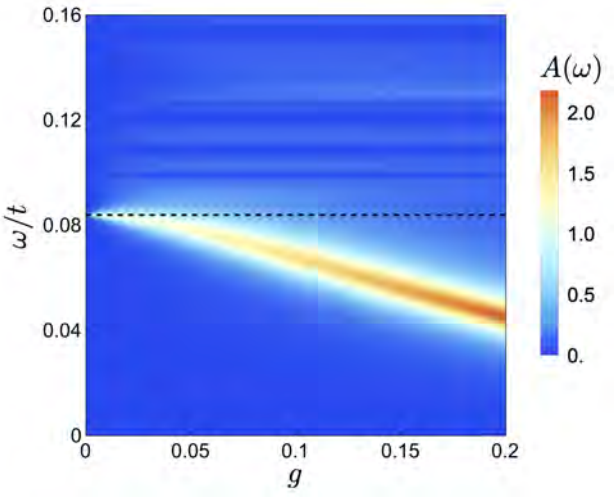


Figure 1: Cavity spectral function of the nanowire as a function of the light-matter coupling and frequency.

Certifying a complex qubit Hilbert space in a prepare-and-measure scenario: how self-testing helps

Gábor Drótos
Károly F. Pál, Abdelmalek Taoutioui, Tamás Vértesi

HUN-REN Institute for Nuclear Research, Bem tér 18/C, H-4026 Debrecen, Hungary

drotos.gabor@atomki.hu

Self-testing is a promising theoretical approach to certifying, e.g., specific quantum states and measurements. Originally, it relied solely on the output statistics of the measurements involved in a device-independent setup. We turn to a semi-device-independent setup by considering a prepare-and-measure scenario for qubit messages.

We construct linear witnesses W (i.e., linear functionals on the outcome statistics of the measurements) for performing self-tests in possibly minimal setups within this scenario. In a setup involving four (three) preparations and three (two) projective measurements in addition to the target, we exemplify how to self-test any four- (three-) outcome extremal positive operator-valued measure. We also achieve self-testing of any number of pure state preparations with the help of three projective measurements at most.

However, self-testing is a purely theoretical tool, since it requires reaching the theoretical quantum maximum W_C^2 of the witness by the outcome statistics. A relaxation is to certify only a single but well-defined property of the preparations or the relevant measurement.

In this spirit, we provide a means to certify that a set of four prepared states spans a complex qubit Hilbert space. For this purpose, we introduce a specific configuration of four complex qubit states, which we call umbrella-like and which depends on a real parameter $c\in[0,3)$, and design a linear witness for self-testing this set in a minimal setup.

We then determine, for any given c, the maximum value W_R^2 attainable by evaluating the so-defined witness for any configuration of four real qubit preparations. Then should we perform an experiment and evaluate the witness (for a c value of our choice) to exceed W_R^2, the complex nature of the Hilbert space spanned by the actual preparations becomes certified. We expect such a certification scheme to be useful for preparations that are intended to implement the set of states targeted by the design of the witness but which are subject to experimental noise.

To illustrate the idea experimentally, we implemented prepare-and-measure scenarios for self-testing umbrella-like configurations as quantum circuits on publicly available quantum processors of IBM and IonQ. Experimental witness values exceeded W_R^2 for most values of c (Fig. 1.). Thereby, we successfully certified the existence of a complex qubit Hilbert space in our experiments.

Figures

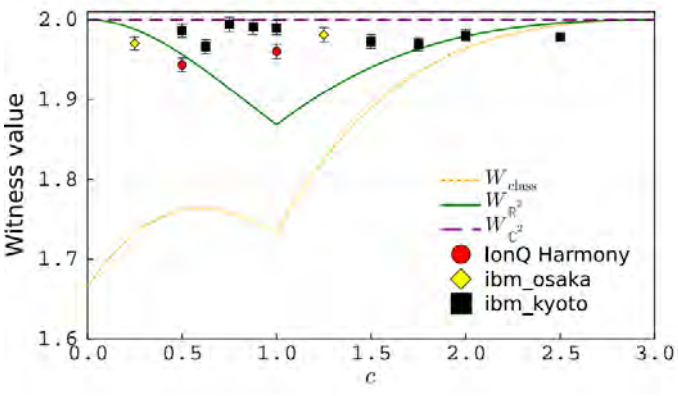


Figure 1: The witness W designed to self-test umbrella-like configurations, as a function of the umbrella parameter c. The maximum values attainable using classical strategies (W_{class}), real qubits (W_R^2), and complex qubits (W_C^2) are presented. The best experimentally measured values are also displayed for specific values of c.

Nuclear spin - photon entanglement on NV center for Quantum Repeater applications

Javid Javadzade[1]
Majid Zahedian[2,3], Florian Kaiser[4], Vadim Vorobyov[1] and Jörg Wrachtrup[1,3]

[1] *3rd Institute of Physics, IQST and Centre for Applied Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany*
[2] *Institute of Quantum Electronics, ETH Zürich, 8093 Z[rich, Switzerland*
[3] *Max Planck Institute for solid state research, 70569, Stuttgart, Germany*
[4] *Luxembourg Institute of Science and Technology (LIST) L-4362, Luxembourg*

d.dzhavadzade@pi3.uni-stuttgart.de

Quantum communication lines have many different applications such as Quantum Key Distribution [1], Cloud Quantum Computing [2] or Telescope baseline extension. For their practical implementation, quantum repeaters are required, the operation of which is based on the effect of spin-photon entanglement [3]. Among the many platforms for the implementation of quantum repeaters, NV centers have proven themselves very well - this is due to their outstanding coherent properties, along with high state readout efficiency [4]. Moreover, the available adjacent nuclear spins could serve as memory qubits, expanding possible applications.
We demonstrated quantum repeater link, which is the building block for quantum network. In the current work, we implement an experimentally robust "spin-photon time bin" type of entanglement [5], demonstrating high fidelities (around 90%) of the entangled state and discussing the problems limiting it. To estimate the Fidelity of entangled state, we performed measurements in different bases. To control the phase of the photonic qubit, we used an unbalanced Mach-Zehnder interferometer, which allows us to replace temporal modes with spatial ones, and then adding a phase is straightforward. It is worth noting here, that spectral diffusion becomes a big problem with this change of basis, however, a quick control using FPGA allows this effect to be reduced.
We also discuss possible solutions for increasing the rate of entanglement generation (directing the light to the desired branch of the interferometer) and fidelity value, as long as the ideas of two-node realization.

References

[1] C. H. Bennett & G. Brassard Sci.560, 7 (2014)
[2] A. Broadbent et al. Computer Science 517 (2009).
[3] D. Luong et al. Appl. Phys. B, 122, 96 (2016).
[4] M. Pompili et al. Sci. 372, 259 (2021).
[5] R. Vasconcelos et al. npj Quantum Inf **6**, 9 (2020).

Exotic electronic states in borylated graphene nanoribbons on a metallic substrate

Shayan Edalatmanesh[1]
N. Friedrich[2], P. Brandimarte[1], J. Li[2], L. Meyer[2], E. Carbonell-Sanroma[2], M. Corso[2], I. Pozo[3], D. Peña[3],A. Garcia-Lekue[1,4], D. Sánchez-Portal[1,5], T. Frederiksen[1,4], J. I. Pascual[2,4]

[1]*Donostia International Physics Center (DIPC), Donostia-San Sebastian, Spain*
[2] *CIC nanoGUNE, Donostia-San Sebastian, Spain*
[3] *CiQUS, Santiago de Compostela, Spain*
[4] *Ikerbasque, Basque Foundation for Science, Bilbao, Spain*
[5] *Centro de Física de Materiales CSIC-UPV/EHU, Donostia-San Sebastian, Spain*

shayan.edalatmanesh@dipc.org

Graphene nanoribbons (GNRs) have emerged as promising platforms for π-magnetism [1], with recent findings revealing the presence of uncompensated spin-polarized states at ribbon edges or interiors due to non-conventional band topology effects. Additionally, advancements in bottom-up growth techniques have enabled the synthesis of GNRs directly on surfaces [2], further enhancing their potential for applications in spintronics and quantum computing.

Here, we investigate the induction of spin polarization in topologically trivial, densely 2B-doped 7AGNRs [3,4] when detached from a metal support. Utilizing a combination of density functional theory (DFT) [5], mean-field Hubbard calculations and topological band theory, as well as low-temperature scanning tunneling microscopy (STM) transport experiments and simulations [6] on borylated GNRs, we demonstrate and study the presence of a Kondo resonance for specific tip-substrate distances while slowly lifting a 2B-7AGNR from an Au(111) substrate using the tip of an STM. Additionally, we observe the emergence of a low-energy electronic state (Fig. 1) at the terminal of an asymmetric 2B-7AGNR, with an additional anthracene unit on one end. Due to asymmetry, a topological classification based on the bulk-boundary correspondence isn't possible for this structure. However, our theoretical analysis of the electronic structure underscores the potential for substrate-mediated charge transfer effects and hopping processes, enabling the emergence of topological edge states. This discovery provides a compelling basis for exploring complex spin physics and exotic quantum phases in low-dimensional organic materials.

References

[1] D. G. de Oteyza and T. Frederiksen, JPCM 34, 443001 (2022)
[2] J. Cai, et al. Nature 466, 470-473 (2010)
[3] E. Carbonell-Sanromà, et al. J. Phys. Chem. 122,16092–16099 (2018)
[4] N. Friedrich, et al. Phys. Rev. Lett. 125, 146801 (2020)
[5] J. M Soler, et al. JPCM 14, 2745 (2002)
[6] O. Krejčí, et al. Phys. Rev. B 95, 045407 (2017)

Figures

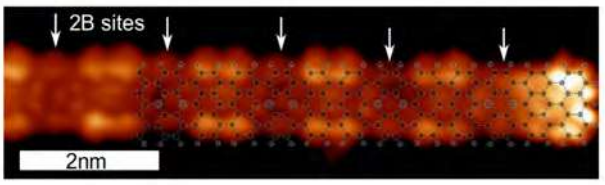
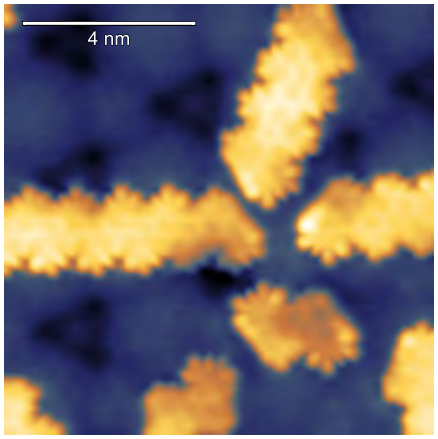


Figure 1: constant-height STM image of the edge state of a densely 2B-doped 7AGNR (V_b = 5 mV).

Spin and charge control of topological end states in exchange biased chiral graphene nanoribbons

L. Edens[1], F. Romero Lara[1], M. Vilas-Varela[2], G. Beretta[3], S. Sanz[4], T. Frederikssen[4], D. Peña[2], and J. I. Pascual[1,5]

[1]CIC nanoGUNE, 20018 San Sebastián, Spain
[2]Centro Singular de Investigación en Química Biolóxica e Materiais Moleculares (CiQUS), and Departamento de Química
Orgánica, Universidade de Santiago de Compostela, Spain
[3]Politecnico di Torino, 10129 Torino, Italy
[4]Donostia International Physics Center (DIPC), 20018 San Sebastián, Spain
[5]Ikerbasque, 48011 Bilbao, Spain



Nanographene can exhibit radical states due to sublattice imbalance or nontrivial topological phases. On-surface synthesis (OSS) enables growth of such structures with atomic precision, whose electronic structure and magnetism can then be probed by scanning tunnelling spectroscopy. The magnetism of the topological end states in chiral graphene nanoribbons (chGNRs) however remains unobserved, as electron transfer of two electrons to or from the substrate readily occurs for small mismatches in electron affinity, quenching magnetism [1].
When alloyed with rare-earth metals [2], gold still catalyses OSS, while exhibiting a much lower work function [3]. We show here that defect-free (3,2,8)-chGNRs can be synthesized on the ferromagnetic $GdAu_2$ intermetallic surface, and do not undergo charge transfer. We furthermore observe that the occupancy of the two topological end states, as well as their total spin multiplicity, can be switched reversibly from a doublet to a singlet, and then to a triplet configuration by lateral manipulation. The prominent spin-flip excitation is interpreted as a Kondo-screened π-radical state acted upon by the highly site-dependent [4] exchange bias.

[1] Li, J. et al., Nat Commun 12, 5538 (2021)
[2] Corso, M et al., ACS Nano 4, 1603–1611 (2010)
[3] Que, Y. et al., J. Phys. Chem. Lett. 11, 5044–5050 (2020)
[4] Bazarnik, M. et al., Phys. Rev. B 99, 174419 (2019)

QuantumSolver AI:
A Quantum Artificial Intelligence Module

Daniel Escanez-Exposito
Pino Caballero-Gil

University of La Laguna, 38271 La Laguna, Tenerife,
Spain

jescanez@ull.edu.es

Abstract

This project introduces the development of a robust quantum artificial intelligence module [1,2], implemented as an extension of the open-source QuantumSolver quantum library [3]. The module enables the application of various quantum supervised learning models [4] to any classical dataset. Users are provided with a curated selection of pre-defined models and datasets, along with an intuitive tutorial for seamless integration into the platform. Established configurations are aggregated for default operations, while also allowing users the flexibility to adjust different parameters, providing a comprehensive research toolkit. Thus, the main implementation details, as well as the designed representations of the results and the conclusions drawn from the study conducted on the included models, are elaborated upon. Furthermore, special emphasis is placed on the generated graphics by the tool itself (Fig. 1).

References

[1] Ciliberto, C., Herbster, M., Ialongo, A. D., Pontil, M., Rocchetto, A., Severini, S. y Woss- nig, L. (2018). Quantum machine learning: a classical perspective. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 474 (2209), 20170551.

[2] Russell, S. J. y Norvig, P. (2009). Artificial Intelligence: a modern approach. Pearson.

[3] Escanez-Exposito, D., Caballero-Gil, P. y Martin-Fernandez, F. (2022). QuantumSolver: A quantum tool-set for developers. The 2022 World Congress in Computer Science, Computer Engineering, and Applied Computing.

[4] Sebastianelli, A., Zaidenberg, D. A., Spiller, D., Saux, B. L. y Ullo, S. L. (2022). On Circuit- Based Hybrid Quantum Neural Networks for Remote Sensing Imagery Classification. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 15, 565-580.

Figures

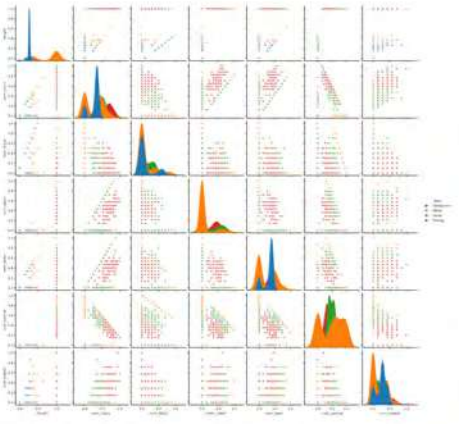


Figure 1: Password Strength dataset representation generated by QuantumSolver AI

Unconventional charge transport nonreciprocity in the superconductor $ZrTe_3$

Sofia Ferreira Teixeira[1]
Daniel Tezze[1], Lucia Olano[1], Beatriz Martín-García[1,2], Bing Wu[3], Fèlix Casanova[1,2], Zdeněk Sofer[3], F. Sebastian Bergeret[4,5], Luis E. Hueso[1,2], Marco Gobbi[2,4]

[1]*CIC nanoGUNE BRTA, 20018 Donostia - San Sebastian, Basque Country, Spain*
[2]*IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Basque Country, Spain*
[3]*Department of Inorganic Chemistry, University of Chemistry and Technology, 16628 Prague, Czech Republic*
[4]*Centro de Física de Materiales (CFM-MPC) Centro Mixto CSIC-UPV/EHU, 20018 Donostia - San Sebastian, Basque Country, Spain*
[5]*Donostia International Physics Center (DIPC), 20018 Donostia - San Sebastian, Basque Country, Spain*

s.ferreira@nanogune.eu

The breaking of inversion and time-reversal symmetries is the basis behind nonreciprocal charge transport, making the electrical resistance dependent on the relative orientation between charge current and magnetic field [1]. In the past years, two-dimensional (2D) superconductors have emerged as an excellent platform for exploring this nonreciprocity [2, 3]. Near the superconducting state, the nonreciprocal signals are substantially enhanced, and the nonreciprocal transport appears due to the chirality of the supercurrent or of the Cooper pairs. Recently, this nonreciprocal transport has also been observed in the centrosymmetric CsV_3Sb_5 [4], where it was proposed that the nonreciprocity arises due to the symmetry breaking of an unconventional superconducting order parameter.

Here, we investigate the nonreciprocal transport of $ZrTe_3$, a centrosymmetric van der Waals material which displays a charge-density wave phase and superconductivity. We mechanically exfoliate $ZrTe_3$ into nanowires that become superconducting at ~3.5 K, and perform second harmonic resistance measurements close to its critical temperature. The second harmonic magnetoresistance is made up of several antisymmetric peaks with respect to the magnetic field. The magnitude and sign of the peaks are controlled by the applied current, which is indicative of a tuneable rectification effect. Moreover, a previously unexplored symmetric component that persists at zero magnetic field is also detected in the second harmonic magnetoresistance. This nonreciprocal transport is observed with an out of plane magnetic field as well as with in-plane magnetic fields, both perpendicular and parallel to the current. These results demonstrate that even without inversion symmetry breaking, a wide range of nonreciprocal effects are present in 2D superconductors, paving the way for potential applications in photodetectors, antennas, and rectifier devices [5].

References

[1] Rikken, G. L. J. A., & Raupach, E. Nature, 390, 6659 (1997) 493-494
[2] Wakatsuki, R., et al. Science advances, 3, 4 (2017) e1602390
[3] Zhang, E., et al. Nature communications, 11, 1 (2020) 5634
[4] Wu, Y., et al. npj Quantum Materials, 7, 1 (2022) 105
[5] Isobe, H., Xu, S. Y., & Fu, L. Science advances, 6, 13 (2020) eaay2497.

Shortcuts for Adiabatic and Variational Algorithms in Molecular Simulation

Julian Ferreiro-Velez
Iñaki Iriarte-Zendoia, Alejandra Ruiz, Yue Ban and Xi Chen

TECNALIA, Basque Research and Technology Alliance (BRTA), 48160 Derio, Spain
EHU Quantum Center, University of the Basque Country UPV/EHU, 48940 Leioa, Spain
julian.ferreiro@tecnalia.com

Quantum algorithms are prominent in the pursuit of achieving quantum advantage in various computational tasks. However, addressing challenges such as limited qubit coherence and high error rate in near-term devices requires extensive efforts. In this paper, we present a significant advancement in quantum chemistry [1] by integrating shortcuts to adiabaticity techniques into adiabatic and variational algorithms for calculating molecular ground state properties. Our approach includes a counterdiabatic [2] term that accelerates adiabatic evolution, reducing Trotter errors and enabling faster computations. Additionally, we introduce the counterdiabatic term as the adiabatic gauge ansatz for variational quantum eigensolver, the *Adiabatic Gauge Ansatz* (AGA) and the Reduced-AGA, which exhibits favourable convergence properties with a fewer number of parameters, thereby reducing the number of qubits and circuit depth. Our approach achieves comparable accuracy to the established ansatz, while advancing practical applications in material science, drug discovery, and molecular simulations.

References

[1] A. Peruzzo, J. McClean, P. Shadbolt, M.-H. Yung, X.-Q. Zhou, P. J. Love, A. Aspuru-Guzik, and J. L. O'Brien, Nat. Commun. 5, 4213 (2014).

[2] D. Guéry-Odelin, A. Ruschhaupt, A. Kiely, E. Torrontegui, S. Martínez-Garaot, and J. G. Muga, Rev. Mod. Phys. 91, 045001 (2019).

Figures

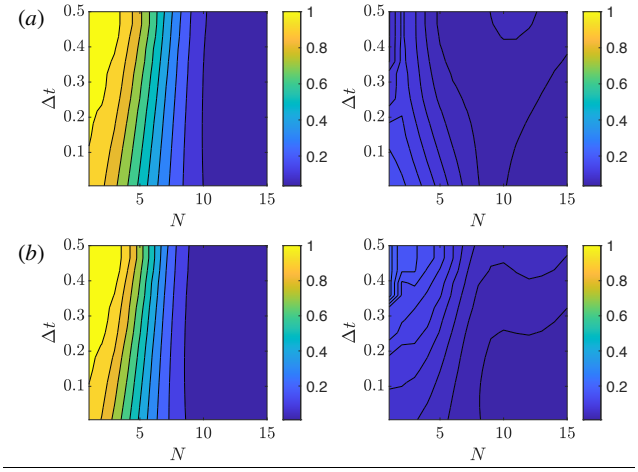


Figure 1: Adiabatic ground state energy deviation in *LiH*-(a) and *BeH_2*-(b) molecules with (right) and without (left) counterdiabatic assistance w.r.t the time steps Δt and the number of steps N.

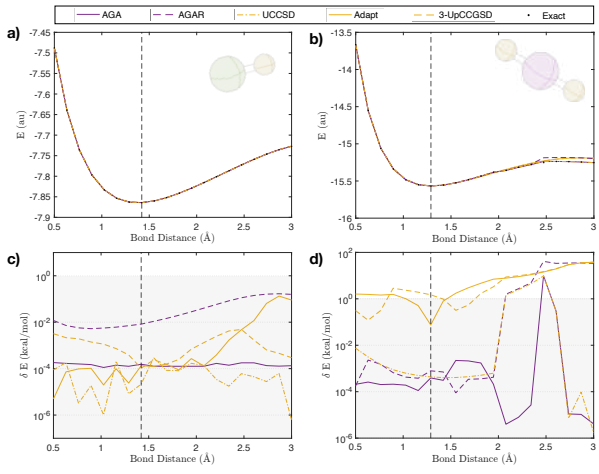


Figure 2: VQE ansatzes comparation for *LiH* (left) and *BeH_2* (right) energy ground state simulation. (c)-(d) figures represents the discrepancy among the simulated energy and the exact for the different ansatzes.

Enhanced Superconducting Fluctuations in Two-Dimensional Oxide Superconductor

Ulderico Filippozzi[1], Graham Kimbell[2,], Stefano Gariglio[2], Andreas Glatz[3,4], Andrey Varlamov[5], Andrea Caviglia[2]

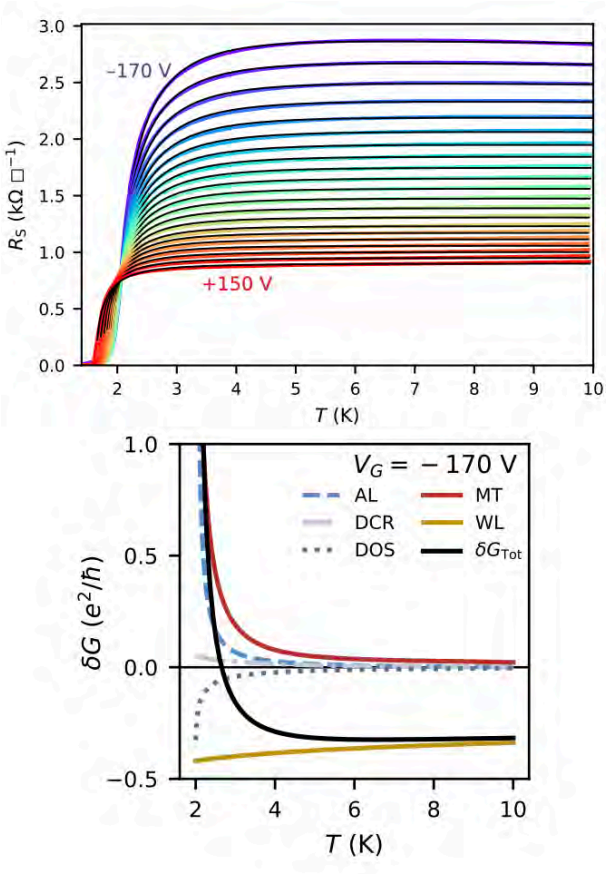
1. Kavli Institute of Nanoscience, Delft University of Technology, *Delft, The Netherlands*
2. Department of Quantum Matter Physics, University of Geneva, *Geneva, Switzerland*.
3. Materials Science Division, Argonne National Laboratory, *Argonne, Illinois, USA*
4. Department of Physics, Northern Illinois University, *DeKalb, Illinois USA*
5. Institute of Superconductivity and Innovative Materials (CNR-SPIN), *Rome, Italy*

u.filippozzi@tudelft.nl

Strong spin-orbit coupling, and low crystal symmetry are key ingredients for the search of non-conventional superconducting systems [1,2]. The recent discovery of superconductivity at the (111) surface of $KTaO_3$ sparked a renewed interest in the investigation of interfacial superconductivity in oxides. The surface of $KTaO_3$(111) has been shown to host non-coplanar spin textures and strong spin-orbit coupling [4,5], crucial factors to attain non-standard superconducting states or nontrivial band topology[1-3].
Although early observations yield a promising outlook for this material platform [4-7], the thermodynamics of the superconducting state of $KTaO_3$ (111) remains undetermined.
We study the increase in conductivity above the transition temperature in superconducting field effect devices at the surface of $KTaO_3$(111). The conductivity's enhancement in these devices is considerably underestimated by the standard Aslamazov-Larkin contribution. The discrepancy is resolved by considering a comprehensive model including other fluctuation mechanisms such as the phase coherent Maki-Thompson (MT) correction. The theoretical model accounts also for dynamical and short-wavelength fluctuations, which makes it applicable over a broad range of temperatures. This analysis allows to capture an enhancement in conductivity that extends up to 4 times the critical temperature and highlight MT corrections as the leading contribution to the conductivity's enhancement.

References

1. Scheurer, M. S. et al. , Nat. Comm. 6, 6005 (2015).
2. Fukaya, Y. et al. Phys. Rev. B 97, 1–17 (2018).
3. Lesne, E. et al., Nat. Mat. 22, 576–582 (2023)
4. Bareille, C. et al., Sci. Rep. 4, 3–7 (2014).
5. Bruno, F. Y. et al., Adv. Electron. Mater. 5, 1–7 (2019)
6. Chen, Z. et al., Science 372, 721–724 (2021).
7. Liu, C. et al., Nat. Comm. 14(1), 951 (2023)



Figures

Figure 1: Top panel: electrostatically tunable superconducting transition with overlaid fits. Bottom panel: separate contributions at fixed gate voltage (170V) shows MT contributions dominating over the entire temperature range.

Crossed graphene nanoribbons for electron quantum optics and spintronics

Thomas Frederiksen,[1,2] Sofia Sanz,[3] Nick Papior,[4] Geza Giedke,[1,2] Daniel Sanchez-Portal,[3] Mads Brandbyge[5]

[1]*Donostia International Physics Center*
[2]*IKERBASQUE, Basque Foundation for Science*
[3]*Centro de Física de Materiales, CSIC-UPV/EHU*
[4]*DTU Computing Center, Technical University of Denmark*
[5]*Department of Physics, Technical University of Denmark*
thomas_frederiksen@ehu.eus

Graphene nanoribbons (GNRs) are emerging as versatile platforms for quantum technology, leveraging tunable electronic and π-magnetic properties [1]. The minimal spin-orbit and hyperfine interactions inherent in graphene position GNRs as prime candidates for developing sophisticated functionalities, including spin filters, spin qubits, and electron quantum optics setups.

In our theoretical exploration, we examine electronic transport within devices composed of crossed zigzag GNRs, applying the mean-field Hubbard model alongside Green's function techniques under open boundary conditions. By orienting one ribbon across another at approximately a 60º angle, we find that electron waves, upon injection from an electrode, are split at the junction into two of the three outgoing ports. Importantly, with edge spin polarization taken into account, our findings suggest that such arrangements can serve as efficient spin-polarizing beam splitters [2]. We extend our study to Mach-Zehnder-like interferometers utilizing zigzag GNR arrays to study quantum interfererence [3], underpinning the versatility and potential of GNRs in constructing complex quantum devices.

References

[1] D. G. de Oteyza and T. Frederiksen, *Carbon-based nanostructures as a versatile platform for tunable π-magnetism*, J. Phys.: Condens. Matter **34**, 443001 (2022)

[2] S. Sanz, N. Papior, G. Giedke, D. Sánchez-Portal, M. Brandbyge, and T. Frederiksen, *Spin-polarizing electron beam splitter from crossed graphene nanoribbons*, Phys. Rev. Lett. **129**, 037701 (2022)

[3] S. Sanz, N. Papior, G. Giedke, D. Sanchez-Portal, M. Brandbyge, and T. Frederiksen, *Mach–Zehnder-like interferometry with graphene nanoribbon networks*, J. Phys.: Condens. Matter **35**, 374001 (2023)

Figures

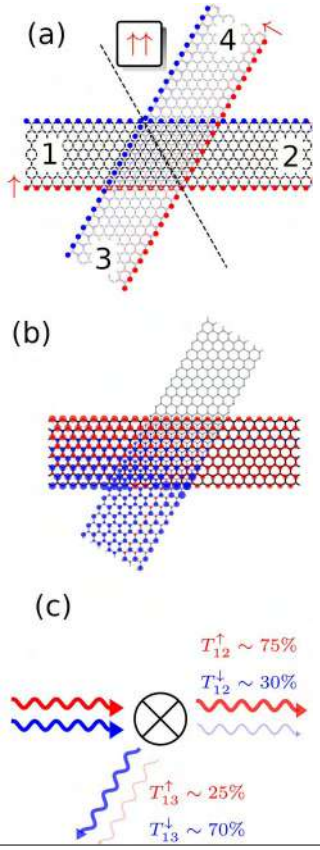


Figure 1: A spin-polarizing beam splitter with two crossed GNRs [2]. **(a)** Spin density configuration in a device composed of two AB-stacked 8-ZGNRs. **(b)** Spin-resolved scattering state of electrons incoming from the left in the conduction band (E-E_F=0.5 eV). **(c)** Sketch of incoming/outgoing waves at the intersection with the corresponding spin-resolved transmission probabilities indicated.

Variational Quantum Regression on NISQ Hardware with Error Mitigation

Eider Garate[1]
Guillermo Valverde[2], Paul San Sebastian[3], Alejandra Ruiz[4], Meritxell Gómez-Omella[1]

[1] Tekniker (BRTA), Iñaki Goenaga, 5, 20600, Eibar, Spain
[2] Vicomtech (BRTA), Zorrotzaureko Erribera, 2, 48014, Bilbao, Spain
[3] Ikerlan (BRTA), J.M. Arizmendiarrieta, 2, 20500 Arrasate-Mondragon, Spain
[4] Tecnalia (BRTA), Astondo Bidea, 700, 48160, Derio, Spain

eider.garate@tekniker.es

At the intersection of two promising technologies, machine learning (ML) and quantum computing (QC), Quantum Machine Learning (QML) emerges. However, while QC is still in an early stage of development, QML is even more so. In this study, the Auto-MPG dataset [1] has been used to examine the state of the art of QML models in regression problems [2]. To this end, a preliminary analysis was conducted using a classical model as a reference point for subsequent evaluation. The XGBoost algorithm has proven to be a powerful ML algorithm that can be used for this task obtaining un R2 of 0.874 in the training phase and a 0.872 in the 20% of the data reserved for validation. Also, XGBoost can measure the contribution of each variable, which can be key when it comes to reducing the problem's dimensionality in the quantum approach. After that, the quantum experimentation was carried out in two phases. First, the model was trained in a perfect simulator of Pennylane to determine the best hyperparameters of the model. The best result achieved an R^2 of 0.860 for the training and 0.896 for the testing. Then, the best model was run against a simulator that include the noisy model extracted from the IBM Brisbane device using different error mitigation techniques. Among all of them, Zero Noise Extrapolation technique [3] was chosen as it yielded the most suitable results according to the selected simulator. To conclude, the QML model outperformed classical methods, demonstrating robustness with minimal R^2 reduction in the noisy simulator (by 0.001) during training and achieving consistent test performance using error mitigation.

References

[1] Quinlan,R.. (1993). Auto MPG. UCI Machine Learning Repository.
[2] Hirai, H., 2023. Application of quantum neural network model to a multivariate regression problem.
[3] He, A., Nachman, B., de Jong, W. A., & Bauer, C. W. (2020). Zero-noise extrapolation for quantum-gate error mitigation with identity insertions. *Physical Review A*, *102*(1), 012426.

Figures

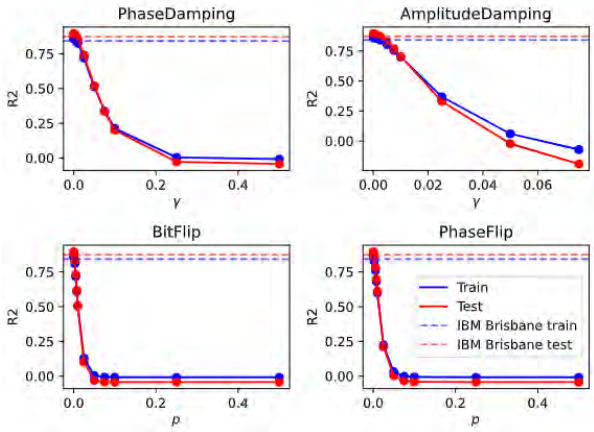


Figure 1: Study of the effect of different types of noise in the performance of the model

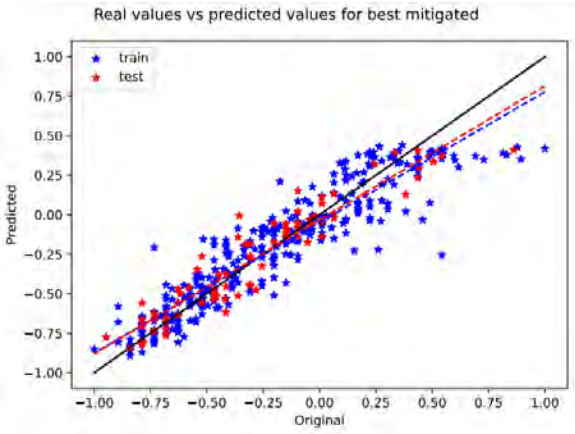


Figure 2: Comparison of predicted values and original values in train and test sets obtained by a noisy quantum circuit with the best error mitigation strategy.

Generalized spin squeezing with limited measurements

Irene García Martínez
Departamento de Física Teórica, IFIC, Universidad de Valencia, CSIC, C/ Dr. Moliner 50, 46100 Burjasot (Valencia), Spain

Manuel Gessner
Departamento de Física Teórica, IFIC, Universidad de Valencia, CSIC, C/ Dr. Moliner 50, 46100 Burjasot (Valencia), Spain

irene.garcia@uv.es

An important and widely used tool in quantum metrology is the spin squeezing parameter. Its development was mainly motivated by two applications: the improvement of precision measurements beyond the classical limit and the study of particle correlations and entanglement [1]. In quantum metrology, the spin squeezing parameter determines the sensitivity that can be achieved through the measurement of a fixed, possibly suboptimal observable. It therefore determines a lower bound on the quantum Fisher information, which expresses the maximal sensitivity achievable with an optimal observable.

However, these sensitivities can only be achieved for an asymptotically large number of measurements. Since these are a limited resource, it is crucial to explore precision bounds in the low data regime. Guided by the recently derived hierarchy of quantum metrology bounds [2], we investigate approximations to generalized quantum information functions beyond the Fisher information that are of relevance in the presence of low data. We present a family of generalized bounds that includes the relation between standard spin squeezing and Fisher information as a particular case.

Our generalized spin squeezing type of bounds are analytically derived from averages and variances of arbitrary measurement observables. We study the families of quantum bounds that may involve higher-order derivatives (Bhattacharyya) and others that avoid the use of differentials altogether (Barankin), as well as combinations of both of them (Hybrid).

We derive analytical expressions for the bounds and for the coefficients that optimize them. For a single qubit, the derived generalized bounds show saturation (see Fig. 1).

References

[1] L. Pezzè et al., *Quantum metrology with nonclassical states of atomic ensembles,* Rev. Mod. Phys. 90, 035005 (2018)

[2] M. Gessner and A. Smerzi, *Hierarchies of Frequentist Bounds for Quantum Metrology: From Cramér-Rao to Barankin*, Phys. Rev. Lett. **130**, 260801 (2023).

Figures

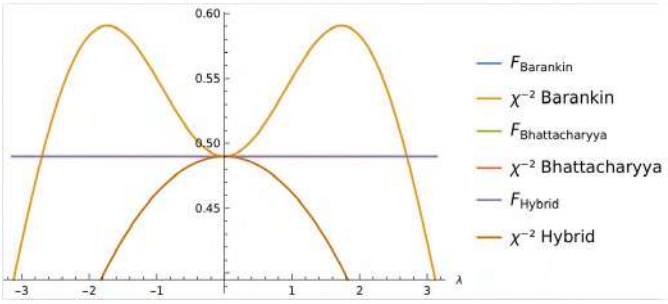


Figure 1: Comparison of the generalized spin squeezing bounds and the generalized quantum information functions that include the Fisher information as a special case. All three families saturate the bound for all values of the single free parameter λ. The Bhattacharyya type of bound coincides with the quantum Cramér-Rao bound for all λ, while the other bounds recover it as λ→ 0.

Extensions of Digital-Analog Quantum Computation

Mikel Garcia de Andoin
Álvaro Saiz, Pedro Pérez-Fernández, Lucas Lamata, Izaskun Oregi, Mikel Sanz

TECNALIA, Basque Research and Technology Alliance (BRTA), Astondo Bidea Edificio 700, 48160 Derio, Spain
EHU Quantum Center, University of the Basque Country UPV/EHU, Barrio Sarriena s/n, 48940 Leioa, Spain
mikel.garciadeandoin@tecnalia.com

Digital-analog quantum computing is a computational paradigm which employs an analog Hamiltonian resource together with single-qubit gates to reach universality [1]. This protocol benefits from the natural interaction Hamiltonian of quantum systems, as instead of trying to eliminate it enables us to use it as a resource. Additionally, it has been shown that this paradigm has inherent error mitigation capabilities [2]. Since it only requires the application of single qubit gates, it avoids the use of the noisier two qubit gates, providing a promising way of implementing algorithms in the NISQ era.

Regarding its applicability, it has already been shown useful for implementing ubiquitous quantum algorithms and solving various problems. Among them, the quantum Fourier Transform [3], the algorithm for solving a linear system of equations (HHL) [4] or a simulation of fermionic systems [5].

In this talk, we will focus on the theoretical background of this paradigm, providing tools for extending it to a large set of problems and systems. In our last work [6], we designed a new scheme which employs an arbitrary two-body source Hamiltonian, extending the experimental applicability of this computational paradigm to most quantum platforms. We showed that the simulation of an arbitrary two-body target Hamiltonian of n qubits requires $O(n^2)$ analog blocks with guaranteed positive times, providing a polynomial advantage compared to the previous scheme (Figure 1). Additionally, we proposed a classical strategy which combines a Bayesian optimization with a gradient descent method, improving the performance by ~55% for small systems measured in the Frobenius norm.

References

[1] A. Parra-Rodriguez, P. Lougovski, L. Lamata, E. Solano, M. Sanz, Phys. Rev. A **101** (2020), 022305
[2] P. García-Molina, A. Martin, M. Garcia de Andoin, M. Sanz, arXiv:2107.12969 (2022)
[3] A. Martin, L. Lamata, E. Solano, M. Sanz, Phys. Rev. Research **2** (2020), 013012
[4] A. Martin, R. Ibarrondo, M. Sanz, Phys. Rev. Applied **19** (2023), 064056
[5] L. C. Céleri, D. Huerga, F. Albarrán-Arriagada, E. Solano, M. Garcia de Andoin, M. Sanz, Phys. Rev. Applied **19** (2023), 064086
[6] M. Garcia de Andoin, Á. Saiz, P. Pérez-Fernández, L. Lamata, I. Oregi, M. Sanz, arXiv:2307.00966 (2023)

Figure

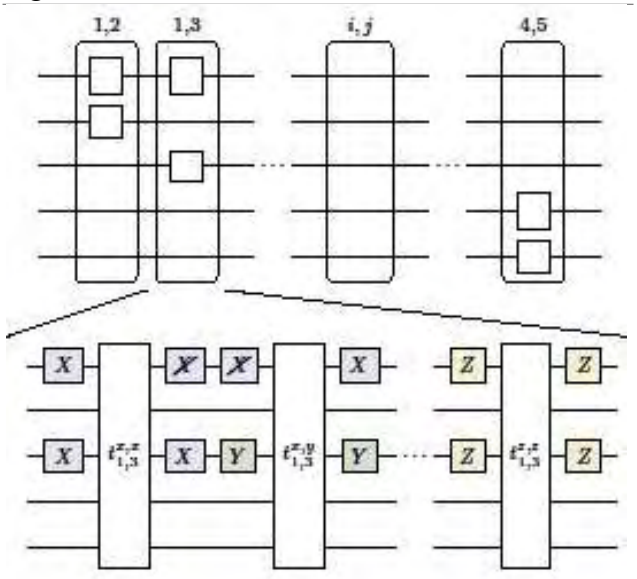


Figure 1: Example of a digital-Analog schedule for an arbitrary two body Hamiltonians composed of pairs of single qubit gates.

Experimental study of GdW10 and GdW30 molecular magnets

David García-Pons
Xavier del Arco Fargas, J. Pérez-Bailón, F. Luis, D. Zueco, M.J. Martínez-Pérez

Instituto de Nanociencia y Materiales de Aragón (CSIC-Universidad de Zaragoza), Zaragoza, España

dgpons@unizar.es

Single-molecule magnets such as GdW10 and GdW30 are promising spin qubit candidates [1].
Here we explore experimentally the field dependent transitions in these materials via VNA-FMR experiments [2,3] at different temperatures and compare our result to theoretical predictions based on the Hamiltonian of the crystal. These experiments allow us to develop a technique to interact with these molecules, aiming to integrate them in hybrid quantum systems through their interactions with superconducting microwave cavities or magnons.

Figures

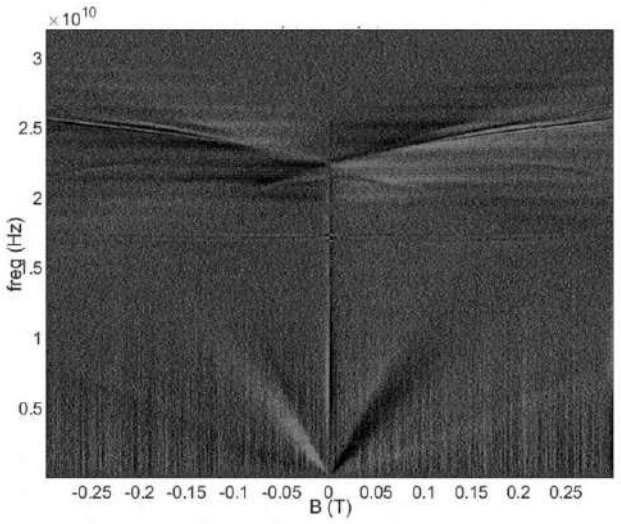


Figure 1: FMR spectrum measured for one GdW_{10} crystal at 60mK. The first few allowed level transitions are easily distinguished around 20-27GHz.

References

[1] M.J. Martínez-Pérez et al., Phys Rev Lett, (2012) 108(24):247213
[2] I. Gimeno et al., ACS Nano, 14, 7(2020) 8707-8715
[3] S. Martinez-Losa del Rincon et al., Phys. Rev. Applied, 19, 014002 (2023)

Development of an automated workflow for well converged DFT calculations using SIESTA and the AiiDA infrastructure satisfying FAIR data principles

Jaime Garrido Aldea[1], Stephan Roche[1,2], Jose Hugo García Aguilar[1]
[1]*ICN2, Instituto Catalan de Nanociencia y Nanotecnología UAB Campus, Bellaterra, 08193, Spain*
[2]ICREA — Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain
jaime.garrido@icn2.cat

In the realm of materials science, the advent of advanced computational resources has set the stage for two pivotal ambitions: unravelling the intricate properties of materials and pioneering the discovery of novel ones [1]. Among the myriad of materials, 2D materials stand at the forefront, captivating interest for their versatile applications. This fascination has culminated in the creation of comprehensive databases, cataloguing their properties as predicted by Density Functional Theory (DFT) [2]. These databases are the product of sophisticated high-throughput frameworks designed to streamline and automate computational processes. However, the quest for precision necessitates meticulous attention to ensure that the computational results are not just extensive but also converged and reliable.

Despite the progress, there remains ample scope for refining existing data and unveiling new properties yet to be discovered. One of the challenges in high-throughput computational science is adhering to the FAIR principles — ensuring that data are Findable, Accessible, Interoperable, and Reusable [3]. These principles are fundamental in fostering an environment of transparency and reproducibility in scientific research.

Moreover, such databases could serve to identify patterns in materials features which could be of great use for material engineering. In particular, we developed an automated workflow utilizing AiiDA [4], DFT simulations package SIESTA [5] and TB2J for exchange constant calculations [6] to compute bandgap, band structure plots, and exchange constant [6]. These calculations will enable us the possibility to compute the Curie temperature of 2D magnetic materials through Monte Carlo methods. We expect this work will serve to identify the critical features required to further increase the Curie temperature of 2D magnets thus opening a new gate for low-power low-dimensional magnetic memories.

References

[1] Feliciano Giustino et al, J. Phys. Mater., 3 (2021) 042006
[2] Sten Haastrup et al, 2D Mater., 5 (2018) 042002
[3] Wilkinson, M., Dumontier, M., Aalbersberg, I. et al., Sci Data, 3 (2016) 160018
[4] Huber, S.P., Zoupanos, S., Uhrin, M. et al, Sci Data, 7 (2020) 300
[5] Alberto García et al, J. Chem. Phys., 152 (2020) 204108
[6] Xu He et al, Computer Physics Communications, 264 (2021) 107938

Spin impurity in interaction with multiple baths via non-commuting coupling operators: An analytic approach

Jakub Garwola
Nicholas Anto-Sztrikacs, Brett Min, Dvira Segal

University of Toronto, 27 King's College Cir, Toronto, Canada

jakub.garwola@mail.utoronto.c

The Effective Hamiltonian theory [1] allows analytical studies of quantum dynamics and thermodynamics in the strong system-bath coupling limit. Here, we present an extension to the Effective Hamiltonian framework and tackle the problem of quantum systems coupled to *multiple* reservoirs through *non-commuting* system's operators. We report that this approach, which includes generalizing the mapping procedure, yields closed-form analytical expressions that expose the nontrivial impact of strong coupling effects on, e.g., spin magnetization at equilibrium and heat current in a nonequilibrium steady state. This tool will augment numerical studies based on quantum master equations and path integral approaches. Future prospects include extending this procedure to study dissipative spin chains. For example, coupling spin lattices to multiple environments could allow engineering their magnetic or topological order [2].

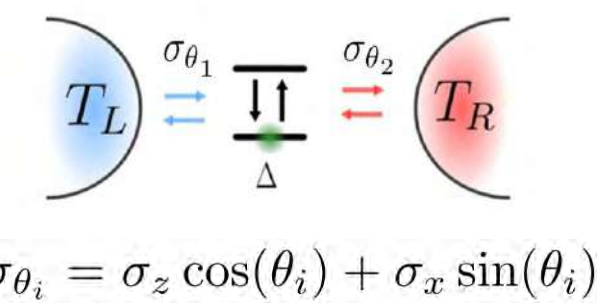


Figure 1: Example of a two-level system, coupled to two bosonic bath of different temperature via coupling operators in the form of linear combinations of Pauli Matrices. This system can now be analytically described using the generalized effective Hamiltonian method described above. Figure based on [1].

References

[1] Nicholas Anto-Sztrikacs, Ahsan Nazir, Dvira Segal, PRX Quantum, 2023

[2] Brett Min, Nicholas Anto-Sztrikacs, Marlon Brenes, Dvira Segal, arXiv preprint, 2024

Quantum Control of nano-diamond Nitrogen Vacancy spin ensembles

Jemy Geordy[1,2]
Alexander Hahn[1,2], Anirban Dey[1,2], Kazuya Yuasa[3], Daniel Burgarth[4], Sarath Raman Nair[1,2], Thomas Volz[1,2]

[1]*School of Mathematical and Physical Sciences, Macquarie University, Australia*
[2]*ARC Centre of Excellence for Engineered Quantum Systems, Macquarie University, Australia*
[3]*Department of Physics, Waseda University, Tokyo, Japan*
[4]*Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany*

jemy.geordy@students.mq.edu.au

Abstract

Nitrogen-Vacancy (NV) colour centre in diamond is a powerful tool as a quantum sensor that works under ambient conditions. An ensemble of such sensors in nanoparticle size with reduced coupling to its immediate intrinsic surroundings can enhance the sensitivity and offer high spatial resolution [1]. Two main challenges need to be addressed to make the full potential of NV nano-diamond sensors based on the spin ensembles. The first one is the fast decay of the quantum coherence of the NV spin ensemble system due to the coupling to its intrinsic surrounding spin bath, and the second one is the random orientation of the NV ensembles originating from the random orientation of nanodiamonds relative to the external control fields [2, 3, 4]. Here I present the latest results from our ongoing experiments in nano-diamond NV spin ensembles. To address the fast decay due to the intrinsic spin bath we use various dynamical decoupling (DD) methods along with controlled spin-bath driving. We are also exploring optimization algorithms to address the problems arising due to the random orientation of the nano-diamonds. Furthermore, we introduce additional pulse rotations in conventional DD and observe an 'unusual' sharp change in the coherence decay timescales and phase transitions in comparison with the conventional DD.

References

[1] Rondin, Loïc, et al. "Magnetometry with nitrogen-vacancy defects in diamond." *Reports on progress in physics* 77.5 (2014): 056503.

[2] Knowles, Helena S., Dhiren M. Kara, and Mete Atatüre. "Observing bulk diamond spin coherence in high-purity nanodiamonds." *Nature materials* 13.1 (2014): 21-25.

[3] Bauch, Erik, et al. "Decoherence of ensembles of nitrogen-vacancy centers in diamond." *Physical Review B* 102.13 (2020): 134210.

[4] Segawa, Takuya F., and Ryuji Igarashi. "Nanoscale quantum sensing with Nitrogen-Vacancy centers in nanodiamonds–A magnetic resonance perspective." *Progress in Nuclear Magnetic Resonance Spectroscopy* 134 (2023): 20-38.

Investigation of dissipative Rashba nanowire

Arnob Kumar Ghosh

Annica M. Black-Schaffer

Department of Physics and Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden

arnob.ghosh@physics.uu.se

Abstract

Condensed matter systems are continuously subjected to dissipation and seem to affect the system adversely. In this context, our study focuses on the impact of dissipation on a superconducting Rashba nanowire. We reveal that the system can still host Majorana zero-modes (MZMs) with a finite lifetime in the presence of dissipation. Interestingly, we can generate two kinds of boundary states via dissipation-four robust zero-modes (RZMs) and two MZMs, depending upon the amplitude of the dissipation. The RZMs are not associated with any bulk states and possess no winding number, but we can relate the generation of the RZMs to exceptional points. Meanwhile, the MZMs appear in the system via bulk gap closing and can be topologically characterized by a winding number. We investigate the stability of the RZMs and MZMs in the presence of onsite random disorder. Our study paves the way for stabilizing and realizing MZMs in an experimental setup.

Figures

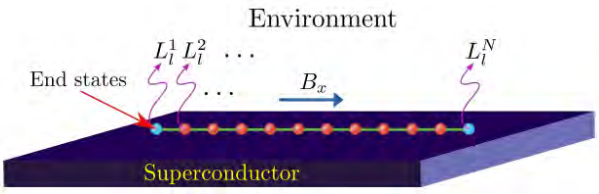


Figure 1: We demonstrate the schematic representation of our setup encompassing a one-dimensional Rashba nanowire in close proximity to a bulk s-wave superconductor. The system is coupled to the environment via dissipation.

Random number generation using single photon emitters embedded in nanopillars

Madhura Ghosh Dastidar[1]
Aprameyan Desikan[2], Vidya Praveen Bhallamudi[1]

[1]*Department of Physics, Indian Institute of Technology Madras, Chennai 600036, Tamil Nadu, India*
[2]Department of Physical Sciences, Indian Institute of Science Education & Research Mohali Sector 81 SAS Nagar, Manauli PO 140306 Punjab, India

ph20d750@smail.iitm.ac.in;
praveen.bhallamudi@iitm.ac.in

Random number sequences have wide applications in science and technology [1,2]. A crucial application of random number generation is in the field of secure quantum communication [3], where photons act as qubits. Typically, such sequences can be generated by algorithmic methods via pseudorandom number generators. However, for a truly unpredictable random number sequence, inherent properties of a quantum system must be utilized [1]. Here, we implement a quantum random number generator (QRNG) based on single photon detection from a solid-state emitter (nitrogen vacancy – NV center in diamond) [4]. The principle is based on the inherent randomness of path selection by a photon incident on a symmetric beam splitter. The emitter is embedded in a nanopillar which helps in enhanced brightness of emission and knowing the precise location of these emitters. We investigate the photon statistics of emission by performing an anti-bunching measurement. This ensures the single photon nature of the emitted light for characterizing of the non-classicality of the source. Then, we experimentally demonstrate a real-time quantum random number generator at room-temperature for these NV centers. We perform von Neumann de-biasing to extract the random number sequence from the raw bit sequence and show a comparison of the random numbers generated for different emitters. The sequences pass the randomness tests with p-values >> 0.1, indicating high quality of randomness. Our results highlight the importance of true random number generation using single photon emitters.

References

[1] M. Herrero-Collantes and J. C. Garcia-Escartin, Rev. Mod. Phys. 89, 015004 (2017)
[2] X. Ma, X. Yuan, Z. Cao, B. Qi, and Z. Zhang, npj Quantum Inf. 2, 16021 (2016)
[3] W. Tittel, H. Zbinden, and N. Gisin, Phys. Rev. A 63, 042301 (2001)
[4] X. Chen, J. N. Greiner, J. Wrachtrup and I. Gerhardt, Scientific Reports, 9(1), 18474 (2019)

Figure

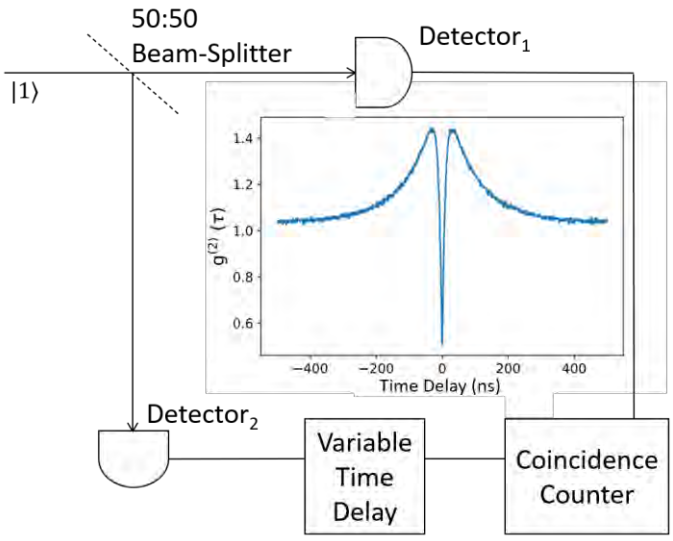


Figure 1: Experimental setup for random number generation and studying antibunching (inset: measured antibunching plot for NV center in nanopillar)

Heat and charge transport in interacting nanoconductors driven by time-modulated temperatures

Rosa Lopez, Minchul Lee, Pascal Simon

Institute of Cross Disciplinary Physics and Complex Systems, University of Balearic Islands
rosa.lopez-gonzalo@uib.es

We investigate the quantum transport of the heat and the charge through a quantum dot coupled to fermionic contacts under the influence of time modulation of temperatures [1].
We derive, within the nonequilibrium Keldysh Green's function formalism, generic formulas for the charge and heat currents by extending the concept of gravitational field introduced by Luttinger to the dynamically driven system and by identifying the correct form of dynamical contact energy. In linear response regime our formalism is validated from satisfying the Onsager reciprocity relations and demonstrates its utility to reveal nontrivial dynamical effects of the Coulomb interaction on charge and energy relaxations.

Reference
[1]Rosa López, Pascal Simón, Minchul Lee arXiv:2308.03426 (2023)

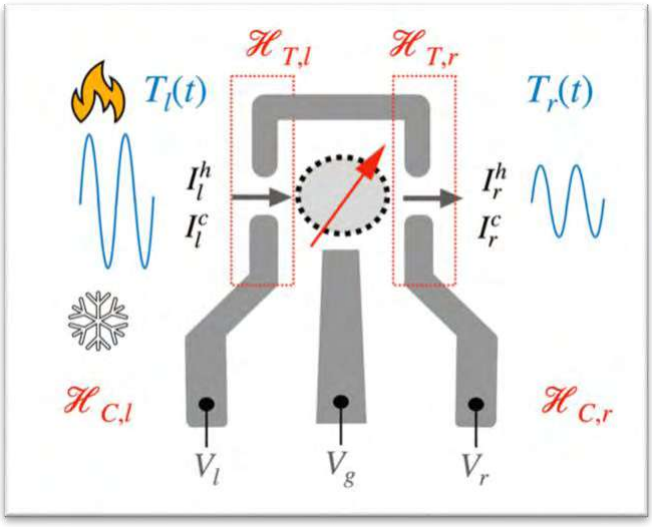


Figure 1: Lateral quantum dot system coupled to a left reservoir (l) and a right reser- voir (r) that are described by $H_{C,l}$ and $H_{C,r}$. Each reservoir is under the influence of a modulated temperature in time with $T_l(t)$ and $T_r(t)$. Left and right tunneling barriers are described by $H_{T,l}$ and $H_{T,r}$, respectively, as indicated. The central part corresponds a spinful quantum dot. Plunger gates V_l and V_r control the barrier transparency, an additional gate V_g is applied to the quantum dot region to tune the dot level position denoted by ε_σ.

Simulation of a Rohksar-Kivelson ladder on a NISQ device

Sabhyata Gupta
Younes Javanmard, Tobias J. Osborne, and Luis Santos
Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany
sabhyata.gupta@itp.uni-hannover.de

We present a quantum-classical algorithm to study the dynamics of the Rohksar-Kivelson plaquette ladder on NISQ devices. We show that complexity is largely reduced using gauge invariance, additional symmetries, and a crucial property associated to how plaquettes are blocked against ring-exchange in the ladder geometry. This allows for an efficient simulation of sizable plaquette ladders with a small number of qubits, well suited for the capabilities of present NISQ devices. We illustrate the procedure for ladders with simulation of up to 8 plaquettes in an IBM-Q machine, employing scaled quantum gates.

References

[1] Sabhyata Gupta,Younes Javanmard, Tobias J. Osborne,Luis Santos, arXiv:2401.16326 [quant-ph],2024

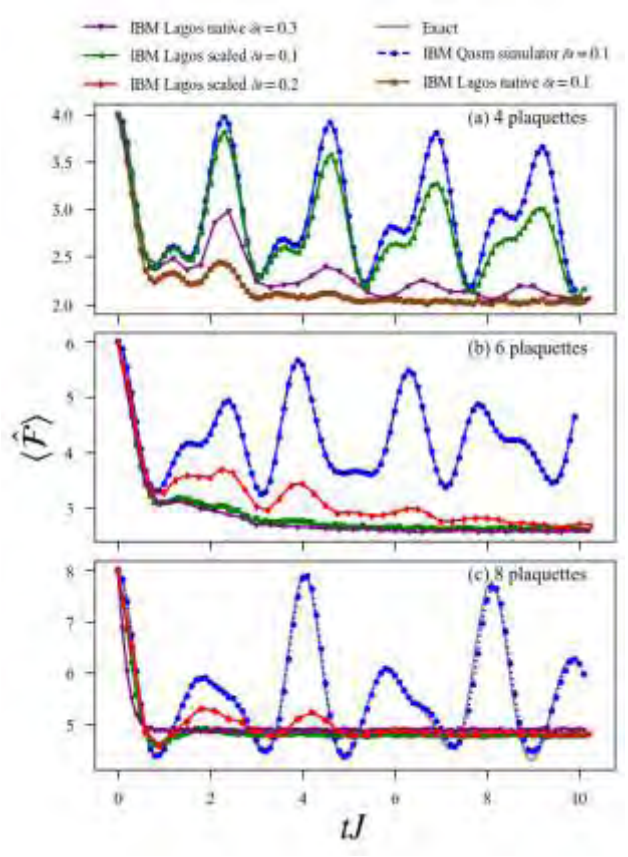


Figure 1: Average number of flippable plaquettes ⟨F⟩ as a function of time for an RK-ladder with λ = 1 and (a) 4 (b) 6 (c) 8 plaquettes. We compare the results obtained from exact time evolution, the ideal simulator, and the noisy circuit with non-scaled and scaled gates for different Trotter steps δt (see legend over Fig. (a))

Quantum Emitter-Mediated Robust Chirality in the Vicinity of Nanophotonic Waveguide

Jabir Hakami

Department of Physics, College of Science, Jazan University, P.O. Box. 114, Jazan, 45142, Saudi Arabia

E-mail: j.hakami@jazanu.edu.sa

ABSTRACT:

We studied systematically the directionality of emitted photons from an emitter with orthogonal polarizations in the vicinity of nanowire waveguide. Our calculations of the electromagnetic modes are based on Green's function technique which gives the exact solutions to all modes, radiation, guided, and surface plasmon modes. In such a structure, TE mode and TM mode will excite simultaneously both the scattered TE mode and the scattered TM mode. As a result of the strong transverse confinement, light emitted near an optical waveguide is captured and equally split into two modes with opposite directions of propagation. Enabling the control of the dipole spin of the emitter, it is possible to break the symmetry of the scattering photons and select only one direction with very high efficiency.

Toponomic Quantum Computation

Christian Louis Hanotel Pinzón
C. Chryssomalakos, L. Hanotel, E. Guzmán-González, E. Serrano-Ensástiga

Moscow Institute of Electronics and Mathematics HSE University, Tallinskaya ul. 34, Moscow, Russia.

khanotel@hse.ru
hanotel@ciencias.unam.mx

Abstract

Holonomic quantum computation is a formalism of quantum computation where quantum gates are generated through non-abelian geometric phases obtained from suitable chosen quantum evolutions [1].

Recently we have shown [2] that for hamiltonians producing rotations, robust quantum gates can be produced by using the topological properties of a particular class of antisymmetric quantum states, known as anticoherent planes, which generalize anticoherent spin states [3], i.e. , states whose polarization vector vanishes.

This result generalizes a special topological property of anticoherent spin states when evolving under rotations [4]. This explains the origin of the word *toponomic* to describe this topologically robust way to perform holonomic quantum computation, extending the robustness against noise already presented in all schemes of holonomic quantum computation.

In this work, after a short presentation of the above model for holonomic quantum computation, we explicitly generate CNOT and TOFFOLI quantum gates using this formulation, in a way that allows for a generalization to a broader class of quantum gates of type CC…CNOT.

We also use the Majorana stellar representation of quantum spin states to find the suitable symmetry properties to get the target quantum gate. In Fig, 1 are presented the Majorana points of four different states used to find a CNOT gate.

References

[1] P. Zanardi, M. Rassetti, Phys. Lett. A, 264 (1999) 94-99
[2] C. Chryssomalakos, L. Hanotel, E. Guzmán-Gonzáles, E. Serrano-Ensástiga, Mod. Phys. Lett. A, 37 (2022) 2250184
[3] J Zimba, EJTP, 3 (2006) 143-156
[4] P. Aguilar, C. Chryssomalakos, E. Guzmán-Gonzáles, L. Hanotel, E. Serrano- Ensástiga, J. Phys. A: Math. Theor., 53(6) (2020) 065301

Figures

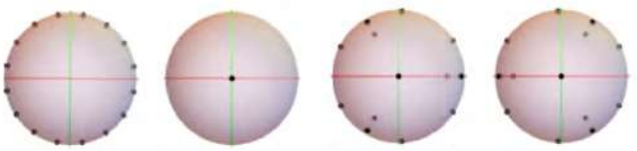


Figure 1: Geometric representation of four spin states used to the generation of topologically robust CNOT gates,

Non-destructive measurement of trapped-ion mechanical oscillators

Presenting Author : Pan-Yu Hou

Tsinghua University, Beijing, China

houpanyu@mail.tsinghua.edu.cn

Abstract

Bosonic quantum error correction (QEC) encodes quantum information in high-dimensional harmonic oscillators, providing hardware-efficient alternatives to traditional QEC approaches using two-level systems. Recent breakthroughs in cavity quantum electrodynamics systems have demonstrated bosonic QEC beyond the break-even point. While motional modes of trapped ions exhibit excellent coherent properties, their exploration of bosonic QEC has been hindered by backaction from photon recoil during state-dependent fluorescence detections. Here, we propose a scheme that enables non-destructive readout of a trapped-ion motional mode. This scheme leverages a 'protection' mode in a symmetric odd-number ion chain and high-fidelity two-mode state transfer. I will present the principle and details of this scheme, as well as the results of repetitive readout for the lowest two Fock states of a motional mode.

Figures

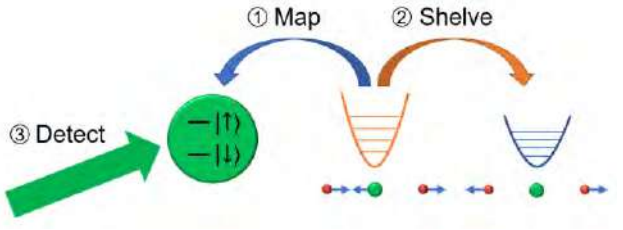


Figure 1: Diagram of a non-destructive measurement for a trapped ion motional state.

References

[1] Pan-Yu Hou, Jenny J Wu, Stephen D Erickson, Daniel C Cole, Giorgio Zarantonello, Adam D Brandt, Andrew C Wilson, Daniel H Slichter, Dietrich Leibfried arXiv:2205.14841 (2022)

Optimizing Bell Inequalities via Tensor Network Contractions in Tropical Algebra

Mengyao Hu[1]
Eloïc Vallée[1], Tim Seynnaeve[2], Patrick Emonts[1], Jordi Tura[1]

1.Instituut-Lorentz, Universiteit Leiden, 2300 RA Leiden, The Netherlands
2.Department of Computer Science, KU Leuven, 3001 Leuven, Belgium

mengyao@lorentz.leidenuniv.nl

Abstract

Bell inequalities are natural tools used as witnesses of nonlocality in composite systems. Interestingly, finding the classical bound for a given Bell inequality is in one-to-one correspondence with finding the minimal energy configuration of an associated classical spin system, which is a well-established NP-hard problem.

For Bell inequalities in one-dimensional infinite, translationally invariant (TI) systems with O(1) correlator length, we introduce how to find their corresponding tensors and establish a connection between the notions of tropical eigenvalue and the classical bound per particle as a fixed point of a tropical tensor renormalization procedure [1]. Further, we show the relation between the tropical eigenspaces of the tensor of local deterministic strategies, and their characterization as irreducible domino loops proposed in [2]. This allows us to recover their result in an elegant way, extending it to the finite number of parties case, and for the infinite case as a fixed point of a tropical tensor renormalization procedure. The procedure is also applicable to Bell inequalities with many outcomes such as CGLMP [3], and SATWAP inequalities [4] as a recursive tropical tensor network contraction. Lastly, for the multipartite scenario with any number of inputs and outputs, we show that the upper bound of the number of vertices of the projected Bell local polytope is independent of the number of parties (contrary to e.g. cases with much more symmetry, such as permutational invariance [5,6]) and we provide methods to upper bound its number of vertices.

Our study opens many questions that we leave for future work. In particular, the relation between the tropical eigenspaces of the tensor of local deterministic strategies and the facet structure of the TI local polytope. Also, the study of multipartite nonlocality in systems with e.g. hyperbolic or fractal geometries, which can arise in the context of symmetry-protected topological order [7]. On the numerical side, index slicing and heuristic tensor network contraction orders can improve overall efficiency. The formalism here introduced captures the algorithms based on dynamic programming used for approximating the global optimum of highly nonconvex functions.

References

[1] Hu, M., & Tura, J. arXiv preprint arXiv:2208.02798. (2022).
[2] Wang, Z., Singh, S., & Navascués, M. Physical Review Letters, 118(23), 230401. (2017).
[3] Collins, D., Gisin, N., Linden, N., Massar, S., & Popescu, S. (2002). Physical review letters, 88(4), 040404. (2002).
[4] Salavrakos, A., Augusiak, R., Tura, J., Wittek, P., Acín, A., & Pironio, S. Physical review letters, 119(4), 040402. (2017).
[5] Tura, J., Augusiak, R., Sainz, A. B., Vértesi, T., Lewenstein, M., & Acín, A. Science, 344(6189), 1256-1258. (2014).
[6] Tura, J., Augusiak, R., Sainz, A. B., Lücke, B., Klempt, C., Lewenstein, M., & Acín, A. Annals of Physics, 362, 370-423. (2015).
[7] Stephen, D. T. Doctoral dissertation, Technische Universität München. (2021).

Exploring Quantum Property-Data Correlations in Metal Organic Frameworks using Unsupervised Learning

Pedro Henrique Sophia [1,2*] Felipe Crasto de Lima [2] Adalberto Fazzio [2] Stephan Roche [1,3]
José Hugo Garcia [1]

[1] *ICN2, UAB Campus, 08193, Barcelona, Spain.*
[2] *ILUM, Rua Lauro Vannucci, 1020, Campinas, São Paulo, Brazil.*
[3] ICREA — Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain
*pedro220045@ilum.cnpem.br

In this study, we explore the correlations between quantum properties and experimental data of Metal Organic Frameworks (MOFs) through the analysis of the QMOF database. To reveal these connections, we utilize unsupervised learning techniques, offering valuable insights for researchers engaged in the synthesis of MOFs. The methodology is based on clustering techniques to identify emerging patterns in the quantum properties of MOFs. Furthermore, exploring feature combinations through brute force testing expands our understanding of the complex relationships between properties and behaviour of MOFs. The primary contribution of this study lies in the systematic exploration of feature combinations. Here, the clusterization of the MOFs will unveil a classification of electronic/structural characteristics between different MOFs. The potential practical impact of the project lies in the future creation of algorithms based on the results obtained, which could assist experimental researchers in defining more efficient routes for the synthesis of MOFs with desired characteristics, significantly reducing dependence on empirical methods.

References

[1] Rosen, A.S., Fung, V., Huck, P., *et al. npj Comput Mater* **8**, 112 (2022).
[2] Andrew S. Rosen, Shaelyn M. Iyer, *et al.* Matter **4**, 5 (2021) 1578-1597

Figures

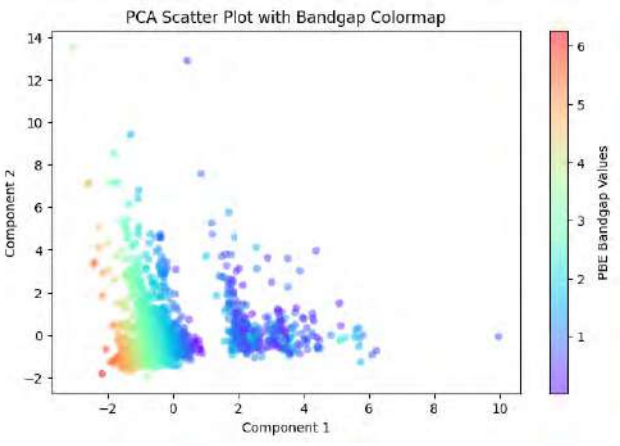


Figure 2: Clusters identified through PCA and K-means analysis, color-coded by bandgap values, offering insight into the data patterns

Photonically Connected Nuclear Spin Microprocessors

Donika Imeri
Timo Eikelmann, Mara Brinkmann, Konstantin Beck, Rikhav Shah, Ralf Riedinger

Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany
The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

dimeri@physnet.uni-hamburg.de

Silicon Vacancy (SiV) color centers in diamond show potential for improving quantum communication systems. SiVs exhibit atom-like optical transitions, enabling high-fidelity interfaces between photons and a long-lived electron spin. The inversion symmetry of the SiV protects its optical transition from electrical noise, allowing integration into nanophotonic cavity QED structures. However, SiV color centers require operation at low temperatures and high radiofrequency fields to manipulate the nuclear spins.

In this work, we present a platform that integrates nuclear magnetic resonance coils with nanophotonic structures designed to operate at millikelvin temperatures, thereby facilitating advances in quantum networks using SiV-based systems.

References

[1] C. T. Nguyen et al., “Quantum Network Nodes Based on Diamond Qubits with an Efficient Nanophotonic Interface “. Phys. Rev. Lett. 123, 183602 (2019).
[2] M.K. Bhaskar et al., “Experimental demonstration of memory-enhanced quantum communication”. Nature 580, 60–64 (2020).
[3] P.-J. Stas et al., “Robust multi-qubit quantum network node with integrated error detection” Science 378, 557 (2022).

Induced supercurrent in the intrinsic magnetic topological insulator $MnBi_2Te_4$

Thies Jansen
Ekaterina Kochetkova[2,3]
Anna Isaeva,[2,3]
Alexander Brinkman[1]
Chuan Li[1]

[1]*MESA+ institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands*
[2]*Institute of Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam*
[3]*Leibniz IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany*

t.jansen@utwente.nl

Topological superconductors hosting chiral Majorana zero modes are of great interest for both fundamental physics and potential quantum computing applications. The recent discovery of the intrinsic magnetic topological insulator $MnBi_2Te_4$ (MBT) [1,2] offers a new material platform that host chiral topological states. In this work, we investigate the transport properties of an MBT Josephson junction and explore their superconducting properties. MBT Josephson junction have been fabricated before, but no supercurrent was observed [3]. We do observe an onset of supercurrent and a clear Josephson coupling through RF measurements. The sensitive nature of superconducting interference, allows us to study the interference patterns in the superconducting junctions revealing interesting asymmetries, suggesting changes in the magnetic ordering of the MBT flakes under small applied magnetic fields. Although we observe a supercurrent, doping effects from the Nb leads hinder the manifestation of chiral Majorana edge modes. Our findings shed light on the interplay between superconductivity and topology in MBT flakes and provide insights into the challenges of inducing topological superconductivity in these systems.

References

[1] Deng Y, Yu Y, Shi MZ, Guo Z, Xu Z, Wang J, Chen XH, Zhang Y. Science, Vol 367, 6480 (2020)

[2] Liu C, Wang Y, Li H, Wu Y, Li Y, Li J, He K, Xu Y, Zhang J, Wang Y. *Nat. Mater.* 19, 522–527 (2020)

[3] Wen-Zheng Xu, Chun-Guang Chu, Zhen-Cun Pan, Jing-Jing Chen, An-Qi Wang, Zhen-Bing Tan, Peng-Fei Zhu, Xing-Guo Ye, Da-Peng Yu, and Zhi-Min Liao, Phys. Rev. B 105, 184515 – May 2022

Figures

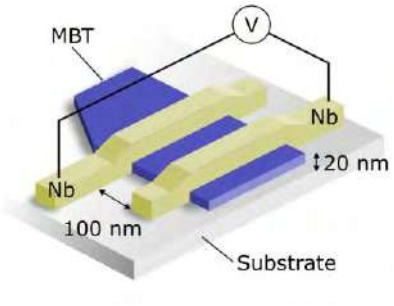


Figure 1: Schematic of the device

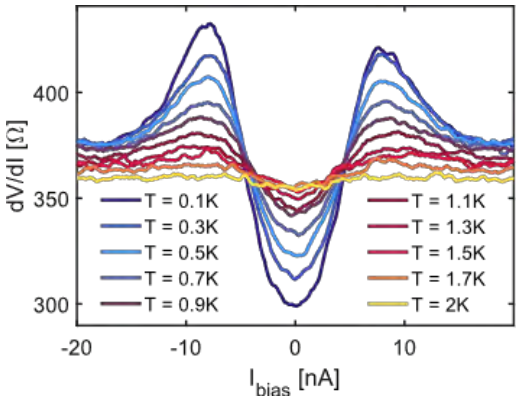


Figure 2: Differential resistance as function of bias current for different temperatures. An onset of supercurrent is observed.

Quantum-enhanced joint estimation of phase and phase diffusion

Jayanth Jayakumar
Monika E. Mycroft, Marco Barbieri, and Magdalena Stobińska

Faculty of Physics, University of Warsaw, ul. Pasteura 5, 02-093 Warszawa, Poland

jay2nth@gmail.com

Accurate phase estimation in the presence of unknown phase diffusive noise is a crucial yet challenging task in noisy quantum metrology. This problem is particularly interesting due to the detrimental impact of the associated noise [1]. In our work, we numerically investigate the joint estimation of phase and phase diffusion using generalized Holland-Burnett (gHB) states [3]. We adopt a twofold approach by analyzing the joint information extraction through double homodyne measurement [2] and the joint information availability across all probe states. Through our analysis, we find that the highest sensitivities are obtained by using states created by directing all input photons into one port of a balanced beam splitter. Furthermore, we infer that good levels of sensitivity persist even in the presence of moderate photon losses, demonstrating both the metrological resourcefulness and experimental feasibility of our probe states.

References

[1] M. G. Genoni, S. Olivares, and M. G. A. Paris, Phys. Rev. Lett 106, 153603 (2011).

[2] M. D. Vidrighin, G. Donati, M. G. Genoni, X.-M. Jin, W. S. Kolthammer, M. Kim, A. Datta, M. Barbieri, and I. A. Walmsley, Nature communications 5, 3532 (2014).

[3] G. S. Thekkadath, M. E. Mycroft, et al., NPJ quantum information **6**, 89 (2020).

Figures

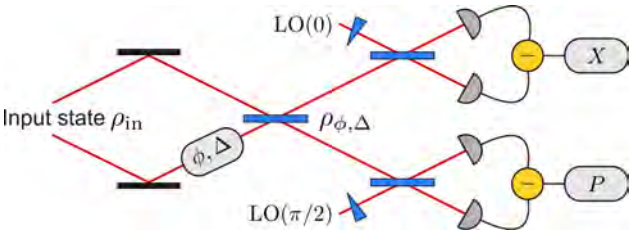


Figure 1: The theoretical scheme for the joint estimation of phase **ϕ** and phase diffusion **Δ** involves a Mach-Zehnder interferometer followed by double homodyne detection.

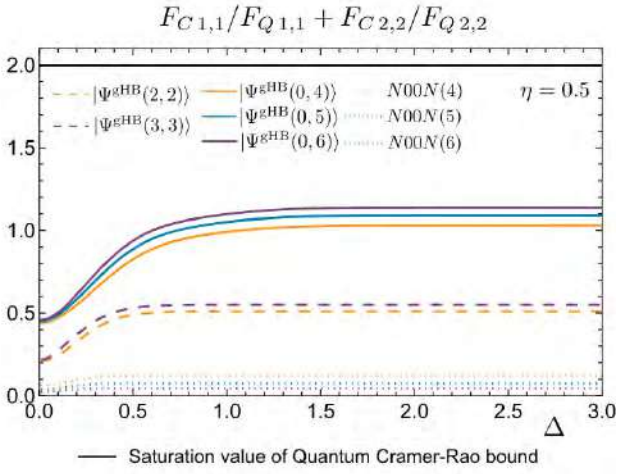


Figure 2: The double homodyne measurement extracts the highest amount of joint information from the family of probe states: $|\Psi^{gHB}(0,N)\rangle$ (N = 4, 5, 6) when compared to HB and N00N states. Note that 50% photon losses (**η** = 0.5) are accounted for, and the joint information extraction is quantified by the sum of the ratios of diagonal elements of classical and quantum Fisher information matrices: $F_{C\,(Q)\,i,i}$.

Static and Dynamic Properties of a 2D Superconductor Investigated by NV Center SPM

Sreehari Jayaram[1]
Malik Lenger[1], Ruoming Peng[1], Dong Zhao[2], Jurgen Smet[2], Jörg Wrachtrup[1]

[1]3rd Institute of Physics, University of Stuttgart, [2]Allmandring 13, Stuttgart 70569, Germany

Max-Planck-Institute for Solid State Research, Heisenbergstrasse 1, Stuttgart, 70569, Germany

s.jayaram@pi3.uni-stuttgart.de

Visualization of nanoscale dynamics in superconducting materials provides a pathway to unravel the pairing mechanisms of interacting electrons [1]. Here, we have employed the state-of-the-art scanning NV probe [2] technique to explore the local magnetic response of the 2D superconductor, 2H-$NbSe_2$, in which we demonstrate full dynamic sensing of vortices with high sensitivity and spatial resolution (fig. 1). Utilizing this quantum probe, we present the first spatio-temporal dynamics of vortices in a 10 nm thin exfoliated 2H-$NbSe_2$, where the arrangement of the vortices shows a strong correlation with the geometric confinement (fig. 2). Notably, we have observed the melting of vortex solids near critical temperature allowing the re-arrangement of the vortices that is governed by the cooling rate. Additionally, our study delves into the dynamics of vortex cores, superconducting-insulator edge dynamics, and phase transitions, all unveiled through spatio-temporal noise spectroscopy with the NV probe.

References

[1] Chatterjee, S. et al., Phys. Rev. Research, 4, (2022), L012001
[2] Casola, F., van der Sar, T. & Yacoby, A., Nat Rev Mater, 3, (2018), 17088

Figures

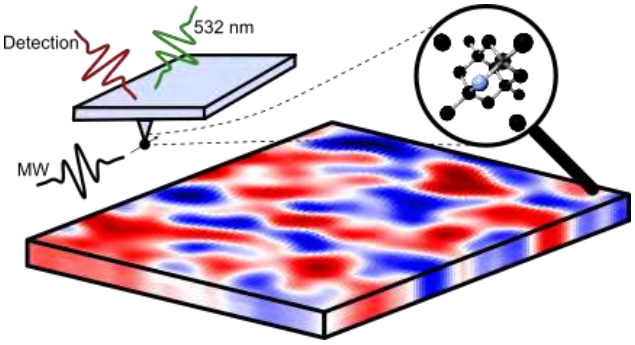


Figure 1: Illustration of the 2D superconductor and NV SPM system. A monolithic diamond probe is brought near a magnetic sample. The single NV center at the apex of the probe is interrogated using various optical and MW pulses to read out the Zeeman shifted spin state

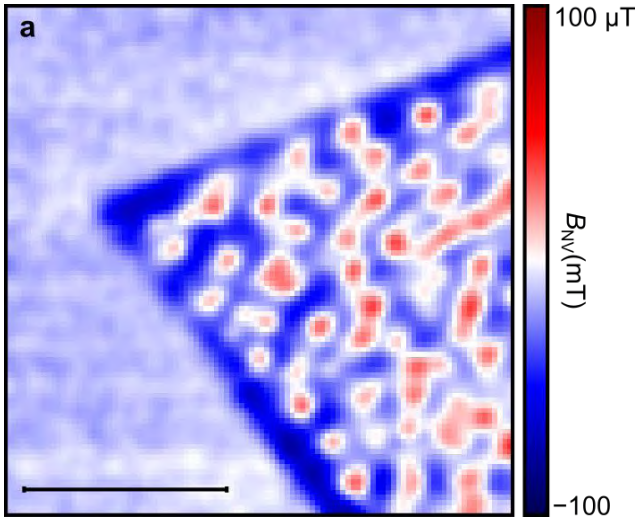


Figure 2: Magnetometry of a 2H-$NbSe_2$ flake showing a weakly ordered vortex arrangement with strong geometric confinement effects. Scan performed at 2.5 K and 6 mT field applied out of plane. Scale bar is 4 µm.

Ultra-robust topologically protected edge states in quasi-1D systems

Valerii Kachin
J. C. López Carreño, and Magdalena Stobińska

Institute of Informatics, Faculty of Mathematics, Informatics and Mechanics, University of Warsaw, Banacha 2, 02–097 Warsaw, Poland

v.kachin@uw.edu.pl

Abstract

Topological materials yield robust edge states with potential applications in electronics or quantum technologies[1,2]. Yet, their simplest Su--Schrieffer--Heeger model covers only coupling disorders, leaving other types uncovered. Here, by studying a quasi-one-dimensional zigzag model with negative couplings, we show non-chiral edge states, which remain well localized in the simultaneous presence of dissipation and disorders in short- and long-range interactions, as well as in on-site energies, whose strengths are comparable with interactions in the system. To this end, we derive regularized values of the topological invariant via a novel approach. Our work hints on constructing topological phases even in the absence of usual symmetries.

References

[1] Z. Yue, M. Topological insulator materials for advanced optoelectronic devices. Advanced Topological Insulators. pp. 45-70 (2019)

[2] Xue, H., Yang, Y. & Zhang, B. Topological Valley Photonics: Physics and Device Applications. Adv. Photonics Res.. 2, 2100013 (2021)

Figures

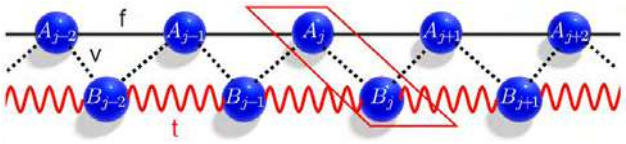


Figure 1: Quasi-1D zigzag structure with interacting chains *A* and *B* connected by strength $v > 0$ (dashed line). The coupling strengths between the sites within chain *A* is $f > 0$ (black line), while within *B* is $t < 0$ (red line). An elementary two-site unit cell is shown as a red frame.

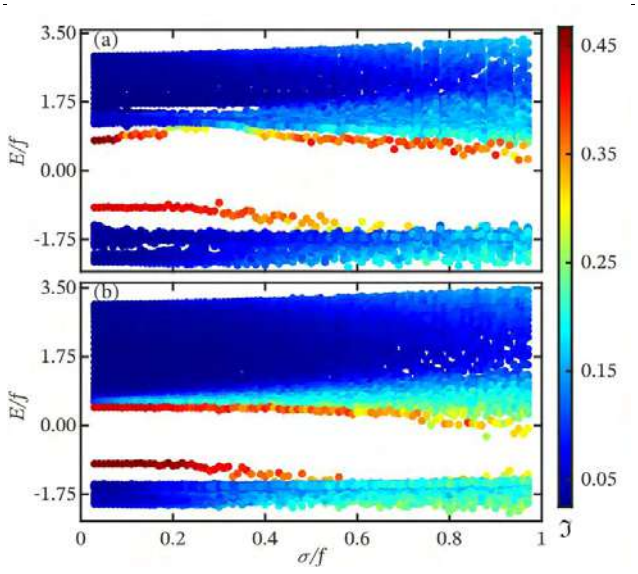


Figure 2: Our main result: robust topologically protected edge states in a zigzag system affected simultaneously by losses and disorders in next-neighbor and long-range interactions, and on-site energies; all quantified with strength σ. Remarkably, the edge states remain well localized for the disorders and losses comparable with the system interaction strength, $\sigma/f \leq 0.3$. The plot is computed for a chain of $N=60$ sites, $v/f=1$, (a) $t/f=-0.7$, (b) $t/f=-0.3$.

Coherent control of Tin-Vacancy centers in diamond using superconducting waveguides at 50 mK

Ioannis Karapatzakis[1]
Jeremias Resch[1], Marcel Schrodin[1], Philipp Fuchs[3], Michael Kieschnick[4], Jan Meijer[4], Christoph Becher[3], David Hunger[1,2], Wolfgang Wernsdorfer[1,2]

[1]*Physikalisches Institut, Karlsruhe Institute of Technology, Karlsruhe, Germany*
[2]*Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany*
[3]*Department of Physics, Saarland University, Saarbrücken, Germany*
[4]*Felix-Bloch-Institute for Solid State Physics, University of Leipzig, Leipzig, Germany*

ioannis.karapatzakis@kit.edu

Robust quantum networks require an interface between photons and long-lived spin degrees of freedom. Group-IV color centers exhibit an inversion symmetry protecting them from surface charge noise. For high fidelity control, the use of microwave fields is required. However, the magnetic transitions are heavily suppressed in unstrained emitters. This limitation can be overcome by inducing strain and precisely aligning the DC magnetic field orientation. Recent work has shown the manipulation of the electron spin using aluminum wire bonds [1] and on-chip gold waveguides [2]. Both methods suffer from Ohmic losses in the microwave line, restricting coherence through heat induction. To overcome this challenge, we fabricate a superconducting coplanar waveguide on a diamond membrane and strain is induced by specific sample mounting. We demonstrate high fidelity coherent manipulation of the electron spin at 50 mK temperature and further determine pure dephasing times by Ramsey interferometry and spin coherence times by Hahn-Echo measurements under varying magnetic fields. Spin coherence is extended by three orders of magnitude by using standard dynamical decoupling sequences.

References

[1] Rosenthal et al., Phys. Rev. X, 13 (2023), 031022
[2] Guo et al., Phys. Rev. X, 13 (2023), 041037

Figures

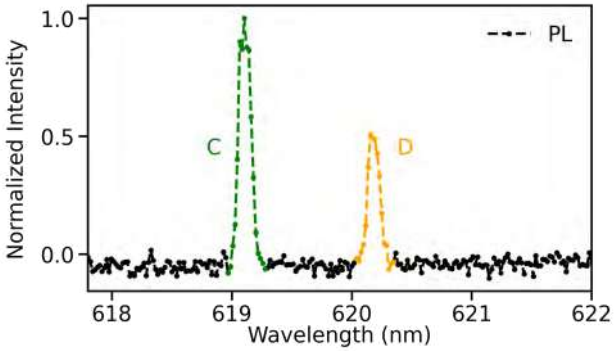


Figure 1: Photoluminescence spectrum of an unstrained Tin-Vacancy center.

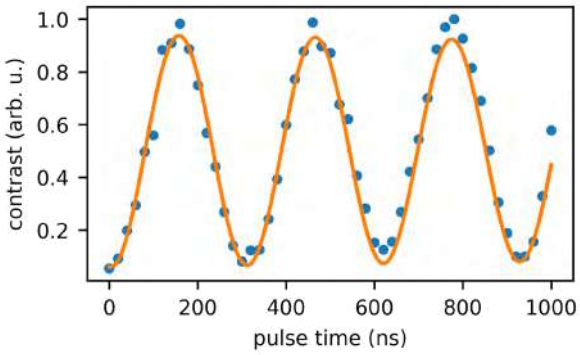


Figure 2: Coherent Rabi oscillations using microwave control pulses.

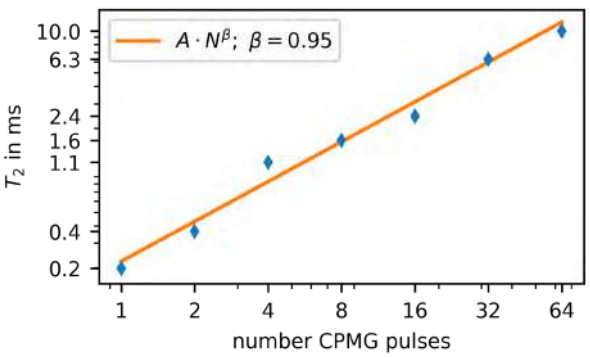


Figure 3: Scaling of the coherence time with increasing number of CPMG pulses.

Self-heating effects and switching dynamics in graphene multiterminal Josephson junctions

Máté Kedves
Tamás Pápai, Gergő Fülöp, Kenji Watanabe, Takashi Taniguchi, Péter Makk, Szabolcs Csonka

Budapest University of Technology and Economics, 1111, Műegyetem rakpart 3, Budapest, Hungary

kedvesm@edu.bme.hu

Multiterminal Josephson junctions (MTJJs) consisting of a single scattering region connected to multiple superconducting terminals were shown to exhibit non-trivial topology and simulate the band structure of Weyl semimetals [1]. Furthermore, recent experimental advances led to the observation of hybridized ABSs [2], signatures of quartet supercurrents [3,4], the Josephson diode effect [5] and topological phase transitions [6].
We experimentally investigate the electronic transport properties of a three-terminal graphene Josephson junction. We find that self-heating effects strongly influence the behaviour of this MTJJ system. We show that existing simulation methods based on resistively and capacitively shunted Josephson junction networks can be significantly improved by considering these heating effects. We also investigate the phase dynamics in our MTJJ by measuring its switching current distribution and find correlated switching events in different junctions. We show that the switching dynamics is governed by phase diffusion at low temperatures. Furthermore, we find that self-heating introduces additional damping which results in overdamped I-V characteristics when normal and supercurrents coexist in the device.

References

[1] R-P. Riwar et al. Nat. Comm. 7, 11167 (2016)
[2] M. Coraiola, et al., Nat. Comm. 14, 6784 (2023)
[3] A. H. Pfeffer, et al., Phys. Rev. B 90, 075401 (2014).
[4] E. G. Arnault, et al., Nano Letters 22, 7073 (2022)
[5] J. Chiles, et al., Nano Letters 23, 5257 (2023)
[6] E. Strambini, et al., Nature Nanotechnology 11, 1055 (2016)

Figures

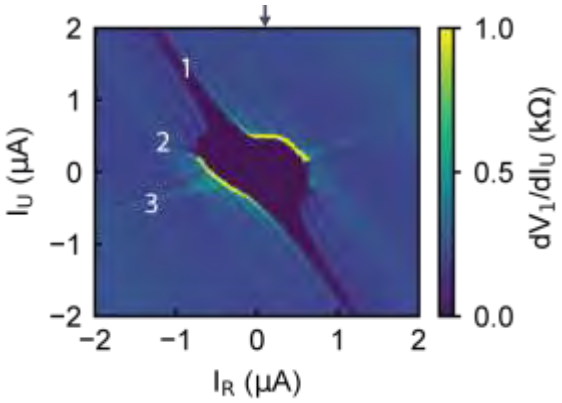


Figure 1: Measured differential resistance map of the 3-terminal Josephson junction.

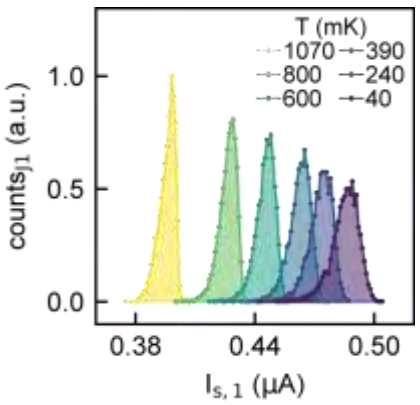


Figure 2: Switching current distribution of the 3-terminal Josephson junction as a function of bath temperature.

Probing charge neutrality in InAs/GaSb coupled quantum wells

Megan E. Kelly
Abhirami Saminathan, Mark C. Rosamond, Thomas A. Moore, Lianhe H. Li, Edmund H. Linfield, Christopher H. Marrows

University of Leeds, Leeds, United Kingdom

py17mk@leeds.ac.uk

Abstract

The quantum spin Hall effect (QSHE) defines a two-dimensional topological insulating state [1,2]. The characteristic spin-momentum locked helical edge states offer potential for novel spintronic devices. Evidence for the QSHE in coupled InAs/GaSb quantum wells (QWs), a III-V semiconductor grown by conventional molecular beam epitaxy methods, has been demonstrated [3,4]. Here, we report the fabrication and transport characteristics of dual gated InAs/GaSb QW devices, where electron and hole populations have been tuned to charge neutrality (a necessary condition for the QSHE to manifest itself). Fig. 1 shows an example, where the sheet resistance peak accompanied by a change in sign of the Hall coefficient indicates a crossing of the charge-neutral point. This may correspond to the topologically non-trivial insulating band gap of the QSHE.
Fig. 2 shows further gate voltage sweeps at varying B-fields, with integer QH features highlighted, again converging at the charge-neutral point.

References

[1] Kane et al., PRL, 95 (2005) 226801
[2] Bernevig et al., PRL, 96 (2006) 106802
[3] Knez et al., PRL, 107 (2011) 136603
[4] Knez et al., PRL, 112 (2014) 026602

Figures

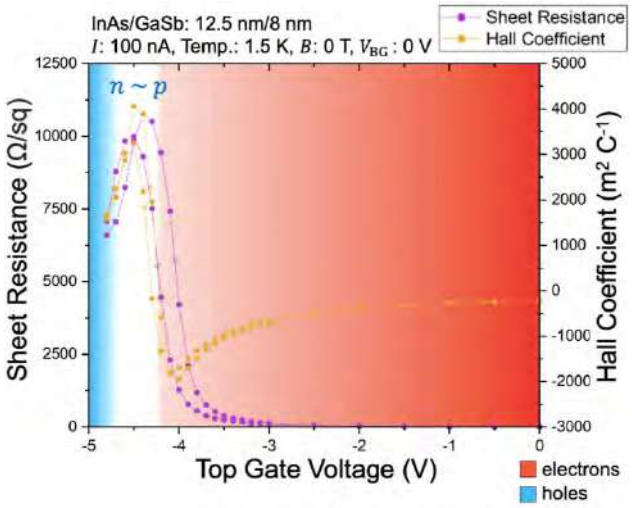


Figure 1: Sheet resistance and Hall coefficient with varying top gate voltage. The carrier dominance is switched from electrons to holes, with a charge neutrality resistance peak consistent with a change-of-sign of the Hall coefficient.

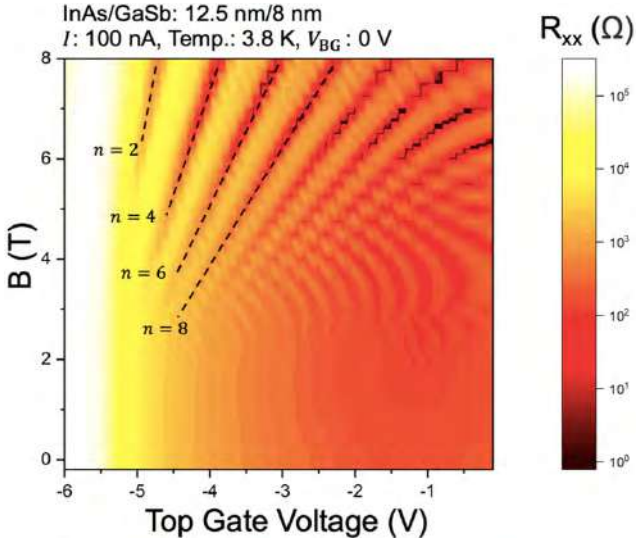


Figure 2: Sheet resistance response to -6 to 0 V top gate voltage sweep, at various B-field values. The ridges of resistance minima correspond to the Landau level filling factors, as determined from the Hall resistance.

Two room-temperature superconductivity claims in 2023: Separating fact from fiction

Sun-Woo Kim

Department of Materials Science and Metallurgy, University of Cambridge, UK

swk38@cam.ac.uk

In 2023, two experimental claims of room-temperature superconductivity shocked the world. The first claimed to show near-ambient superconductivity in lutetium-hydride compounds coinciding with drastic colour changes of the samples from blue to pink to red [1]. We present a full microscopic theory of colour in lutetium hydride, revealing that hydrogen-deficient LuH_2 is the only phase which exhibits colour changes under pressure consistent with experimental reports, with a sequence blue-violet-pink-red-orange (Fig. 1) [2]. In addition, we find *no* phonon-mediated superconductivity near room temperature in the claimed pink phase.

The second claim concerns "LK99" [3], a copper-doped lead apatite compound which has motivated numerous contradictory theoretical reports. Puzzlingly, previous theoretical works claimed that experimentally reported structures of both the parent and copper-doped lead apatite are dynamically unstable. By pioneering the inclusion of anharmonic phonon-phonon interactions, we show that both compounds are dynamically stable at room temperature, consistent with the experimental reports (Fig. 2**a**) [4]. We resolve all existing inconsistencies about the dynamical stability of the LK99 compound by clarifying the role of volume and electronic correlation strength. Furthermore, we demonstrate it is *not* a superconductor but instead a strongly correlated Mott insulator whose phenomenology differs from that of d^9 cuprate superconductors by performing comprehensive DFT+DMFT calculations in Hubbard U-J parameter spaces (Fig. 2**b**) [5].

References

[1] N. Dasenbrock-Gammon *et al.*, Nature **615**, 244 (2023)
[2] S.-W. Kim *et al.*, Nature Communications **14**, 7360 (2023)
[3] S. Lee *et al.*, arXiv:2307.12037 (2023)
[4] S.-W. Kim *et al.*, npj Computational Materials **10**, 16 (2024)
[5] S.-W. Kim *et al.*, in preparation

Figures

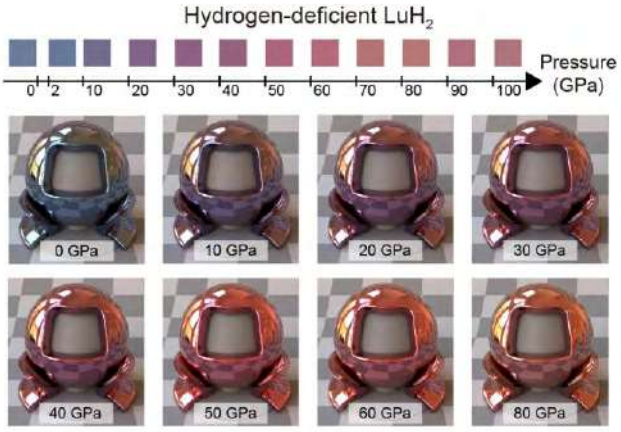


Figure 1: Colour and photorealistic rendering of hydrogen-deficient LuH_2 as a function of pressure.

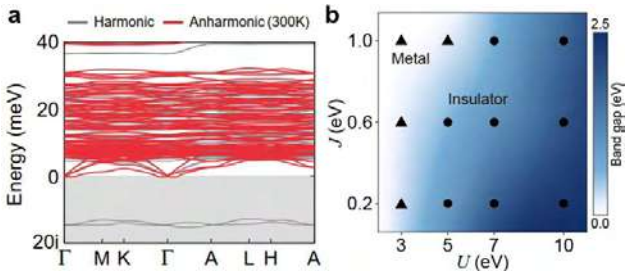


Figure 2: (a) Harmonic and anharmonic phonon dispersions and **(b)** Hubbard U-J phase diagram of the LK99 compound.

Acknowledgements

The following collaborators have contributed to some or all of theses works: Kang Wang, Siyu Chen, Lewis J. Conway, Ion Errea, G. Lucian Pascut, Kristjan Haule, Chris J. Pickard, and Bartomeu Monserrat.

Quantum Spin Hall States and Topological Phase Transition in Germanene

Dennis J. Klaassen[1]
Carolien Castenmiller[1], Jelle van Mil[1], Yichen Liu[2], Cheng-Cheng Liu[2], Yugui Yao[2], Motohiko Ezawa[3], Alexander N. Rudenko[4], Harold J.W. Zandvliet[1] and Pantelis Bampoulis[1]

[1]*University of Twente, The Netherlands*
[2]*Beijing Institute of Technology, China*
[3]*University of Tokyo, Japan*
[4]*Radboud University Nijmegen, The Netherlands*

d.j.klaassen@utwente.nl

We provide experimental evidence of a topological phase transition in the monoelemental quantum spin Hall insulator, germanene. Low low-buckled epitaxial germanene on buffer-layer/Ge_2Pt is a quantum spin Hall insulator with a large bulk gap and robust metallic edges. The topological edge states have distinct dispersion characteristics depending on their termination. Particularly, we observe a pronounced variance in Fermi velocity, with armchair edges exhibiting a velocity higher than zigzag edges by about an order of magnitude. Moreover, we demonstrate that the application of a critical perpendicular electric field closes the topological gap and makes germanene a Dirac semimetal. Increasing the electric field further results in the opening of a trivial gap and the disappearance of the metallic edge states. This electric field-induced switching of the topological state and the sizable gap make germanene suitable for room-temperature topological field-effect transistors, which could revolutionize low-energy electronics.

References

[1] P. Bampoulis et al. Phys. Rev. Lett. 130, 196401 (2023)
[2] H.J.W. Zandvliet, D.J. Klaassen, P. Bampoulis. Phys. Rev. B. *accepted* DOI: 10.1103/PhysRevB.00.005400
[3] B. Weber et al. J. Phys. Mater. 7, 022501 (2024)

Figures

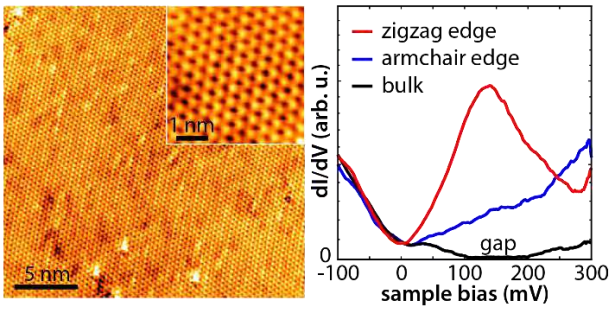


Figure 1: Left: STM image of the hexagonal buckled lattice of germanene, the inset is a zoomed-in image [1]. Right: dI(V)/dV curves taken at a zigzag terminated edge, an armchair terminated edge, and of the bulk [2].

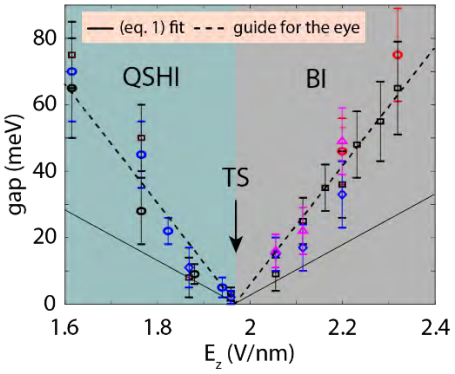


Figure 2: Bandgap size as a function of the electric field. The material transitions from a QSH insulator to a topological semimetal (TS) and finally to a trivial band insulator (BI). Markers indicate the results of multiple experiments [1].

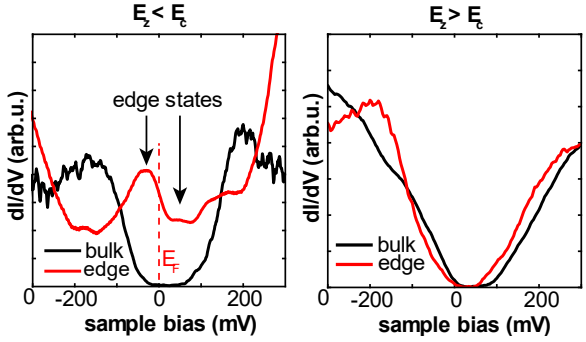


Figure 3: dI(V)/dV taken at low E-field in the QSH insulator state (left), and taken at high E-field in the band insulator state (right) [1].

Nanosecond switching of gate controlled supercurrent in an Al/InAs nanowire

Mátyás Kocsis
Lőrinc Kupás, Zoltán Scherübl, Gerg Fülöp, Péter Makk, Szabolcs Csonka.

Department of Physics, Institute of Physics, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest, Hungary)

matyaskocsis@edu.bme.hu

Figure 1: SEM image of the gated superconducting device.

Gate controlled supercurrent (GCS) has recently attracted much attnetion[1][2][3], as it is essential for many potential electronic applications, such as superconducting switches, and even logic gates. We show that by embedding the superconductor to be gated in an appropriate circuit, we can induce the supra to normal switching within nanoseconds using a gate electrode. We modell the whole circuit to demonstrate how displacement currents contribute to the fast switching, and show experimental evidence of such displacement currents in our sample.

References

[1] J. Basset, *et. al.* "Gate-assisted phase fluctuations in all-metallic Josephson junctions". Phys. Rev. Res. 3 (2021)
[2] T. Elalaily *et. al.* "Signatures of Gate-Driven Out-of-Equilibrium Superconductivity in Ta/InAs Nanowires". ACS Nano 17.6 (2023)
[3] T. Elalaily *et. al.* "Gate-Controlled Supercurrent in Epitaxial Al/InAs Nanowires". Nano Letters 21.22 (2021)

Figures

2K, 300mm Wafer Level Characterization of Josephson Junctions for Transmon Qubits

Nikola David Komerički (Fraunhofer IAF)
Anton Potocnik (imec)
Massimo Mongillo (imec)
Joonas Govenius (VTT)
Mika Prunnila (VTT)
Juha Hassel (IQM)
Rüdiger Quay (Fraunhofer IAF)

Fraunhofer Institute for Applied Solid State Physics (IAF), Tullastraße 72, 79108 Freiburg im Breisgau,Germany

nikola.komericki@iaf.fraunhofer.de

Abstract
Transmon qubits are the leading physical qubit realisation in terms of generalist quantum computers. The essential component of the Transmon qubit circuit is the Josephson junction. This talk will present the first cryo-statistical 2K characterization of Josephson junctions at full 300mm wafer level. Analysing the quality and homogeneity of Josephson junctions (different sizes) on the whole wafer to address their optimisation and provide a selection basis for Transmon qubits. The Josephson junctions are fabricated in an industrial silicon-based process.

Figures

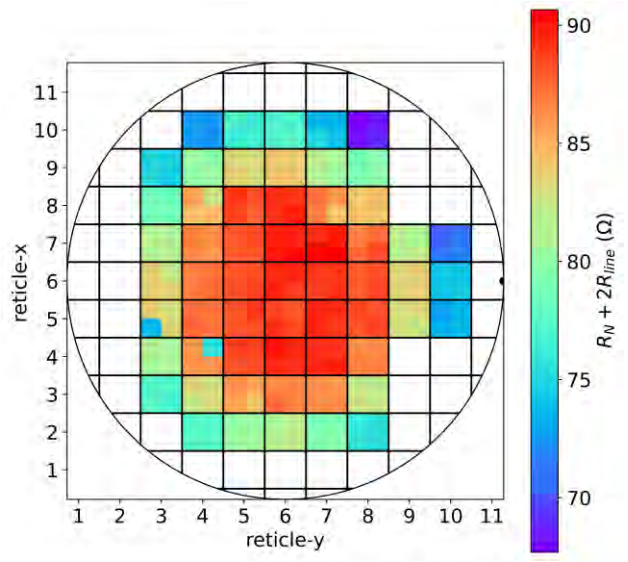


Figure 1: Wafer map of the normal state resistance R_N of a 2 µm square Josephson junction, 232 in total over a 300mm wafer obtained at 2K from I-V 2-point measurements.

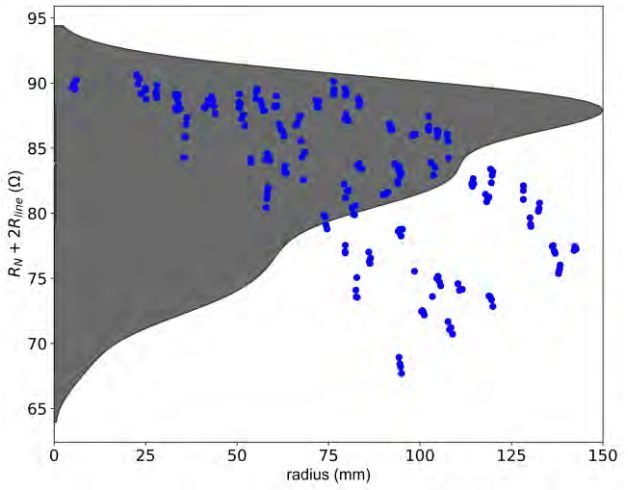


Figure 2: Normal state resistance R_N of a 2 µm square Josephson junction with kernel density estimation applied over the wafer radius, 232 in total obtained at 2K from I-V 2-point measurements.

Coherent control of a few-channel hole type gatemon qubit*

Artem Kononov[1]
Han Zheng[1], Luk Yi Cheung[1], Nikunj Sangwan[1], Roy Haller[1], Joost Ridderbos[2], Carlo Ciaccia[1], Jann Hinnerk Ungerer[1], Ang Li[3], Erik P.A.M. Bakkers[3], Andreas Baumgartner[1,4], Christian Schönenberger[1,4]

[1] *Department of Physics, University of Basel, Basel, Switzerland*
[2] *MESA+ Institute for Nanotechnology University of Twente, Netherlands*
[3] *Department of Applied Physics, Eindhoven University of Technology, Netherlands*
[4] *Swiss Nanoscience Institute, University of Basel, Basel, Switzerland*

artem.kononov@unibas.ch

Gatemons are the electrically tunable cousins of superconducting transmon qubits, in which the metallic Josephson junction is replaced by a gate-tunable superconducting weak link [1,2]. This allows the qubit frequency to be tuned by a gate voltage. Currently, gatemons are mostly realized in InAs platforms, relying on the unique epitaxially grown aluminum layer to provide a high-quality interface. Here, we demonstrate the full coherent control of a gatemon based on hole carriers in Ge/Si core/shell nanowires. For this purpose, we take advantage of the high-quality Josephson junctions that we obtain by simple ex-situ annealing step, in which superconducting Al penetrates into the Ge core of a nanowire from the reservoirs on both sides. We report full coherent control of the gatemon, with energy relaxation time up to ~1.3 μs, which is the longest coherence time in group IV material gatemons to date. In addition, we characterize the anharmonicity of the excitation spectrum in the device and show that the supercurrent through the nanowire junction is dominated by at most two conducting channels, with transparencies up to unity. Our results establish Ge/Si core/shell nanowires as a unique platform for novel quantum technologies, potentially also useful for other types of qubits like Andreev spin qubits [3], or for circuit QED experiments [4] with hole-carriers having a very large spin-orbit interaction.

References

[1] T.W. Larsen et al., Phys. Rev. Lett. 115 (2015) 127001.
[2] G. de Lange et al., Phys. Rev. Lett. 115 (2015) 127002.
[3] M. Hays et al., Science 373 (2021) 430.
[4] M. Mergenthaler et al., Phys. Rev. Applied 15 (2021) 064050.

*This research was supported by the Swiss National Science Foundation SNSF, Swiss Nanoscience Institute SNI, European Commission Horizon-2020 projects FET-open AndQC and TOPSQUAD.

A cavity-enhanced spin-photon interface for color centers in diamond

Kerim Köster[1]
M. Pallmann[1], A. Lauko[1], J. Heupel[2], P. Fuchs[3], M. Kieschnick[4], M. Förg[5], T. Hümmer[5], C. Popov[2], J. Meijer[4], C. Becher[3], D. Hunger[1]

[1]Karlsruher Institut für Technologie, Wolfgang-Gaede-Str. 1, 76131 Karlsruhe

[2]Universität Kassel
[3]Universität des Saarlandes
[4]Universität Leipzig
[5]Qlibri GmbH

kerim.koester@kit.edu

Building a long-distance quantum network is one of the big challenges in the field of quantum communication, which requires the development of a quantum repeater. A crucial component of this device is an efficient, coherent spin photon interface. Coupling color centers in diamond to a microcavity shows promise as a viable approach.
In our experiments, we integrate diamond membranes into open access fiber-based Fabry-Perot microcavities to attain emission enhancement into a single well-collectable mode [1,2]. We present our fully tunable, cryogenic cavity platform operating either in a dilution or closed-cycle cryostat where we achieve a picometer mechanical stability [3]. By utilising this versatile platform, we show Purcell-enhanced fluorescence of an ensemble of nitrogen vacancy (NV) centers [4] as well as first results from a single tin vacancy (SnV) coupled to a cryogenic cavity.

References

[1] D. Hunger et al.
AIP Advances **2** (2019) *012119*
[2] D. Hunger et al.
NJP **12** (2010) *065038*
[3] M. Pallmann, T. Eichhorn et al.
APL Photonics **8** (2023) *046107*
[4] M. Pallmann, K. Köster et al.
arXiv:2311.12723 (2023)
[5] J. Heupel et al.
Micromachines **11** (2020) 1080

Figures

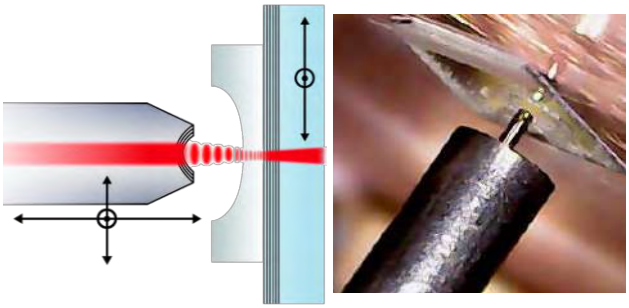


Figure 1: A fully tunable fiber-based Fabry-Perot microcavity. The diamond membrane is integrated via a van der Waals-Bond [5].

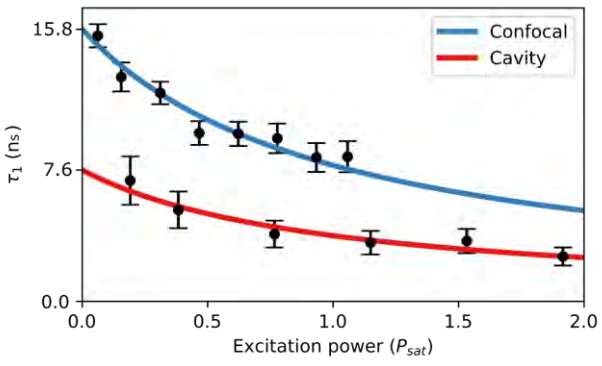


Figure 2: Purcell-enhancement of an ensemble of NV centers apparent as a lifetime shortening. The lifetime was extracted from the antibunching time constant of a power-dependent set of $g^{(2)}$ measurements.

Magnetization Signature of Topological Surface States in a Nonsymmorphic Superconductor

Wenjun Kuang
G. Lopez-Polin, H. Lee, N. Walet, A. Principi, I. V. Grigorieva, Zhenyu Wang, Fufang Xu

University of Manchester, Manchester, UK
Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland
National Innovation Institute of Defense Technology, Beijing, China
Instituto de Ciencia de Materiales de Madrid (ICMM), Madrid, Spain
Hefei National Laboratory, Hefei, China
wenjun.kuang@outlook.com

Abstract

We report a highly anomalous behavior of surface superconductivity in topologically nontrivial 3D superconductor In_2Bi, where the surface states result from its nontrivial band structure, itself a consequence of the non-symmorphic crystal symmetry and strong spin–orbit coupling. In contrast to smoothly decreasing diamagnetic susceptibility above the bulk critical field, H_{c2}, as seen in conventional superconductors, a near-perfect, Meissner-like screening of low-frequency magnetic fields well above H_{c2} is observed. The enhanced diamagnetism disappears at a new phase transition close to the critical field of surface superconductivity, H_{c3}. The anomalous screening is shown to be consistent with modification of surface superconductivity by the topological surface states. The possibility of detecting signatures of the surface states using macroscopic magnetiza-tion provides a new tool for the discovery and identification of topological superconductors..

Figures

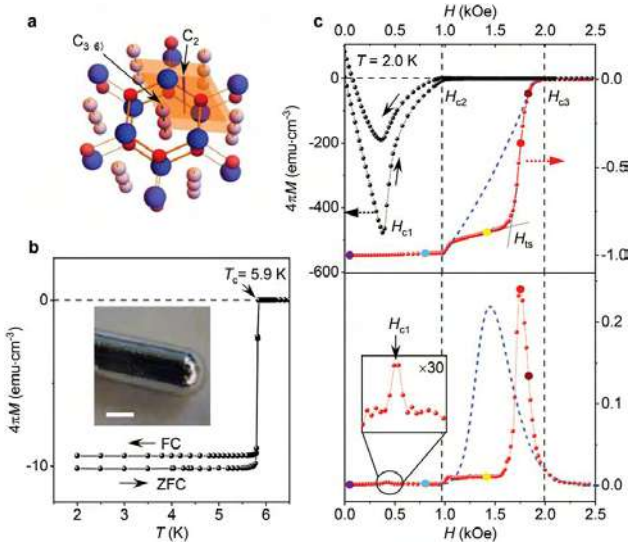


Figure 1: Anomalous AC susceptibility of In_2Bi. **a**, Schematic crystal structure of In_2Bi. Bi atoms are shown in blue and In atoms in different shades of red, to distinguish between In atoms within the hexagonal planes (dark red) and those making up In chains (light red). The shaded areas denote the unit cell containing four In and two Bi atoms. Symmetry axes are indicated by arrows. **b**, ZFC and FC magnetization as a function of T at H = 10 Oe. Inset: photo of our typical cylindrical crystal; scale bar: 1 mm. **c**, AC susceptibility measured using h_{ac} = 0.1 Oe and frequency f = 8 Hz (red curves). Black curves: DC magnetization and its hysteresis for this sample. As a reference, the blue dashed curves show the standard response expected for surface superconductivity. The inset in the lower panel shows a zoom of χ'' indicating the transition to the vortex state at H_{c1}. The vertical dashed lines indicate H_{c2} and H_{c3}, and the arrows the sweep directions.

References

[1] W. J. Kuang, *et al.*, Adv. Mater., **33** (2021) 2103257.

Hybrid Qubits in Kitaev Chains

Tobias Kuhn
Raffael Klees
Monica Benito

University of Augsburg, Universitätsstraße 1, 86159 Augsburg, Germany

tobias.kuhn@uni-a.de

The goal of this project is to investigate superconducting quantum dot arrays integrated with superconducting circuits as possible platforms for hybrid qubits. Under the appropriate magnetic fields, the effective mechanism of superconducting pairing along such arrays was predicted to be a spinless *p*-wave type, leading to the realization of a Kitaev chain with Majorana zero modes [1]. When two such chains are embedded in a transmon circuit, hybrid qubits are formed [2] that could harness the controllability of transmon qubits and the topological protection of Majorana modes. In particular, we derive an effective low-energy Hamiltonian of the minimal Kitaev model [3], study extensions to longer chains as well as embeddings into circuit QED architectures [4]. As a future goal, the ability to perform single-qubit operations will be a first step towards quantum computing in such hybrid devices [5,6].

References

[1] A. Y. Kitaev, Phys.-Usp. **44,** 10S (2001) 131
[2] D. M. Pino, R. Seoane Souto, and R. Aguado, Phys Rev. B **109,** 7 (2024) 075101
[3] M. Leijnse and K. Flensberg, Phys. Rev. B **86**, 13 (2012) 134528
[4] A. Blais, A. L. Grimsmo, S. M. Girvin, and A. Wallraff, Rev. Mod. Phys. **93**, 2 (2021) 025005
[5] A. Bargerbos et al., Phys. Rev. Lett. **131**, 9 (2023) 097001
[6] M. Geier et al., arXiv:2307.05678 (2023)

Figures

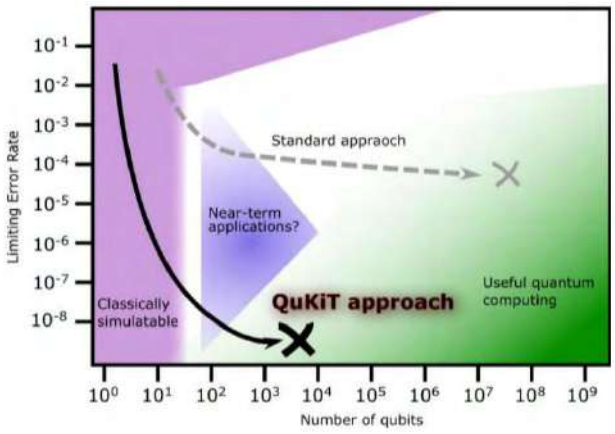


Figure 1: Roadmap for the QuKiT project to fabricate high fidelity qubits. The Kitmon qubit is expected to reduce the limiting error rate harnessing topological protection of Majorana modes while sacrificing some scalability.

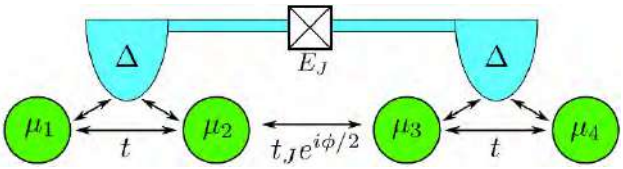


Figure 2: Proposed minimal realization of the Kitmon qubit. Two minimal Kitaev chains (green) with onsite energy μ_{1-4} coupled by a superconducting transmon circuit (cyan) with Josephson energy E_J form a local parity qubit. This device supports elastic cotunneling t, crossed Andreev reflection Δ and Josephson coupling t_J with superconducting phase difference ϕ.

Topological phase enhancement in planar Josephson junction in the long junction regime

Dibyendu Kuiri[1]
M.P. Nowak[1], P. Wojcik[2]

[1]AGH University of Krakow, Academic Centre for Materials, and Nanotechnology, al. A. Mickiewicza 30, 30-059 Krakow, Poland.

[2]AGH University of Krakow, Faculty of Physics and Applied Computer Science, al. A. Mickiewicza 30, 30-059 Krakow, Poland.

kuiri@agh.edu.pl
mpnowak@agh.edu.pl
pawel.wojcik@fis.agh.edu.pl

Planar Josephson junctions are considered promising devices for the realization of Majorana bound states (MBS) thanks to the possibility of controlling the topological transition by superconducting phase difference [1]. The topological transition occurs even at small magnetic fields, but typically the phase range with the topological superconductivity is small and cannot be probed directly when the superconducting phase difference is implied by the external magnetic flux [2]. Here, we theoretically show that the topological phase region can be significantly extended by elongating the junction, which leads to the amplification of the Zeeman effect. We point out that the decrease in the induced gap in long junctions, due to transverse modes with high momenta parallel to the superconducting interfaces that can lead to the destruction of MBS [3], can be overcome by the introduction of additional superconducting contacts that further proximitize the semiconductor region and reopen the superconducting gap. We show that in the proposed system, the topological transition can be probed by critical current measurements.

References

[1] F. Pientka, A. Keselman, E. Berg, A. Yacoby, A. Stern, and B. I. Halperin, Phys. Rev. X 7, 021032 (2017)
[2] D. Kuiri and M. P. Nowak, Phys. Rev. B 108, 205405 (2023).
[3] T. Laeven, B. Nijholt, M. Wimmer, and A. R. Akhmerov, Phys.Rev. Lett. 125, 086802 (2020).

Figures

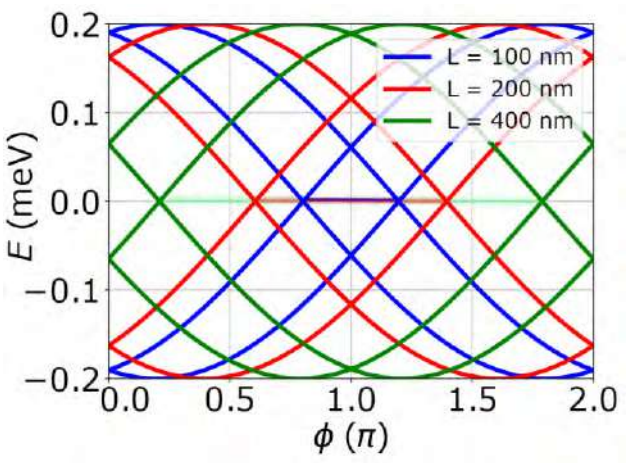


Figure 1 Schematic of an energy-phase relation of a Josephson junction. Three lines at zero energy, depicted in blue, red, and green, denote the region where Majorana bound states appear for three different junction lengths.

Quantum Phase transition in proximity induced superconducting Palladium/WTe_2 junction

Richa Mitra[1]
Kuldeep Kuldeep[1], LD Varma Sangani, AA Zyuzin, Takashi Taniguchi, Kenji Watanabe, Pertti Hakonen, Manohar Kumar

Applied Physics Department, Aalto University, Espoo, Finland

richa.mitra@aalto.fi

Abstract

In 2D superconductors, the transition to the superconducting state is heavily influenced by quantum fluctuations and reduced dimensionality. The metallic phase transition can undergo quantum phase transitions driven by factors like magnetic field or temperature. These transitions involve changes in the ground state due to quantum fluctuations, offering valuable insights into the nature of 2D superconductivity.

Quantum Griffiths singularity (QGS) [1] is a fascinating phenomenon arising from the interplay between disorder and quantum fluctuations near a quantum critical point (QCP). QGS reveals the effect of quenched disorder with rare superconducting regions which support a vortex-glass-like phase near the phase boundary of the QCP.

We report the first observation of a magnetic field driven superconductor-metal transition (SMT) in a $PdTe_x$ superconductor embedded in a WTe_2/Pd junction. Palladium (Pd), which is a normal metal, diffuses laterally within tungsten ditelluride to form intercalated $PdTe_x$, a superconducting compound [2]. Utilizing scaling analysis [1,3], we show that, the dynamical critical exponent diverges near the characteristic magnetic field $B_c^* = 7.8$ T in agreement with an infinite randomness critical point. Our R(B,T) data also yields information on the nature of the anomalous metallic state of inhomogeneous $PdTe_x$ superconductor.

References

[1] Xing, Ying, et al. *Science* 350.6260 (2015): 542-545.
[2] Endres, Martin, et al. Physical Review Materials 6.8 (2022): L081201.
[3] Liu, Yi, et al. *Physical Review Letters* 127.13 (2021): 137001.

Figures

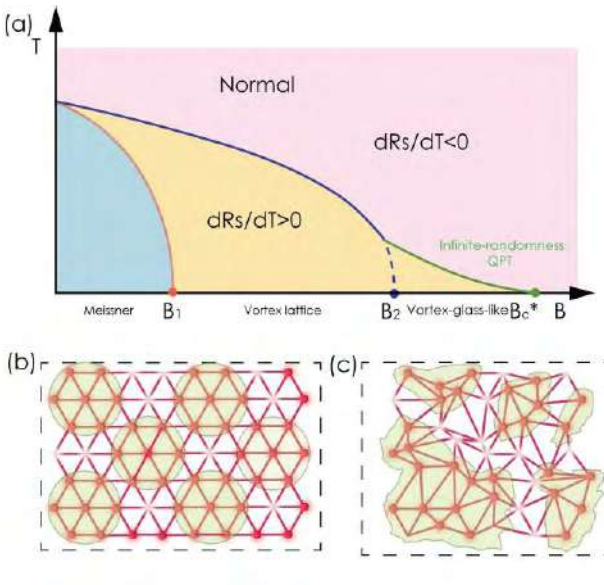


Figure 1: (a) Sketch of B-T phase diagram of demonstrating SMT in 2D superconductor with quenched disorder. Pictorial representation of the (b) vortex-lattice phase, (c) vortex-glass-like phase in such SMT phase transition.

Quantum anomalous Hall effect materials and devices for metrology: An EPM project

Susmit Kumar1
Jan Kučera2, Martina Marzano3, Luca Callegaro3, Hansjörg Scherer4, Mattias Kruskopf4, Ayşe Gökçe Özbay5, Charles Gould6a,b, Laurens W. Molenkamp6a,b, Mehmet Cengiz Onbaşlı7, Nathaniel Huang8, Olga Kazakova8, Stephen Giblin8, Sayani Majumdar9, Thorsten Hesjedal10, Giuseppe Maruccio11, Nobu Kaneko12, Frédéric Overney13, Johannes Hoffmann13, Martino Poggio14

[1]*Justervesenet (JV), Fetveien 99, 2007 Kjeller, Norway*
[2]*Cesky Metrologicky Institut (CMI), Brno, Czech Republic*
[3]*Istituto Nazionale di Ricerca Metrologica (INRIM), Strada delle Cacce 91, 10135 Torino, Italy*
[4]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
[5]Turkiye Bilimsel ve Teknolojik Arastirma Kurumu (TUBITAK), Ankara, Türkiye
[6a]Faculty for Physics and Astronomy (EP3), Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany. [b]Institute for Topological Insulators, Am Hubland, D-97074 Würzburg, Germany
[7]Koç Üniversitesi, Istanbul, Türkiye
8National Physical Laboratory (NPL), London, United Kingdom
[9]Tampereen korkeakoulusäätiö sr, Tampere, Finland
[10]University of Oxford, Oxford, United Kingdom
[11]Universitá del Salento, Lecce, Italy
[12]National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan
[13]Eidgenössisches Institut für Metrologie (METAS), Bern, Switzerland
[14]Univsersitat Basel, Basel, Switzerland

sku@justervesenet.no

Abstract

Quantum anomalous Hall effect materials and devices for metrology (QuAHMET) is a Joint research Project of the European Partnership on Metrology[1]. The project will focus on the traceable measurement and characterisation of quantum anomalous Hall effect (QAHE) materials as devices and primary resistance standard candidates.

The QuAHMET project consortium consists of 14 partners and gathers 7 leading European national metrology institutes (NMIs), a Japanese NMI for metrology, complemented by 6 globally recognized institutes from academia and applied research.

Within the project, the partners will explore and understand in-depth a new but scientifically grounded methodology for developing metrology grade QAHE devices, and to achieve higher operating temperatures and currents compared to the current state-of-the-art.

References

1. European Partnership on Metrology [Online]

Figure

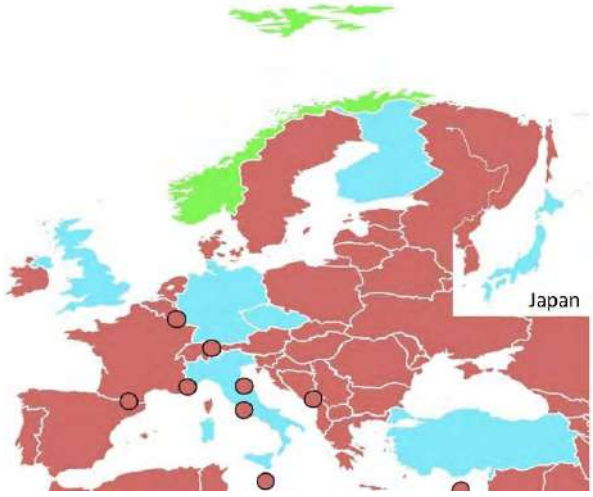


Figure 1: Map showing geographical locations of QuAHMET Partners

Demonstrating Quantum Enhancement in Light-Harvesting Systems

Adesh Kushwaha, Ivan Kassal

The University of Syndey, NSW 2006, Australia
akus7347@uni.sydney.edu.au

The most promising quantum enhancement of light harvesting is supertransfer [1,2], a collective quantum effect related to superradiance that enhances the rate of energy transfer between delocalised states. Despite its proposed significance in photosynthesis, there has been no direct experimental demonstration of supertransfer, as delocalisation of states cannot be turned on or off in a molecular system. Here, we demonstrate that this elusive quantum effect could be directly observed using a quantum device based on a superconducting circuit. The device's' control over the system and its environment would give full tunability over supertransfer. Additionally, we present design guidelines for optimised energy transfer whose rate scales quadratically with the number of donors and linearly with the number of acceptors. These enhanced rates could inform the design of future, quantum-enhanced light-harvesters.

References

[1] S. Baghbanzadeh and I. Kassal, *J. Phys. Chem. Lett.*, **7** (2016) 3804.

[2] S. Tomasi and I. Kassal, *J. Phys. Chem. Lett.*, **11** (2020) 2348.

Figure

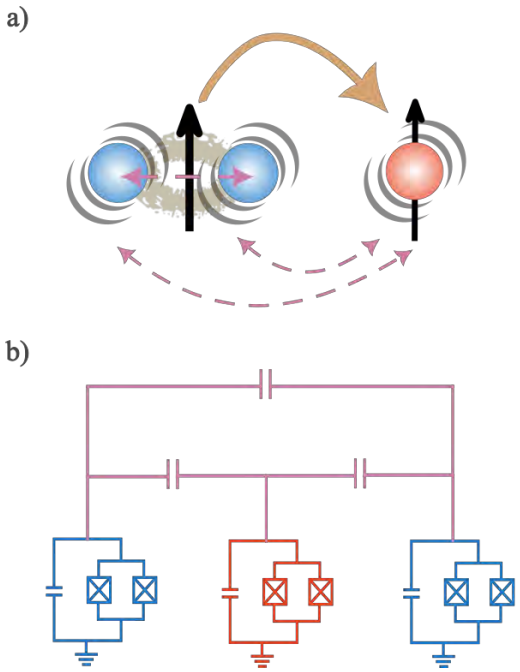


Figure 1: Experimental demonstration of supertransfer using a superconducting circuit. **A)** Supertransfer leads to enhanced transfer from delocalised donors (blue) to an acceptor (red). **B)** A circuit that demonstrates supertransfer by mapping the donor-acceptor system and that can tune the delocalisation using controllable noise.

Associative Memories in the Quantum Regime

Adrià Labay Mora
Roberta Zambrini, Gian Luca Giorgi

Institute for Cross Disciplinary Physics and Complex Systems (IFISC) UIB-CSIC, Campus Universitat Illes Balears, Palma de Mallorca, Spain.

alaba@ifisc.uib-csic.es

Attractor neural networks are brain-inspired computational systems that can solve and model numerous kinds of tasks, ranging from pattern and speech recognition to big data analysis. Associative memories (AMs) are a prominent example of attractor neural networks whose temporal evolution settles on stable solutions. In an AM task, a system stores a set of memory states. Then, it is interrogated using a clue state similar but not necessarily identical to one of the memories; a system equipped with AM can identify the stored pattern most similar to the clue according to a properly defined distance.

To this purpose, we deviate from standard Hopfield network techniques [1] and explore the use of non-linear bosonic oscillators. Our findings show the possibility of storing patterns in the form of coherent [2] or squeezed states [3] that span the metastable phase of the system. In the former work, we study the storage capacity of such oscillators and show that they can overcome the Hebbian limit in a large regime by toggling the oscillator parameters. In the latter, we introduce the possibility of storing patterns as purely quantum states, with no classical analogue. A novelty that had not been pursued in previously studied generalizations of quantum Hopfield networks [4]. We compare the storage capacity between squeezed and coherent states. Being the former more sensible to errors as the states are harder to discriminate.

Concerning AMs, metastability allows systems that converge towards a unique steady state to span a manifold of relevant addressable memories. Yet, there are other possibilities for building an AM. In [5] we investigate the general form of quantum channels that pursue such tasks.

References

[1] J. J. Hopfield, *Proceedings of the national academy of sciences*, ***79***(8), 2554-2558 (1982).
[2] A. Labay Mora, R. Zambrini, and G. L. Giorgi. *PRL* ***130****, 190602 (2023)*
[3] A. Labay Mora, R. Zambrini, and G. L. Giorgi. *arXiv:2309.06300*
[4] E. Fiorelli, M. Marcuzzi, P. Rotondo, F. Carollo, and I. Lesanovsky, *PRL* ***125*** *070604* (2020)
[5] A. Labay Mora, E. Fiorelli, R. Zambrini, and G. L. Giorgi. *In preparation*

Figures

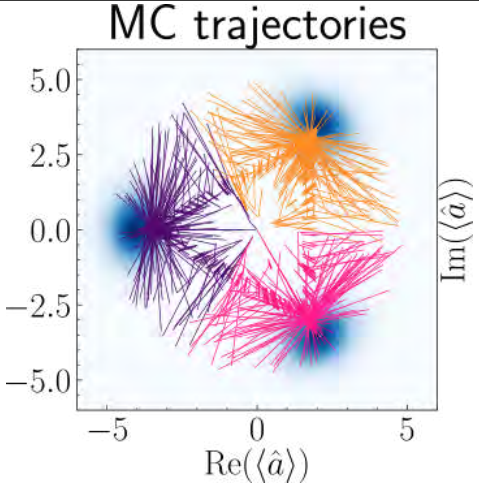


Figure 1: Association of states towards its closest pattern encoded in squeezed states.

Spin-photon entanglement from a telecom wavelength quantum-dot

Petros Laccotripes[1,2]
Tina Müller[2], Joanna Skiba-Szymanska[2], R. Mark Stevenson[2], David A. Ritchie[1], Andrew J. Shields[2]

[1]*Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge, CB3 0HE, UK*

[2]*Toshiba Europe Limited, 208 Science Park, Milton Road, Cambridge, CB4 0GZ, UK*

pl490@cam.ac.uk
petros.laccotripes@toshiba.eu

The ever-evolving demands for computational power and for a securely connected world dictate the development of quantum networks where entanglement is distributed between connected parties [1]. Using single photons as flying qubits, the existing fibre optics infrastructure can be transformed into a global quantum network. "On-demand" generation of entangled photons, using semiconductor quantum dots (QDs), with telecom wavelength emission is imperative for long-distance transmission. However, the crucial ingredient, namely entanglement between a single spin and a photon at C-band wavelengths, has been elusive so far. Despite the progress achieved in the 900 nm region in recent works [2-4], comparable performance at telecom wavelengths has not been demonstrated yet. Additionally, approximations relying on downconversion sources are inherently lossy and significantly increase experimental complexity [5]. Our recent results show that quantum dot-based entanglement sources can fill this gap [6]. In this work, we use an InAs/InP QD, with direct emission in the telecom C-band, to implement an optically active spin-qubit. We demonstrate a full range of optical manipulation techniques such as high-fidelity spin initialisation and full coherent spin control of the resident electron. Using our telecom wavelength device, we further verify the true single photon nature of our source and measure the coherence of a single undisturbed electron spin in our system. Lastly, for the first time we demonstrate high-fidelity spin-photon entanglement in a solid-state system with direct emission into the telecom C-band and obtain a lower bound on the entanglement fidelity of 80.07 %. Our results highlight the potential of our system for the development of future quantum networking applications.

References

[1] E. Knill, R. Laflamme & G. J. Milburn, Nature, 409 (2001) 46-52.
[2] M. H. Appel, A. Tiranov, S. Pabst, M. L. Chan, C. Starup, Y. Wang, L. Midolo, K. Tiurev, S. Scholz, A. D. Wieck, A. Ludwig, A. S. Sørensen & P. Lodahl, Physics Review Letters, 128 (2022) 233602.
[3] N. Coste, D. A. Fioretto, N. Belabas, S. C. Wein, P. Hiclaire, R. Frantzeskakis, M. Gundin, B. Goes, N. Somaschi, M. Morassi, A. Lemaître, I. Sagnes, A. Harouri, S. E. Economou, A. Auffeves, O. Krebs, L. Lanco & P. Senellart, Nature Photonics, 17 (2023) 582–587.
[4] D. Cogan, Z.-E. Su, O. Kenneth & D. Gershoni, Nature Photonics, 17 (2023) 324–329.
[5] K. De Greve, L. Yu, P. L. McMahon, J. S. Pelc, C. M. Natarajan, N. Kim, E. Abe, S. Maier, C. Schneider, M. Kamp, S. Höfling, R. H. Hadfield, A. Forchel, M. M. Fejer & Y. Yamamoto, Nature, 491 (2012) 421–425.
[6] P. Laccotripes, T. Müller, R.M. Stevenson, J. Skiba-Szymanska, D.A. Ritchie & A.J. Shields, arXiv:2310.16930 (2023).

Ground states of one-dimensional dipolar lattice bosons at unit filling

Mateusz Łącki[1]
Henning Korbmacher[2], G. A. Domínguez-Castro[2], Jakub Zakrzewski[1,3], Luis Santos[2]

1 Institute of Theoretical Physics, Jagiellonian University in Krakow, ul. Lojasiewicza 11, 30-348 Kraków, Poland
2 Institut für Theoretische Physik, Leibniz Universität Hannover, Germany
3 Mark Kac Complex Systems Research Center, Jagiellonian University in Krakow, Łojasiewicza 11, 30-348 Kraków, Poland

mateusz.lacki@uj.edu.pl

In this talk I will exploring possibilities for quantum simulation of extended Hubbard models, focusing on one-dimensional models at unit filling. The dipolar interactions, extending beyond nearest neighbor, are described by effective power-law decay exponent β_{eff}). While normally β_{eff}=3, the dipolar interactions are influenced by transversal confinement allowing to consider β_{eff}=1-3.
Even for β_{eff}=3 the phase diagram already contains phases unobserved under assumption of nearest-neighbor interaction: density waves with longer periods and a novel insulating phase (topologically trivial insulator – TTI).
By adjusting the transversal confinement, a longer tail in Dipolar coefficients decay is achieved (we focus on β_{eff} of 1), enhancing the TTI region and introducing a new TI phase. The TTI phase is between 3DW and Haldane insulator phases, and features interesting correlations of site occupations. Additionally, the TI phase results from the melting of the 4DW phase. Another Mfeature are quantitative changes to the Haldane insulator regime
We will discuss possible realization and observability of these phases in state-of-the-art experiments involving ultracold quantum systems in optical lattices.

The main research method is infinite density-matrix renormalization group (iDMRG) calculation of ground-state phase diagrams.

References

[1] Mateusz Łącki, Henning Korbmacher, G. A. Domínguez-Castro, Jakub Zakrzewski, Luis Santos, https://arxiv.org/abs/2311.14606 (2023)

Figures

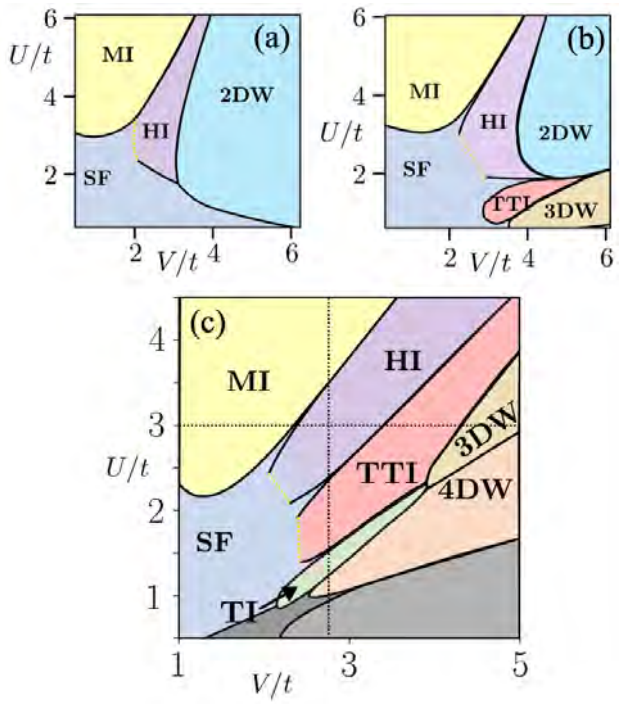


Figure 1: Phase diagrams of Extended Bose-Hubbard model. (a) standard model with nearest-neighbor dipole-dipole Vn_in_{i+1} terms (b) EBH model with V terms beyond nearest neighbor (cubic interaction decay) (c) EBH model with V terms beyond nearest neighbor (β_{eff}=1).

Entanglement growth from squeezing on the matrix product state manifold

Sebastian Leontica
Andrew G. Green

London Centre for Nanotechnology, University College London, Gordon St., London WC1H 0AH, United Kingdom

sebastian.leontica.22@ucl.ac.uk

Finding suitable characterizations of quantum chaos is a major challenge in many-body physics, with a central difficulty posed by the linearity of the Schrödinger equation. A possible solution for recovering non-linearity is to project the dynamics onto some variational manifold. The classical chaos induced via this procedure may be used as a signature of quantum chaos in the full Hilbert space. Here, we demonstrate analytically a previously heuristic connection between the Lyapunov spectrum from projection onto the matrix product state (MPS) manifold and the growth of entanglement. This growth occurs by squeezing a localized distribution on the variational manifold. The process qualitatively resembles the Cardy-Calabrese picture [1], where local perturbations to a moving MPS reference are interpreted as bosonic quasi-particles. Taking careful account of the number of distinct channels for these processes recovers the connection to the Lyapunov spectrum. Our results rigorously establish the physical significance of the projected Lyapunov spectrum, suggesting it as an alternative method of characterizing chaos in quantum many-body systems, one that is manifestly connected to classical chaos.

References

[1] P. Calabrese and J. Cardy, Journal of Physics A: Mathematical and Theoretical **42,** 504005 (2009).

Figures

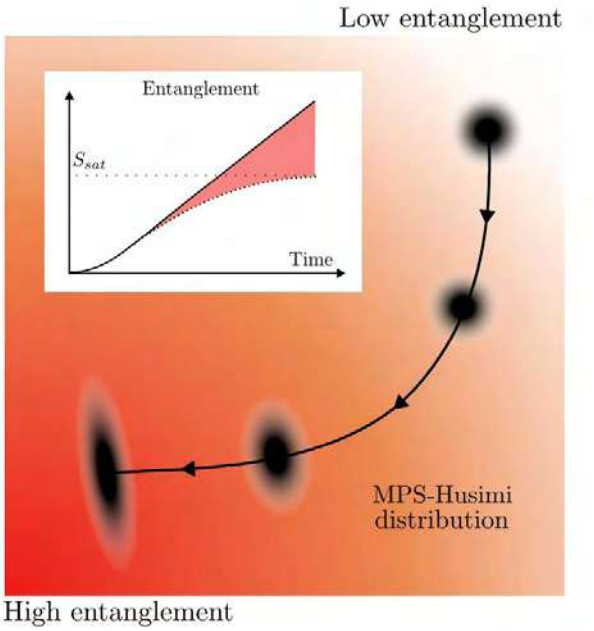


Figure 1: Schematic representation of the entropy growth due to squeezing. The quantum state starts in a low entanglement corner of the MPS manifold and evolves via the time-dependent variational principle (TDVP) towards higher entanglement areas. When saturation is reached, excess entanglement is captured as a squeezing of the MPS-Husimi distribution (light-red contribution in the inset).

Spatially-resolved dissipation in a quantum wire with a coherent scatterer

Nico Leumer[1,2] Denis Basko[3], Rodolfo Jalabert[2], Dietmar Weinmann[2], and Robert Whitney[3]

1)DIPC, Manuel Lardizabal Ibilbidea, 4, 20018 Donostia, Gipuzkoa
2) IPCMS, 23 Rue du Loess Bâtiment 69, 67200 Strasbourg, Frankreich
3)LPMMC lpmmc Av. des Martyrs, 38000 Grenoble, Frankreich

nico.leumer@dipc.org

The recent advent of astonishing measurement techniques allows the near-atomic resolution of tiny local temperature changes, even three orders of magnitude lower than the sample temperature itself [1]. The new approaches confirmed earlier estimations that dissipation (accompanying electric current) is not shared equally among two 1d wires attached to a point contact. Moreover, the formation of so called heat-spots (small and confined areas of increased temperature) were observed in the quantum regime [2]. Evidently, dc charge transport possesses the key to further unravel the microscopic mechanisms behind spatial dissipation profiles.

Based on a model of two 1d wires sandwiching a scatterer (Fig 2 (a)), we studied the spatial profile of the dissipated power (Fig 2 (b)) for generic transmission of the scatterer. We present the mechanism behind the formation of heat/ cold spots and the key role of the electric potential, which is required to maintain the electric current against the increased wire's resistivity in close vicinity to the point contact.

References

[1] D. Halbertal et al., Nature 539 (2016) 407
[2] Q. Weng et al., Nat. Commun. 12 (2021) 4752

Figures

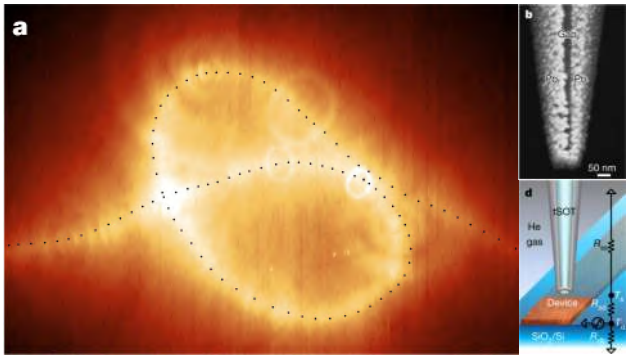


Figure 1: Thermal imaging a current carrying carbon nanotube (dots) using the SQUID-on-tip technique (tSot). Picture from [1].

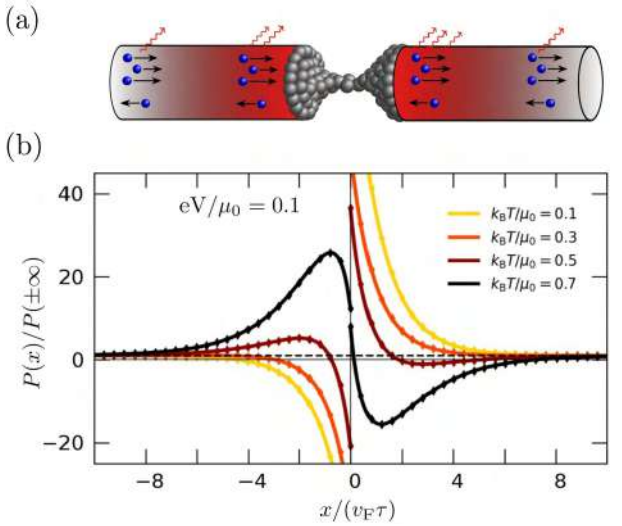


Figure 2: Simulating the local power profile around quantum scatterers. (a) Sketch of the model. The transmission probability of the scatterer (gray) yields an energy loss of the electrons (blue) in the wires (red). (b) Calculated dissipation profile for a Lorentzian transmission at various temperatures and fixed voltage drop inside the scatterer. Low temperatures (black) show the presence of heat (cold) spots as local maximum (minimum).

Geodesic Algorithm for Unitary Gate Design with Time-Independent Hamiltonians [1]

Dylan Lewis
Roeland Wiersema
Juan Carrasquilla
Sougato Bose

Department of Physics and Astronomy, University College London, London WC1E 6BT, United Kingdom

dylan.lewis.19@ucl.ac.uk

The primitive quantum gates of quantum computing platforms usually involve only one or two qubits and simple Hamiltonians. Our aim is to take advantage of the more complex Hamiltonians available in experimental platforms to design larger multi-qubit gates. Finding these restricted Hamiltonians that generate desired quantum gates is numerically challenging. Existing methods of stochastic gradient descent, differential evolution, or variational quantum algorithms have been attempted [2], but have limited success for larger gates.

We offer a solution to the problem of generating multi-qubit gates from time-independent Hamiltonians through the lens of differential geometry of the Lie group structure of quantum gates. Some geometric techniques have previously been crucial for understanding quantum circuit complexity [3]. Our algorithm utilises geodesic information and gradients on the group manifold to rapidly converge to an accurate solution. At each optimisation step, we update the Hamiltonian coupling strengths such that the resulting unitary is closer to the target unitary gate. This can be achieved by updating the couplings such that they follow (as closely as possible) the geodesic curve towards the target. In the paper [1], we formalize this comparison and demonstrate how the geodesic can be generated by updating Hamiltonian coupling strengths in time-independent Hamiltonians.

We demonstrate the algorithms efficiency by comparison to gradient descent techniques for the generation of Toffoli and Fredkin gates. Furthermore, we use the algorithm to generate previously unavailable weight-k parity checks with up to 6 qubits, which are necessary for a wide array of quantum error correcting codes. We find that our geodesic algorithm is significantly more efficient than gradient descent algorithms for finding a restricted generating Hamiltonian of a desired unitary gate. Larger, more complex quantum gates can therefore be implemented directly. Not only could this lead to less noisy gates, but it could also reduce the total time to run a circuit on the hardware. This is crucial for NISQ applications where we have a limited coherence time and gives the significant advantage of increasing the clock speed for fault-tolerant quantum computation.

References

[1] D. Lewis et al. arXiv:2401.05973 (2024)
[2] L. Innocenti, L. Banchi, et al., New J. Phys. 22 065001 (2020)
[3] M. A. Nielsen et al., Science 311 1133 (2006)

Figures

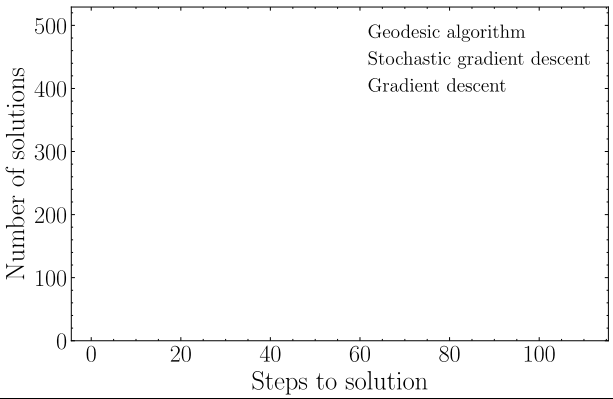


Figure 1: Comparison of number of steps to find Hamiltonian couplings for Toffoli gate for 1000 instances. Our geodesic algorithm significantly outperforms gradient descent methods.

Exploring Quantum Learning Models on Superconducting Devices

Weikang Li
Dong-Ling Deng
[1] Center for Quantum Information, IIIS, Tsinghua University, Beijing 100084, China
[2] Hefei National Laboratory, Hefei 230088, China
lwk20@mails.tsinghua.edu.cn

Quantum computing promises to enhance machine learning and artificial intelligence. However, due to the unavoidable noise in real experiments, it is challenging to design and implement large-scale quantum learning models on real quantum devices.

Here, we report **an experimental demonstration of supervised quantum machine learning with programmable superconducting qubits**. We train quantum classifiers, which are built on variational quantum circuits consisting of ten transmon qubits featuring average lifetimes of 150 μs, and average fidelities of simultaneous single- and two-qubit gates above 99.94% and 99.4%, respectively, with both real-life images (for example, medical magnetic resonance imaging scans) and quantum many-body data. We demonstrate that these well-trained classifiers can achieve high performance on these high-dimensional datasets, with testing accuracy of up to 99%.

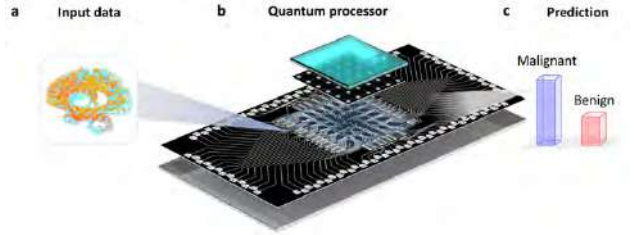


Figure 1: Schematic illustration of the model.

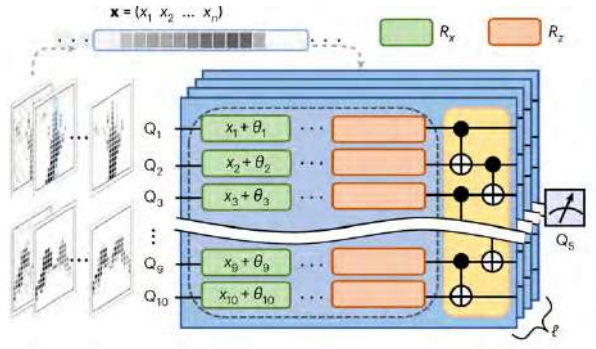


Figure 2: Learning classical data.

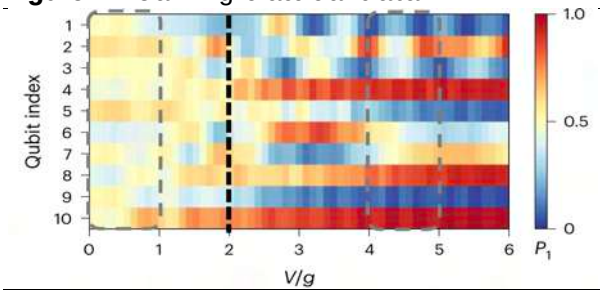


Figure 3: Learning quantum data.

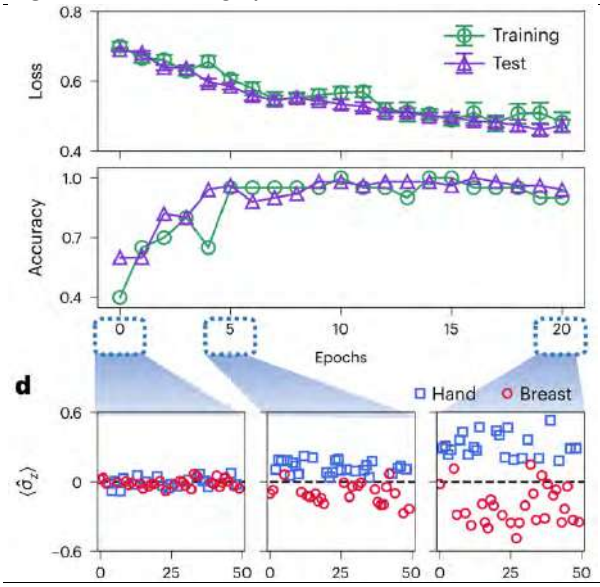


Figure 4: Results for learning classical data.

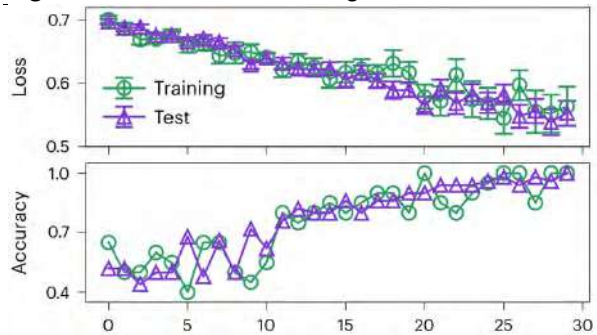


Figure 5: Results for learning quantum data.

References

[1] Ren, **Li**, Xu, et al, Nature Computational Science 2, 711 (2022)
[2] **Li**, Lu, Deng, SciPost Physics Lecture Notes, 061 (2022)

Observing Information Backflow from Controllable Non-Markovian Multi-channels in Diamond

Presenting Author: Ya-Nan Lu

Tsinghua University, Beijing, China

yananlu@mail.tsinghua.edu.cn

Abstract

Any realistic quantum system is inevitably subject to an external environment. This environment makes the open system dynamics significant for many quantum technologies, such as entangled-state engineering, quantum simulation, and quantum sensing. The ordinary environment, usually consisting of a large number of degrees of freedom, is hard to control, despite some attempts on controllable transitions from Markovian to non-Markovian dynamics. Here, we demonstrate the engineering of multiple dissipative channels by controlling the adjacent nuclear spins of a nitrogen-vacancy center in diamond. With controllable non-Markovian dynamics of this open system, we observe that the quantum Fisher information flows to and from the environment using different noisy channels. In this talk, I will present the principle, the experimental schemes and results of information backflow from non-Markovian multi-channels.

References

[1] Ya-Nan Lu *et al.*, Phys. Rev. Lett. 124, 210502 (2020).

Figures

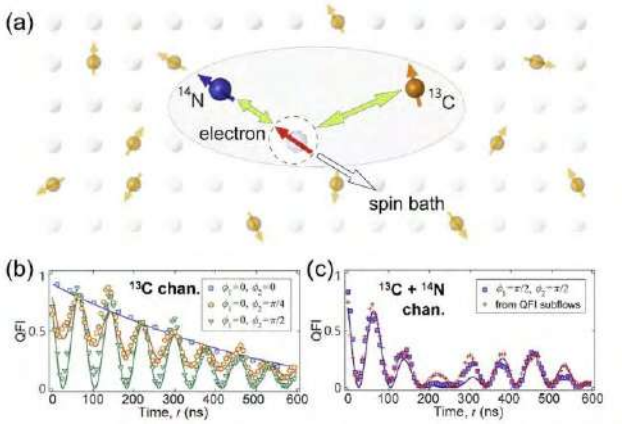


Figure 1: A schematic diagram and experimental results of quantum Fisher information (QFI) backflow from two non-Markovian channels.

Deep quantum neural networks equipped with the backpropagation algorithm

Presenting Author: Zhide Lu

Tsinghua University, Beijing, China

zhide.lu1997@gmail.com

Abstract

Quantum neural networks, typically structured as parameterized quantum circuits, merge the principles of quantum mechanics with the capabilities of neural networks. When dividing general quantum neural networks into multiple layers and restricting operations to be performed only between the nearest neighboring layers, a layer-by-layer deep quantum neural network can be designed. Tailored for this specialized structure of deep quantum neural networks, we design a unique quantum backpropagation algorithm for training. We analyze the training efficiency in terms of the required number of quantum copies for each training data per training iteration. Our analysis suggests that the quantum backpropagation algorithm is more efficient than traditional training algorithms in specific scenarios, particularly when the width of the hidden layers is smaller than the width of the input and output layers in the deep quantum neural network. Our numerical demonstrations highlight the remarkable learning ability of deep quantum neural networks, as well as the effectiveness of the quantum backpropagation algorithm in learning quantum channels.

References

[1] Pan X*, **Lu Z***, et al., Nature Communications 14, 4006 (2023).

Figures

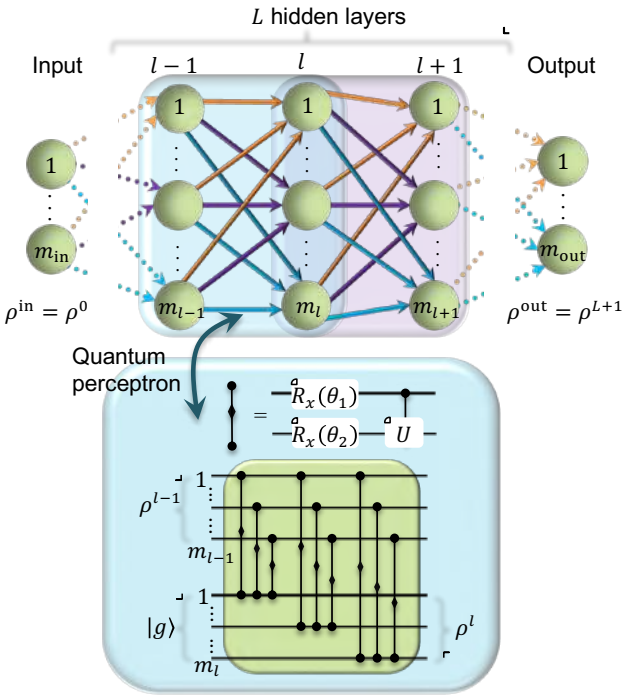


Figure 1: Schematic illustration of deep quantum neural networks.

Figure 2: Exhibition of the backpropagation algorithm.

Two-qubit [Dy_2] molecules deposited into micro-SQUID susceptometers: in situ characterization of their spin response

Fernando Luis
A. Repollés,[1] M. C. Pallarés,[1,2] D. Aguilà,[3,4] O. Roubeau,[1] V. Velasco,[3,4] D. Gella,[1] L. A. Barrios,[3,4] M. J. Martínez-Pérez,[1] J. Sesé,[1] D. Drung,[5] T. Schurig,[5] B. Le Guennic,[6] A. Lostao,[1,2,7] G. Aromí,[3,4]
[1]*Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, 50009, Zaragoza , Spain*
[2]*Laboratorio de Microscopias Avanzadas (LMA), Universidad de Zaragoza, 50018 Zaragoza, Spain*
[3]*Departament de Química Inorgànica i Orgànica, Universitat de Barcelona, Diagonal 645, 08028 Barcelona, Spain.*
[4]*Institut of Nanoscience and Nanotechnology of the University of Barcelona (IN2UB), Barcelona, Spain.*
[5]*Physikalisch-Technische Bundesanstalt (PTB), Abbestraße 2-12, D-10587 Berlin, Germany*
[6]*Univ Rennes, CNRS, ISCR (Institut des Sciences Chimiques de Rennes) - UMR 6226, F-35000 Rennes, France*
[7]*Fundación ARAID, 50018 Zaragoza, Spain*
fluis@unizar.es

The integration of magnetic molecules into superconducting circuits is key for developing hybrid quantum computing architectures [1-4]. Here, we study [Dy_2] molecular dimers deposited onto micro-SQUID susceptometers. The results of magnetic and heat capacity experiments, backed by theoretical calculations, show that each [Dy_2] dimer can act as a two-qubit quantum processor. Arrays of [Dy_2] molecules have been optimally integrated inside the 20 μm wide loops of micro-SQUID sensors by means of Dip-Pen Nanolithography [5]. The equilibrium magnetic susceptibility and the spin tunneling dynamics measured in situ evidence that these molecules preserve the spin ground states, magnetic interactions and magnetic asymmetry that characterize them in bulk. These results show that it is possible to interface multi-qubit molecular complexes with superconducting circuits without disturbing their relevant properties and hints at the potential of soft nanolithography to achieve this goal in practice.

References

[1] A. Gaita-Ariño, F. Luis, S. Hill, and E. Coronado, Nature Chem. 11 (2019) 301.
[2] S. Carretta, D. Zueco, A. Chiesa, Á. Gómez-León, and F. Luis, Appl. Phys. Lett. 118 (2021) 240501.
[3] A. Chiesa, S. Roca, S. Chicco, M.C. de Ory, A. Gómez-León, A. Gomez, D. Zueco, F. Luis, and S. Carretta, Phys. Rev. Applied 19 (2023) 064060
[4] A. Chiesa, P. Santini, E. Garlatti, F. Luis, and S. Carretta, Rep. Prog. Phys. 87 (2024) 034501
[5] I. Gimeno et al, ACS Nano 14 (2020) 8707

Figures

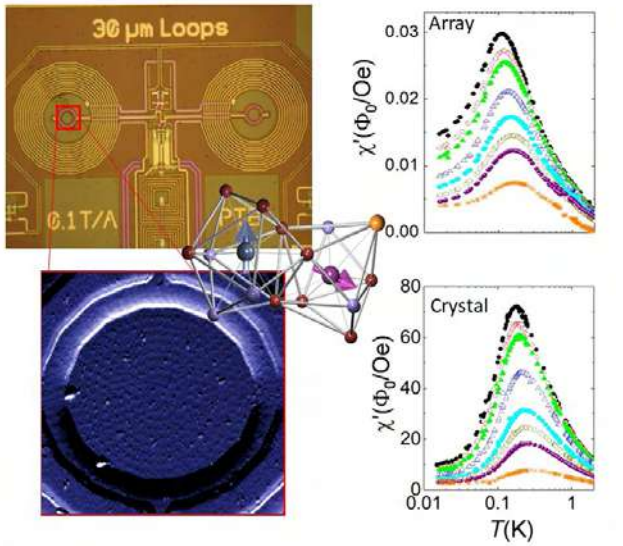


Figure 1: Image of a micro-SQUID ac susceptometer (top left) and of a [Dy_2] nanoarray deposited on one of its pick-up coils (bottom left). Linear ac susceptibility measured on an array (top right) compared to that measured on a bulk crystal (bottom right).

ENDOR-Qdyne: A Nanoscale NMR Spectroscopy Protocol Applicable to High Magnetic Fields

Rouven Maier[1]
Jonas Meinel[1], Vadim Vorobyov[1], Jörg Wrachtrup[1]

[1]*3rd Institute of Physics, University of Stuttgart, Allmandring 13, Stuttgart, Germany*

Rouven.Maier@pi3.uni-stuttgart.de

Nuclear magnetic resonance (NMR) spectroscopy poses one the most widely used spectroscopic techniques of modern times, with applications ranging from the serialized analysis of chemical structures at the molecular level to tissue imaging in clinical applications. However, the inherent insensitivity of conventional NMR spectroscopy prevents its use in the studies of nanoscopic systems. By increasing the sensitivity by several orders of magnitude, Nanoscale NMR spectroscopy based on the nitrogen vacancy (NV) center in diamond as quantum sensor has emerged as a promising research subject [1]. Although recent developments of innovative NMR detection schemes, such as the quantum-heterodyne (Qdyne) detection protocol, enable high spectral resolutions, these schemes are inherently not applicable at high magnetic fields, to further improve the resolution and measurement times [2]. Here we present a high-field compatible extension of the Qdyne measurement scheme by combining it with electron-nuclear-double-resonance (ENDOR) sequences. [3] This approach paves the way for the application of NV-NMR spectroscopy in nano-scale studies of biomolecules and materials attached to the diamond surface.

References

[1] T. Staudacher *et al.*, Science, 6119 (2013) 561.
[2] J. M. Boss *et al.*, Science, 6340 (2017) 837.
[3] J. Meinel *et al.*, Comm. Phys., 302 (2023).

Figures

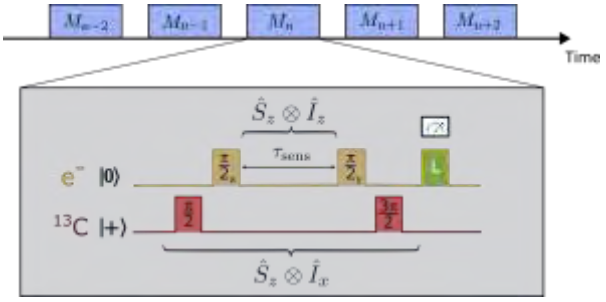


Figure 1: Pulse sequence of the ENDOR-Qdyne protocol. The transverse polarization of the target spin (red) is transferred to longitudinal axis via a RF pulse. This polarization is then read out by the sensor electron spin (yellow) with a Ramsey-type sequence, before the target spin is transferred back to xy-plane with a second RF pulse.

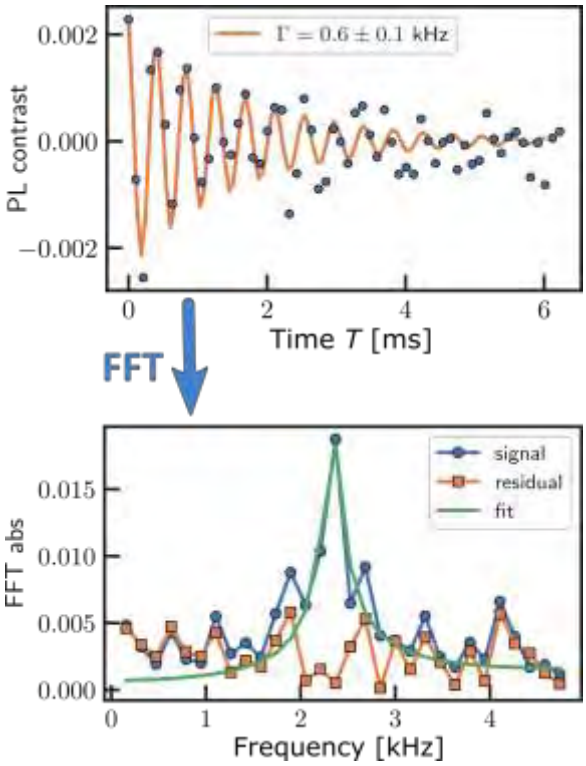


Figure 2: Detected down-converted NMR signal of a ^{13}C spin. The oscillating time trace reveals the Larmor precession of the target spin in the xy plane. The frequency spectrum is obtained through Fourier transformation of the time trace of the oscillation.

Wannier excitons in two-dimensional topological insulators with strong spin-orbit coupling

Lucas Maisel Licerán
Francisco García Flórez
Laurens Siebbeles
Henk Stoof

Institute for Theoretical Physics and Center for Extreme Matter and Emergent Phenomena, Utrecht University, Princetonplein 5, 3584 CC Utrecht, The Netherlands

l.maiselliceran@uu.nl

Thanks to extensive studies in the past two decades, the role of topology in the band structure of noninteracting electrons is well understood. In real materials, however, electronic correlations often give rise to new phenomena which can significantly alter the ground-state properties of the noninteracting system. The question of whether and how the single-particle topology manifests itself in such cases is object of active ongoing research at both the theoretical and experimental level. The aim of this talk is to give an inexhaustive overview of the effects of electronic topology on Wannier excitons in two-dimensional semiconductors with strong spin-orbit coupling. In these materials, the nontrivial momentum-space winding of the underlying electrons and holes strongly modifies the Coulomb interaction between them. The resulting excitonic band structure is greatly modified with respect to that arising from the same model in a trivial regime. In particular, Berry-phase effects leave a clear imprint on the exciton binding energies by lifting the accidental angular-momentum degeneracy present in the hydrogen-like Wannier picture. The optical properties are also affected by the underlying topological single-particle Hamiltonian, with *s*- and *d*-wave excitons coupling selectively to left- or right-circularly polarized light. If time permits, I will discuss the possibility and peculiarities of exciton condensation and squeezing in the presented model.

References

[1] L. Maisel Licerán, F. García Flórez, L. D. Siebbeles, and H. T. Stoof. *Sci. Rep.* **13**(1), 6337 (2023)
[2] J. Zhou, W. Y. Shan, W. Yao, and D. Xiao. *Phys. Rev. Lett.* **115**(16), 166803 (2015)

Figures

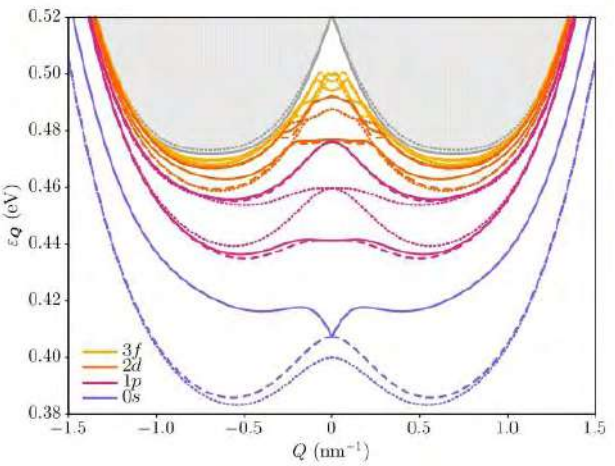


Figure 1: Exciton band structure in the *topological* regime of the underlying single-particle Hamiltonian, strongly deviating from the hydrogen-like spectrum shown below.

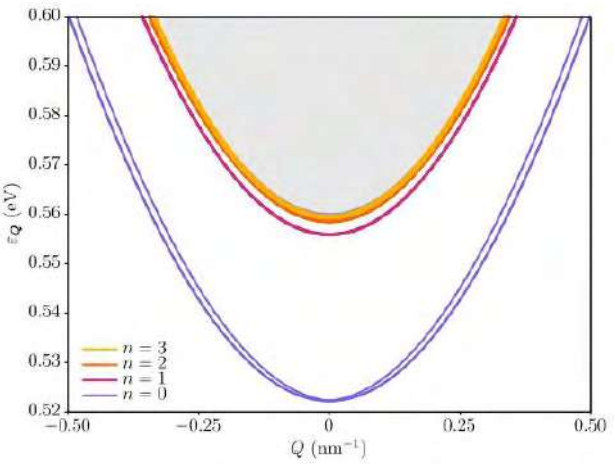


Figure 2: Exciton band structure in the *trivial* regime of the underlying single-particle Hamiltonian. A hydrogen-like spectrum is obtained.

Detection of Majorana bound states by scanning gate microscopy

Shalini Maji
Michał P. Nowak

AGH University of Krakow, Academic Centre for Materials and Nanotechnology, Al. Mickiewicza 30, 30-059 Krakow, Poland

maji@agh.edu.pl
mpnowak@agh.edu.pl

The zero-bias conductance peaks in hybrid nanowires with Rashba spin-orbit coupling and the Zeeman effect [1] have been considered as one of the signatures of the presence of Majorana-bound states (MBS). Nevertheless, the sole observation of a peak at zero energy cannot be considered as unambiguous hallmark of the presence of MBS as the peaks can originate also from the disorder present in the system [2]. Splitting of zero-bias conductance peaks (ZBCPs) with oscillatory behavior in the Zeeman field or varied system size has been regarded as one of the possible routes to evidence the presence of Majorana-bound states [3]. The experimental demonstration of this effect remained challenging. In our work we theoretically study the scanning gate microscopy technique (SGM) which is applied to such hybrid systems [4] and can be used to discriminate between the trivial and topological origin of the zero bias peaks. We show that the scanning probe can induce the localization of two additional Majorana pairs and that the change of the position of the probe changes the overlap between MBS which in turn induces conductance oscillations. We show that the oscillations are absent in the trivial case, where the ZBCPs are induced by the disorder.

References

[1] Y. Oreg, G. Rafael, F. von Oppen, Phys. Rev. Lett. 105, 177002 (2010).

[2] S. Das Sarma, H. Pan, Phys. Rev. B, 103, 195158 (2021).

[3] S. Das Sarma, Jay D. Sau, Tudor D. Stanescu, Phys. Rev. B, 86, 220506(R) (2012).

[4] S. Maji, K. Sowa, M. P. Nowak, arXiv:2310.03523 (2023).

Figures

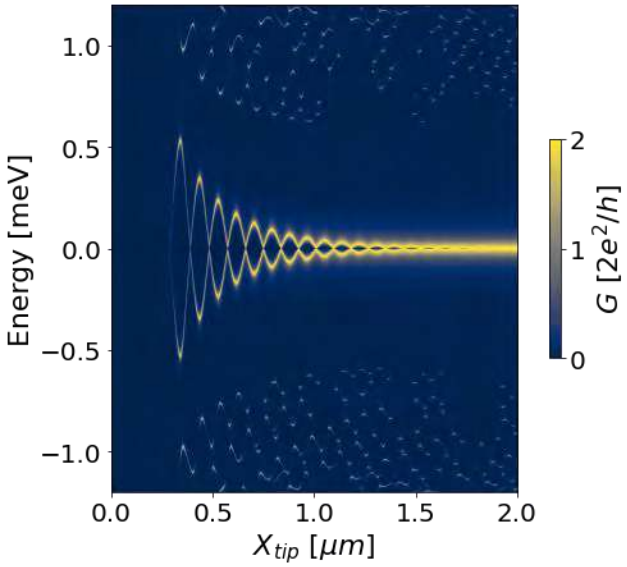


Figure 1: Conductance versus position of the SGM tip at constant magnetic field. Clear oscillations of Majorana zero-bias peaks are visible.

Synchronised nuclear spin drive

Ana Martin[1,2]
Carlos Munuera-Javaloy[1,2]
Jorge Casanova[1,2,3]

[1]*Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, 48080 Bilbao, Spain*
[2]*EHU Quantum Center, University of the Basque Country UPV/EHU, Bilbao, Spain*
[3]*IKERBASQUE, Basque Foundation for Science, Plaza Euskadi 5, 48009 Bilbao, Spain*

ana.martin.fernandez07@gmail.com

Nanoscale nuclear magnetic resonance (NMR) is a technique that enables the study of mater at the nanoscale level. In nanoscale NMR, nitrogen-vacancy (NV) centers can be utilized as highly sensitive magnetic sensors to detect the magnetic fields produced by nearby nuclei. By placing the sample close to the NV ensemble, thermal polarization is replaced by statistical polarization as the dominant signal source. We study correlation spectroscopy methods for nanoscale NMR methods, which involves two "interrogation" pulse sequences during which the NV centers accumulate phase. This process correlates the phases of the oscillating magnetic field and generates oscillations in the readout data. We found that these oscillations depend on the angular distance between the axes along the pulses are applied. Furthermore, we characterize the effect of including a radio frequency pulse over sample's nuclei. Our findings suggest that, in this type of protocols, the outcome does not hinge on the initial random phase of the sample's magnetic field that we aim to detect but rather on the correlation among the initial phases of the drivings applied in various channels.

Figures

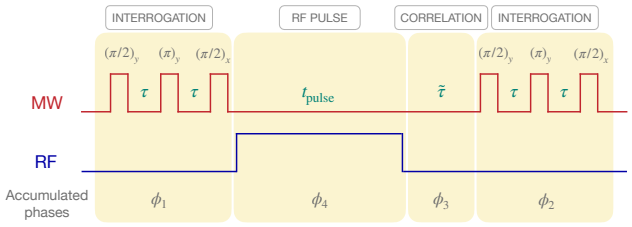


Figure 1: Sequence scheme. Two channels are involved in the sequence. The sequence in the microwave (MW) channel is applied on the NV and the one in the radio frequency (RF) channel is applied on the sample. The sequence is divided into four stages: a first interrogation block, application of an RF pulse on the sample, correlation time and a second interrogation block. In each of these stages the NV accumulate a phase ø.

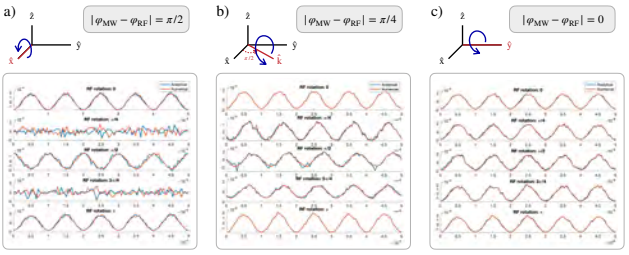


Figure 2: Effect of desynchronization in the initial phases of driving on NV photoluminescence (PL). We investigate PL variations of the NV center for distinct axes of RF pulse application while the first MW pulse is applied along y-axis of the NV. The choice of axes for the drivings is determined by their initial phases. **a)** Application of the RF pulse along the x- axis results in a phase difference of π/2, leading to population inversion in the NV when a π-pulse is applied to the sample. **b)** If the RF pulse is directed along an intermediate axis, k, between x and y we observe changes in the PL phase but not full population inversion. **c)** When both driving axes have the same phase, population inversion is not observed in the NV PL, despite using the same RF pulse on the sample.

Exposing Bound States in the Continuum in InSb Nanowire Networks.

Dunkan Martínez[1]

Pedro. A. Orellana[2], L. Rosales[2], J. Dolado[3], M. Amado[4], E. Díez[4], F. Domínguez-Adame[1] and R. P. A. Lima[1,5]

[1]*GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain.*
[2]*Departamento de Física, Universidad Técnica Federico Santa María, Casilla 110 V, Valparaíso, Chile.*
[3]*ESRF, The European Synchrotron, 71 Avenue des Martyrs, Grenoble 38043, France.*
[4]*Nanotechnology Group, USAL-Nanolab, Universidad de Salamanca, E-37008 Salamanca, Spain.*
[5]*GFTC, Instituto de Física, Universidade Federal de Alagoas, Maceió AL 57072-970, Brazil.*

dunmar01@ucm.es

Abstract

Bound states in the continuum (BICs) are exotic, localized states even though their energy lies in the continuum spectra. Since its discovery in 1929, the quest to unveil these exotic states in charge transport experiments remains an active pursuit in condensed matter physics. In this talk, I will show some proposals of experimental set-ups composed of InSb nanowire arrays that could be used to find BICs in conductance measurements while introducing a perpendicular magnetic field. We find that BICs reveal themselves as distinctive resonances or antiresonances in the conductance by varying the applied magnetic field and the Fermi energy. We systematically consider different lead connections in hashtag-like nanowire networks, finding the optimal configuration that enhances the features associated with the emergence of BICs. Finally, the talk focuses on the effect of the Rashba spin-orbit interaction of InSb on the occurrence of BICs in nanowire networks and its applicability in spintronics.

References

[1] J. von Neumann and E. Wigner, **30** (1929) 465
[2] M. L. L. d. Guevara, F. Claro, and P. A. Orellana *Phys. Rev. B* **67** (2003) 195335
[3] D. Martínez *et. al.* (coming soon at arxiv)

Figures

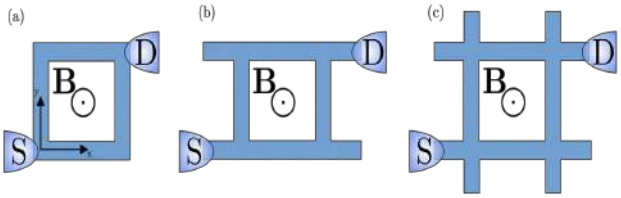


Figure 1: Sketch of the configurationally different geometries of the nanowire network.

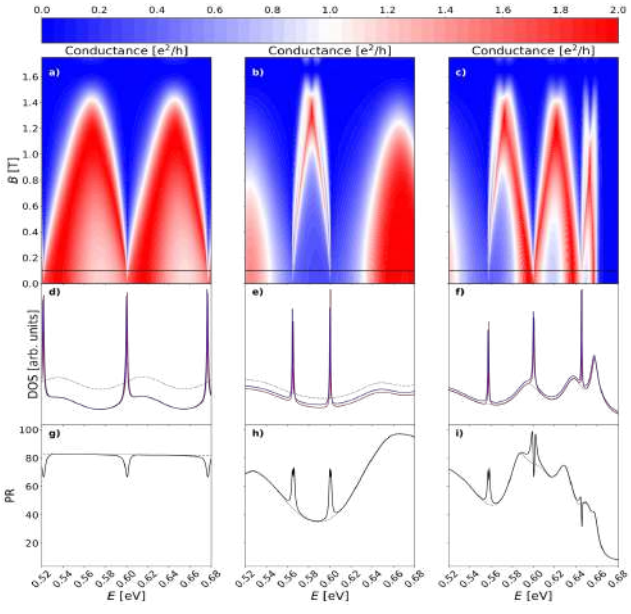


Figure 2: Panels (a), (b), and (c) display the conductance of the nanowire network against the magnetic field B and the Fermi energy E. Panels (d), (e) and (f) correspond to its density of states with and without magnetic field. Panels (g), (h), (i) represent its participation ratio with and without magnetic field.

Enhancing MUMAX³ software for Magnon-Cavity Interactions

Sergio Martínez-Losa del Rincón[1]
Juan Román Roche*,[1], Fernando Luis[1], David Zueco[1,2], María José Martínez-Pérez[1,2]

[1]*Instituto de Nanociencia y Materiales de Aragón, CSIC-Universidad de Zaragoza, C/Pedro Cerbuna 12, 50009, Zaragoza, Spain*
[2]*Fundación ARAID, Av. de Ranillas, 50018, Zaragoza, Spain*

*sergiomtz.losa@unizar.es

MUMAX3 is an open-source software which is GPU-accelerated and it is used to perform micromagnetic simulations, it was developed and maintained at the DyNaMat group at Ghent University (The design and verification of MuMax3 [1]).

We implement a new feature that extends the current capabilities of MUMAX3 by including the effects of coupling a given magnetic material to an electromagnetic cavity. This will enable the study of analytically-intractable models in the field of magnetic cavity QED materials.

To implement these modifications, a fork of the MUMAX3 code was created. The Landau–Lifshitz–Gilbert (LLG) equation that MUMAX3 solves is understood as a phenomenological analogue of the Heisenberg equations of motion of the spin degrees of freedom of the magnetic material. These are extended to include the coupling to the cavity and then the equation of motion of the cavity is integrated out, giving rise to an effective term for the spins. The effect of the cavity is thus included in MUMAX3 as a new contribution to the effective field given by the cavity's zero-point field times a memory factor.

As a benchmark, we simulate the dynamics of the Dicke model, which serves as an analytically-solvable toy model of a paramagnetic material interacting with a single-mode cavity (Photon Condensation and Enhanced Magnetism in Cavity QED [2]). Preliminary results show promising signs, with the observation of two resonant peaks at the polaritonic frequencies of the Dicke model.

In addition, we simulate the coupling between different shaped ferromagnets and cavity photons yielding results comparable with recent experiments.

References

[1] A. Vansteenkiste et al., AIP. Adv. **4** (2014) 107133
[2] J. Román-Roche, F. Luis, D. Zueco, Phy. Rev. Let. **127** (2021) 167201

Quantum reservoir computing in finite dimensions

Rodrigo Martínez-Peña[1]
Juan-Pablo Ortega[2]

[1]*Donostia International Physics Center, Paseo Manuel de Lardizabal 4, E-20018 San Sebastián, Spain*
[2]*Division of Mathematical Sciences, Nanyang Technological University, 21 Nanyang Link, Singapore 637371*

rmartinez@ifisc.uib-csic.es

Quantum reservoir computing (QRC) is a machine learning technique where complex quantum systems are exploited to solve temporal tasks, such as predicting chaotic time series and complex spatiotemporal dynamics [1]. Most existing results in the analysis of QRC systems with classical inputs have been obtained using the density matrix formalism [2]. Our work shows that alternative representations can provide better insights when dealing with design and assessment questions. It has been shown that these vector representations yield state-affine systems (SAS) previously introduced in the classical reservoir computing literature and for which numerous theoretical results have been established. This connection has been used to show that various statements in relation to the fading memory (FMP) and the echo state (ESP) properties are independent of the representation, and also to shed some light on fundamental questions in QRC theory in finite dimensions. Our conclusions can be summarised as: the necessary and sufficient condition that makes a quantum reservoir valuable is strictly contractive dynamics towards input-dependent fixed points. Figure 1 is an illustrative example of our theoretical results. In this example, a single qubit is driven by a temporal signal, and having an input-dependent (bottom) fixed point or not (top) completely determines the usefulness of the system.

References

[1] Fujii, K., & Nakajima, K. (2017). Physical Review Applied, 8(2), 024030.
[2] Chen, J. (2022). Ph. D. thesis, UNSW Sydney).

Figures

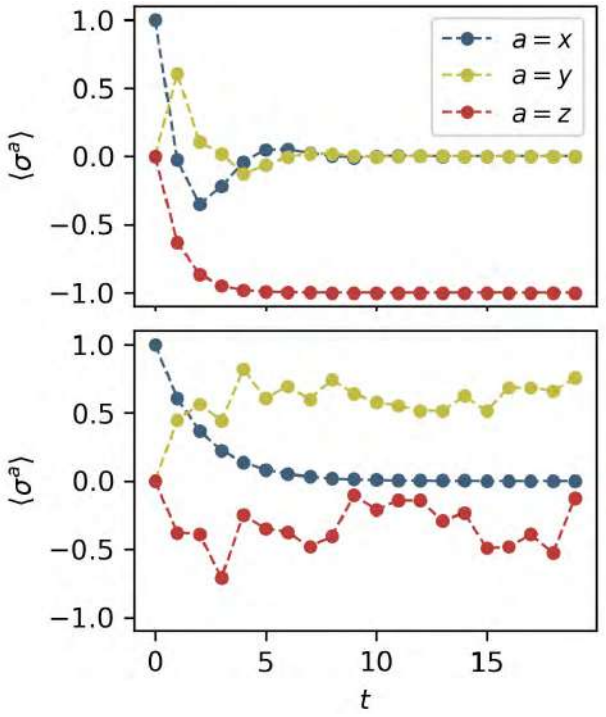


Figure 1: Dynamics of single-qubit observables when driven by a temporal input signal. Top picture represents an input-independent fixed point case while the bottom picture represents an input-dependent fixed point case.

Resilient Intraparticle Entanglement and its Manifestation in Spin Dynamics of Disordered Dirac Materials [1]

Jorge Martínez Romeral
Aron W. Cummings and Stephan Roche

ICN2, Bellaterra (Barcelona), Spain.

jorge.martinez@icn2.cat

Topological quantum matter exhibits novel transport phenomena driven by entanglement between internal degrees of freedom, as for instance generated by spin-orbit coupling effects [2]. Here we report on a direct connection between the mechanism driving spin relaxation and the intertwined dynamics between spin and sublattice degrees of freedom in disordered graphene, Figure 1. Beyond having a direct observable consequence, such intraparticle entanglement is shown to be resilient to disorder, pointing towards a novel resource for quantum information processing, Figure 2.

References

[1] Jorge Martínez Romeral, Aron W.Cummings, Stephan Rochei: arXiv:2310.17950 (2023)

[2] Bruna Gabrielly de Moraes, Aron W.Cummings, Stephan Roche, Phys Rev B, 102 (2020) ,041403.

Figures

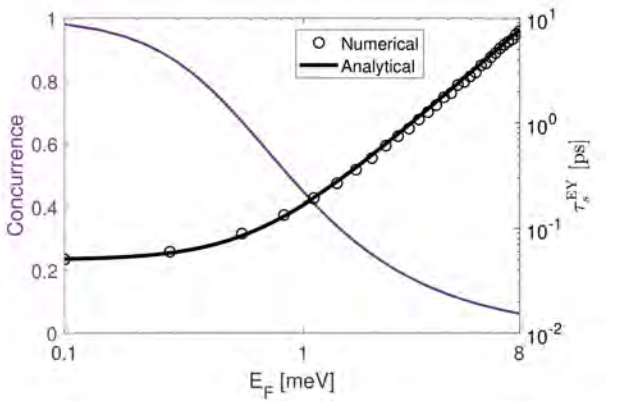


Figure 1: Numerical and analytical spin relaxation times due to the EY mechanism (black, right axis), along with the concurrence (purple, left axis), as a function of the Fermi energy.

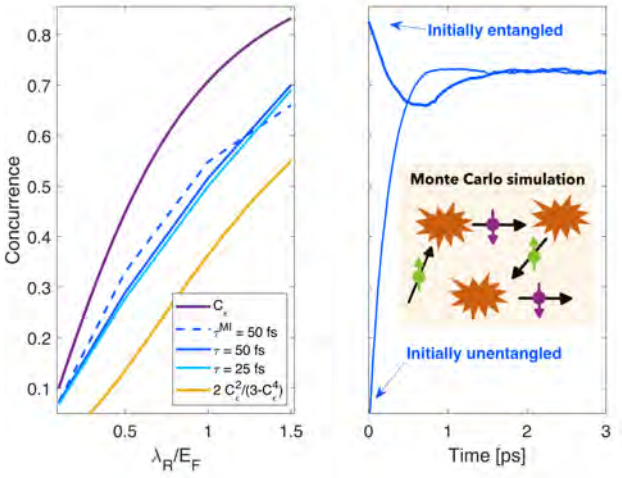


Figure 2: Left panel: Long-time concurrence for different scattering times in the presence of intravalley charge impurities (solid blue lines) and magnetic impurities (dashed blue line). The solid purple line indicates the concurrence of the eigenstates of the system and the upper bound of the converged concurrence, and the solid yellow line represents the lower bound of the converged concurrence. Right panel: concurrence dynamics for the initial states. The inset shows a schematic of the semiclassical Monte Carlo simulation.

Topological properties of a non-Hermitian quasi-1D chain with a flat band

Carolina Martinez Strasser
M.A.J. Herrera, A. García-Etxarri, G.Palumbo, F.K.Kunst, D.Bercioux

Manuel Lardizabal Ibilbidea, 4, 20018 Donostia, Gipuzkoa, España

carolina.martinez@dipc.org

The spectral properties of a non-Hermitian quasi-1D lattice in two of the possible dimerization configurations are investigated. Specifically, it focuses on a non-Hermitian diamond chain that presents a zero-energy flat band. The flat band originates from wave interference and results in eigenstates with a finite contribution only on two sites of the unit cell. To achieve the non-Hermitian characteristics, the system under study presents non-reciprocal hopping terms in the chain. This leads to the accumulation of eigenstates on the boundary of the system, known as the non-Hermitian skin effect. Despite this accumulation of eigenstates, for one of the two considered configurations, it is possible to characterize the presence of non-trivial edge states at zero energy by a real-space topological invariant known as the biorthogonal polarization. This work shows that this invariant, evaluated using the destructive interference method, characterizes the non-trivial phase of the non-Hermitian diamond chain. For the second non-Hermitian configuration, there is a finite quantum metric associated with the flat band. Additionally, the system presents the skin effect despite the system having a purely real or imaginary spectrum. The two non-Hermitian diamond chains can be mapped into two models of the Su-Schrieffer-Heeger chains, either non-Hermitian, and Hermitian, both in the presence of a flat band. This mapping allows to draw valuable insights into the behavior and properties of these systems. [1]

References

[1] C. Martínez-Strasser, M. A. J. Herrera, A. García-Etxarri, G. Palumbo, F. K. Kunst, D. Bercioux, Topological Properties of a Non-Hermitian Quasi-1D Chain with a Flat Band. Adv Quantum Technol. 2023, 2300225

Figures

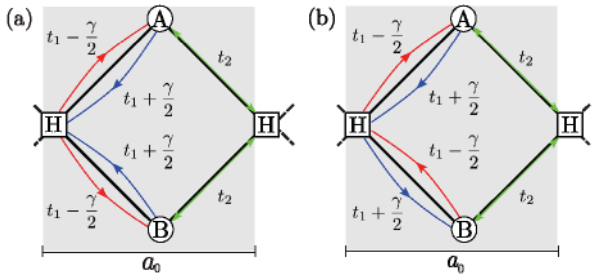


Figure 1: Sketch of the non-Hermitian diamond lattice in the A and B configurations, panel (a) and (b), respectively.

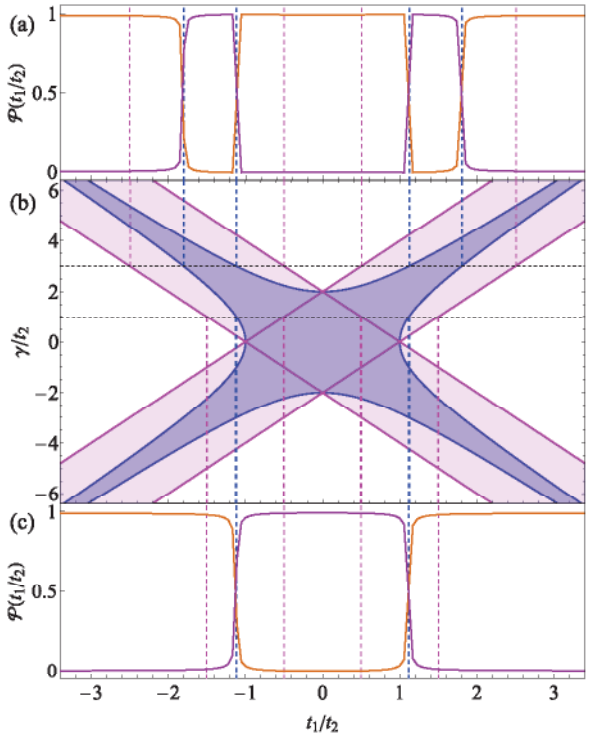


Figure 2: Phase diagram of the DCA model along with the biorthogonal polarization of two cuts in this phase diagram.

Hamiltonian Forging of a Thermofield Double

Javier Mas[1]
Daniel Faílde[2], Juan Santos-Suárez[1], David A. Herrera-Martí[3]
[1] *Universidad de Santiago de Compostela e IGFAE, Santiago de Compostela, España*
[2] *Galicia Supercomputing Center (CESGA), Santiago de Compostela, Spain*
[3] *Université Grenoble Alpe, CEA List, 3800 Grenoble, France*

javier.mas@usc.es

We address the variational preparation of Gibbs states as the ground state of a suitably engineered Hamiltonian acting on the doubled Hilbert space. The construction is exact for quadratic fermionic Hamiltonians and gives excellent approximations up to fairly high quartic deformations. We provide a variational circuit whose optimization returns the unitary diagonalizing operator, thus giving access to the whole spectrum. The problem naturally implements the entanglement forging ansatz, allowing the computation of Thermofield Doubles with a higher number of qubits than in competing frameworks.

Figures

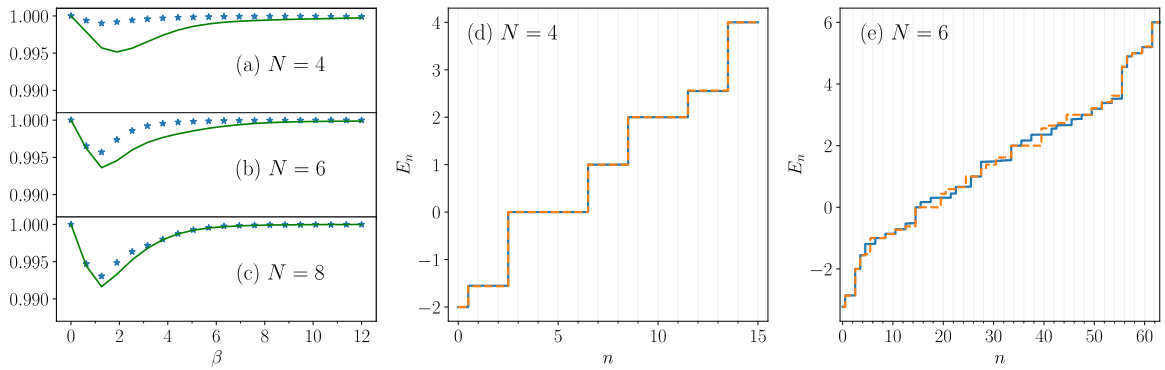


Figure 1:
Simulation for the Hubbard model at t = U = 1. Left, overlap of the engineered variational ground state with the searched Thermofield Double. Right, full spectrum at values of N=4, 6 in orange, versus exact diagonalization, in blue.

References

[1] Daniel Faílde, Juan Santos-Suárez, David A. Herrera-Martí and Javier Mas. https://arxiv.org/abs/2311.10566

Quantum circuits with multiterminal Josephson-Andreev junctions

F. J. Matute-Cañadas[1],
L. Tosi[2] and A. Levy Yeyati[1]

[1]Dpto. de Física Teórica de la Materia Condensada, IFIMAC and INC, Universidad Autónoma de Madrid, 28049 Madrid, Spain
[2]Centro Atómico Bariloche and Inst. Balseiro, CNEA, CONICET 8400 S. Carlos de Bariloche, Río Negro, Argentina
francisco.matute@uam.es

In quantum circuits, a conventional tunnel Josephson junction is described in terms of its macroscopic degrees of freedom: the number of tunneled Cooper pairs and its conjugate variable, the phase difference. But this approximation is only valid when the fermionic excitations of the junction itself are far from the lowest circuit levels. In fact, these junctions are just a particular case of a weak link between superconductors, where their internal structure combines with the superconducting leads to form Andreev bound states, typically examined at a fixed phase difference. Here [1], we explore the intermediate regime, i.e., a weak link where the phase fluctuations are important, which is now becoming experimentally accessible [2]. We consider a multiterminal junction embedded in different kinds of circuits and discuss, on the one hand, its application to the design of protected qubits [3] and, on the other hand, more fundamental questions about its topological properties and the proper quantization rules [4].

References

[1] Cf. arXiv:2312.17305 (2023)
[2] A. Bargerbos et al., Phys. Rev. Lett., 124, 246802 (2020); M. Coraiola et al., arXiv:2307.06715; T. Vakhtel et al., Phys. Rev. B 107, 195405 (2023), arXiv:2310.03102 (2023)
[3] A. Gyenis et al., PRX Quantum 2, 030101 (2021)
[4] R. P. Riwar et al, Nat. Comm., 7, 11167 (2016), npj Q. Inf. 8, 36 (2022); X. You et al., Phys. Rev. B, 99 174512 (2019)

Figures

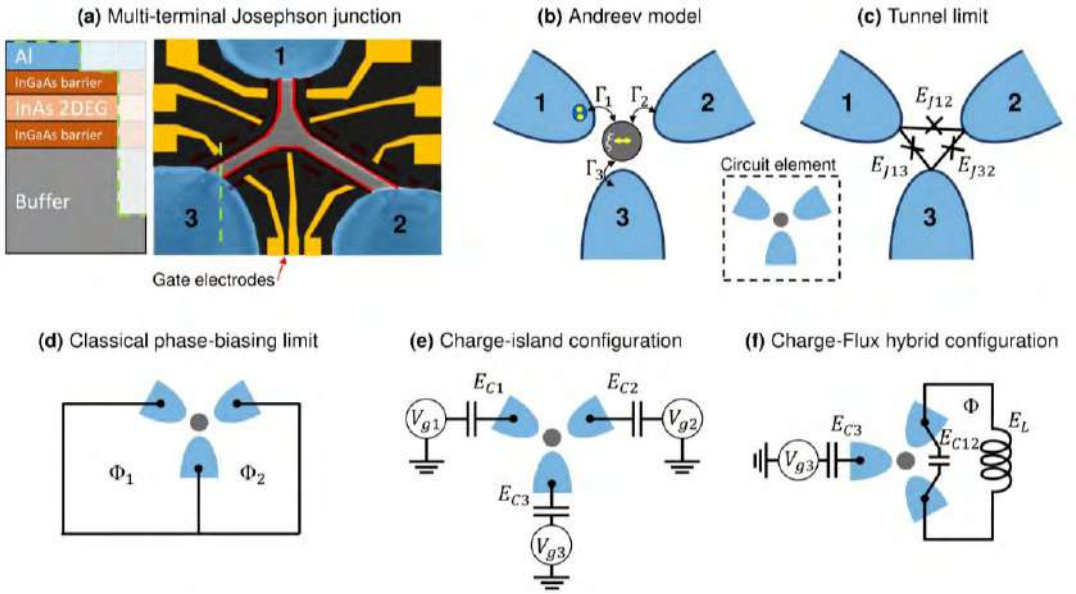


Figure 1: (a) Possible realization of the trijunction with 3 superconducting leads (blue) and a central region confined by tunable barrier gates (yellow). (b) Model accounting for the central region by a single level. (c) Effective model with 3 tunnel Josephson junctions. (d-f) Three circuits we analyse: in (d), the phases are fixed by external fluxes; in (e), the leads are islands with finite charging energy; in (f), two leads form a loop with finite inductance – this configuration can implement analogues of the bifluxon and the 0-π qubits, protected against decoherence induced by charge and flux noise.

Accessing the dynamics of a single spin with a polarization-dependent projective measurement

A. Medeiros Garay[1]
M. Gundín-Martinez[1], E. Mehdi[1], D. A. Fioretto[1], N. Somaschi[2], A. Lemaître[1], I. Sagnes[1], N. Belabas[1], O. Krebs[1], P.Senellart[1] and L. Lanco[1,3]

[1]*Université Paris Saclay, C2N, CNRS, 91120, Palaiseau, France*
[2]*Quandela SAS, 10 Bd Thomas Gobert, 91120, Palaiseau, France*
[3]*Université Paris Cité, 75013, Paris, France*

adria.medeiros@universite-paris-saclay.fr

Key challenges to harness charged semiconductor quantum dots (QD) as qubits are to measure and control the dynamic properties of the resident charge [1]. Indeed, the spin coherence time is one of the limiting factors on the generation of cluster states [2]. Current approaches rely on controlled sequences of pulses and repeated strong measurements of the spin state to measure either lifetime or coherence.

Here, exploiting giant Kerr rotations [3], we introduce a time-dependent tomography protocol to probe the complete dynamics of a single spin in a micropillar cavity. This procedure is based on the interference between the reflected light from the cavity and the single photons from an electron confined in an InGaAs QD when applying a transverse magnetic field (Fig. 1). The information of the electronic spin state is encoded on the polarization degree of freedom of the reflected light.

By performing a polarization dependent measurement on a first photon, we access the conditional density matrix of the spin state. We track its evolution back to the stationary regime through the polarisation state measurement of the successive photons (Fig. 2). With this time-dependent polarization tomography protocol, both the coherence (~2 ns) and the lifetime (~5 ns) of the electron spin can be inferred.

References

[1] N. Coste et al., *Quantum Sci. Technol. 8* (2023) 025021
[2] N. Coste et al., Nature Photonics **17** 582-587 (2023)
[3] E. Mehdi et al., Nat. Commun. **15**, 598 (2024)

Figures

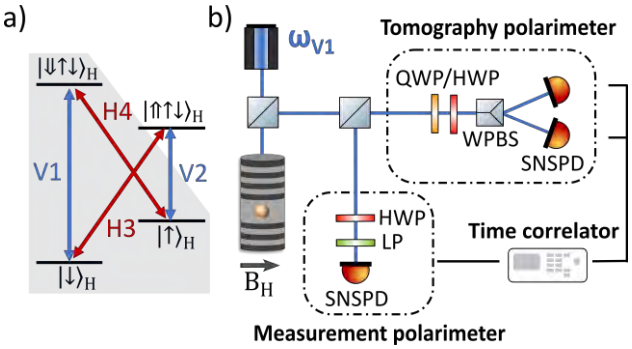


Figure 1: a) Energy levels of the QD system. We drive transition V1 at ω_{V1} with a cw laser and the photons emitted by transitions 1 and 4 are collected. H and V refer to linear polarization states. **b)** Experimental setup with two polarimeters: the measurement polarimeter performs a projective measurement along a given polarization state; the tomography polarimeter measures the polarization state of the reflected photons and track the evolution of the spin state.

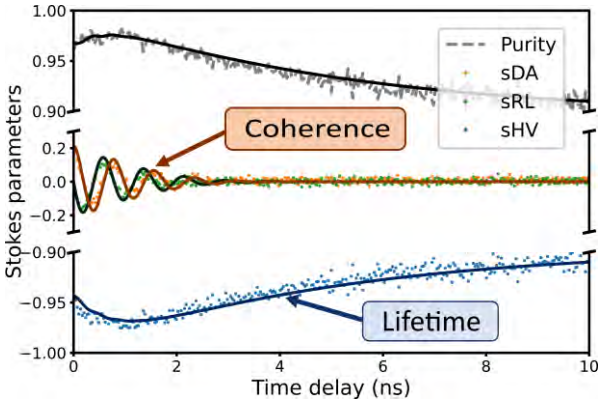


Figure 2: Time-evolution of the polarization state of the reflected photons after performing a measurement on the electronic spin at t=0. The Stokes parameters sHV, sDA and sRL describe the polarization state of the reflected light in the Poincaré sphere and measures both the coherence and lifetime of the free-evolving spin state.

Thermoelectric signatures of Bogoliubov Fermi Surface in superconducting 3D Topological Insulator Heterostructures

Phillip Mercebach[1]
Bo Lu[2], Keiji Yada[3], Yukio Tanaka[3], Pablo Burset[1]

[1]Department of Theoretical Condensed Matter Physics, Condensed Matter Physics Center (IFIMAC) and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, 28049 Madrid, Spain
[2]Department of Physics, Tianjin University, Tianjin 300072, China
[3]Department of Applied Physics, Nagoya University, Nagoya 464-8603, Japan

Phillip.mercebach@uam.es

A weak magnetic field applied to a superconductor (SC) can selectively close the superconducting gap, giving rise to a segmented Fermi surface. These so-called Bogoliubov Fermi surfaces (BFSs) have been observed in recent experiments in a three-dimensional topological insulator (3DTI) in proximity to a SC. In this work, we employ a scattering matrix formalism to reveal signatures of the BFS in the thermoelectric transport properties of a superconducting hybrid junction on the surface of a 3DTI. We consider a setup with two normal probes (N) connected to a SC (N-SC-N configuration) to study local and nonlocal transport under an applied in-plane magnetic field. With a temperature gradient, the magnetic field creates equal local and nonlocal electric Seebeck currents which follow the orientation of the BFS. Furthermore, we predict a switch in the required voltage bias enabling local and nonlocal Peltier cooling, which again depends on the orientation of the BFS. As a result, our work opens new perspective applications in spintronics and provides novel ways of exploring unconventional superconducting phases.

Figures

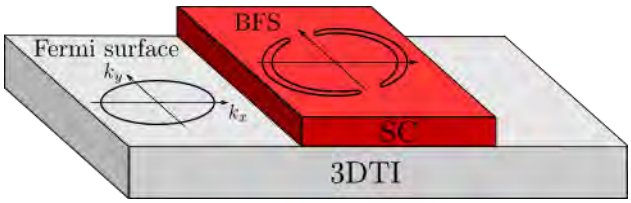


Figure 1: Sketch of the N-SC-N junction where a superconductor is deposited on the surface of a 3DTI. On each region, N and SC, we show an energy contour of the bands at the Fermi level. When $m_0>\Delta$ the superconducting gap closes in a finite region creating a Bogoliubov Fermi surface: a gapless superconducting state.

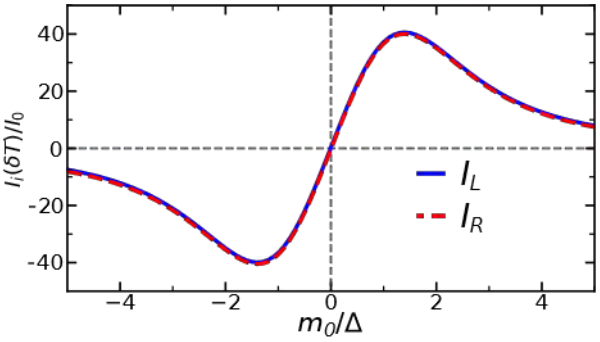


Figure 2: Zero bias electric current in the normal left (I_L) and right (I_R) regions for a given temperature gradient across the junction δT, plotted as a function of applied the magnetic field, m_0, that induces the BFS. We predict a BFS induced Seebeck coefficient of $S\approx 30\mu V/K$ in typical topological insulator-superconductor junctions.

Maximally Violation of Local Realism Using Optical Hybrid Entanglement

Morteza Moradi, Magdalena Stobińska

Faculty of Mathematics, Informatics and Mechanics, University of Warsaw, Banacha 2, 02-097 Warsaw, Poland.
m.moradi@uw.edu.pl

Abstract

Optical hybrid entanglement can be created between two qubits, one encoded in a single photon and another one in coherent states with opposite phases:

$$|\psi\rangle = (|0\rangle|\mathrm{Cat}^{-}\rangle + |1\rangle|\mathrm{Cat}+\rangle)/\sqrt{2}$$

It opens the path to a variety of quantum technologies which often require testing for quantum nonlocality in underlying resources. These tests have been accomplished for two-mode CV states [1], this task becomes particularly challenging when dealing with optical hybrid entanglement which has a DV-CV nature [2].

Here we propose to employ the CHSH inequality and either on/off or parity measurements for testing the nonlocality in the optical hybrid entanglement state $|\psi\rangle$. In Fig.1(a), two modes of the shared state $|\psi\rangle$ are locally interfered with coherent fields, $|\alpha\rangle$ and $|\beta\rangle$ in the homodyne limit (HD), followed by measurements of efficiency $0<\eta\leq 1$. In this limit the beam splitter interference may be approximated with displacement operator $D(\delta)$ with $\delta_a = -i\,\alpha\sqrt{r_a}$ and $\delta_b = -i\,\beta\sqrt{r_b}$ where r_a, r_b are beam splitters' reflectivities and the δ_a and δ_b act as the Bell test settings. The readouts k and L are then coarse-grained into two sets, either zero/non-zero or even/odd numbers of photons.

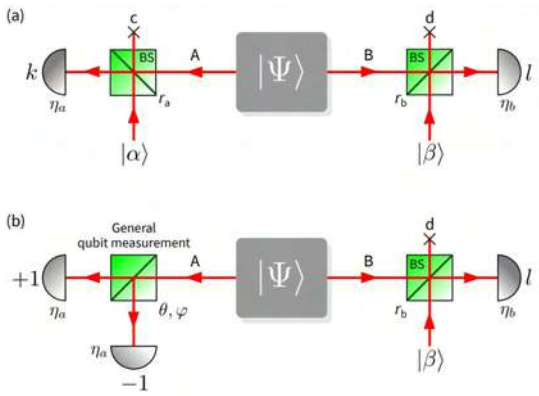


Figure 1: Bell tests setup for optical hybrid entanglement state $|\psi\rangle$.

We show that a practical violation of CHSH inequality is possible with simple photon number on/off measurements if detection efficiencies stay above 82%. We observe Bell violations, up to $S=2.71$, which are demonstrated for states with amplitudes $\gamma < 1.25$. Another test, based on parity measurements, requires 94% efficiency but works well in the limit of higher photon populations. In the ideal lossless conditions, this allows one to perform the even/odd Bell test for arbitrarily large amplitude γ, reaching the maximal value of $S=2.44$.

Another strategy linked to the specific nature of the considered state is to perform the hybrid Bell test, in which a general qubit measurement is performed on mode A while mode B is tested with on/off or parity measurements (Fig.1b). This strategy allowed us to maximally violate the CHSH inequality, up to $S = 2\sqrt{2}$.

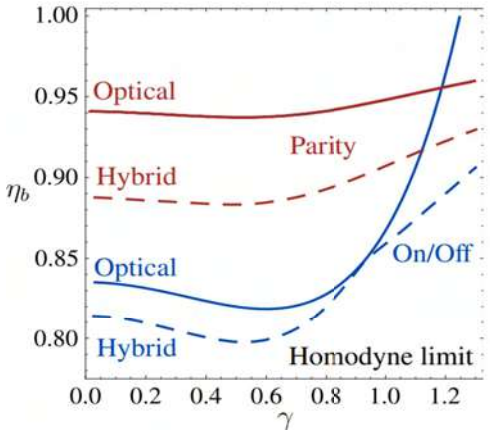


Figure 2: Comparison of CHSH violation for various detection strategies: on/off (blue lines) and parity (red line) with full optical (solid lines) and hybrid (dashed lines) measurements. The various lines correspond to the thresholds above which CHSH violation is observed.

All the tests use no postselection of the measurement outcomes and they are free of the fair-sampling hypothesis. In Fig.2, we compared CHSH violation for various detection strategies.

References

[1] Z.-B. Chen, J.-W. Pan, G. Hou, and Y.-D. Zhang, PRL, 88 (2002) 040406.
[2] H. Kwon and H. Jeong, PRA, 88 (2013) 052127.

Switching currents limited by the inverse proximity effect in a flux-tunable superconductor

Gabriel Moraes Oliveira1*

Ignacio Casal Iglesias1, Mario Gómez1, Ángel Ibabe1, Gorm O. Steffensen2, Thomas Kanne3, Jesper Nygård3, Alfredo Levy Yeyati2, and Eduardo J. H. Lee1

1. Condensed Matter Physics Department, Universidad Autónoma de Madrid, 28049 Madrid, Spain
2. Department of Theoretical Condensed Matter Physics, Universidad Autónoma de Madrid, 28049 Madrid, Spain
3. Center for Quantum Devices & Nano-science Center, Niels Bohr Institute, Univ. of Copenhagen, Copenhagen, Denmark

*gabriel.moraes@uam.es

Hybrid superconductor-semiconductor nanodevices have been intensively explored in the past decade in the context of topological superconductivity [1, 2] and for the development of hybrid superconducting qubits [3]. For these directions, the field has relied on the development of nanostructures with a clean superconductor-semiconductor interface, to ensure a strong superconducting proximity effect. This is typically achieved by the in-situ deposition of superconductors, e.g., by the epitaxial growth of Al shells [4-5].

Of particular interest to this work are so-called full-shell InAs-Al nanowires, whose superconductivity can be tuned by the Little-Parks effect. These wires have received a lot of attention as a potential platform for generating topological superconductivity [6-7]. Interestingly, a recent work [8] addressing the properties of the Al shell in such wires has reported on an anomalous metallic phase in the Little-Parks regime, suggesting that the superconductivity in these systems is interesting in its own. In this work, we perform a thorough study of the superconductivity of the Al layer in similar full-shell nanowires. We have found that the switching current of these wires is typically limited by the inverse proximity effect imposed by the electrical leads, being several times lower than the expected value due to depairing. In addition, we observe that such a premature switching can either trigger a thermal runaway, in which the entire Al shell turns normal due to Joule heating, or to the stabilization of a normal region within the shell, reflected by the appearance of an intermediate resistance state. Remarkably, this intermediate resistance state displays a behavior typically associated with Josephson junctions, most notably the onset of Shapiro Steps when applying AC radiation [9].

References

[1] Kitaev, A. Yu. *Physics-uspekhi* 44.10S (2001): 131.
[2] Prada, Elsa, et al. *Nature Reviews Physics* 2.10 (2020): 575-594.
[3] Aguado, Ramón. *Applied Physics Letters* 117.24 (2020): 240501.
[4] Krogstrup, P., et al. *Nature materials* 14.4 (2015): 400-406.
[5] Kanne, Thomas, et al. *Nature Nanotechnology* 16.7 (2021): 776-781.
[6] Vaitiekėnas, S., et al. "Flux-induced topological superconductivity in full-shell nanowires." *Science* 367.6485 (2020): eaav3392.
[7] Valentini, Marco, et al. "Majorana-like Coulomb spectroscopy in the absence of zero-bias peaks." *Nature* 612.7940 (2022): 442-447.
[8] Vaitiekėnas, S., Peter Krogstrup, and C. M. Marcus. *Physical Review B* 101.6 (2020): 060507.

[9] Bae, Myung-Ho, et al. *Nano letters* 9.5 (2009): 1889-1896.

Electromagnetic coupling and transport in a topological insulator–graphene heterostructure

Enrique Muñoz
D, Bonilla, J. Castaño-Yepes, A. Martín-Ruiz

Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Santiago, Chile

ejmunozt@uc.cl

Abstract

The electromagnetic coupling between heterostructures made of different materials is of great interest, both from the perspective of discovering new phenomena, as well as for its potential applications in novel devices. In this work, we study the electromagnetic coupling of a heterostructure made of a topological insulator (TI) slab and a single graphene layer (Fig. 1), where the later presents a diluted concentration of ionized impurities. We explore the topological effects of the magnetoelectric polarizability of the TI, as well as its relative dielectric permittivity on the electrical conductivity in graphene at low but finite temperatures.

We consider a heterostructure composed of a TI slab and a single graphene layer, and we further assume that a diluted concentration of ionized impurities is present in the graphene monolayer. The presence of such charged impurities will induce a local distortion of the charge density of the 2D electron gas, leading to a nontrivial electromagnetic coupling between the TI and the graphene monolayer in the heterostructure. As a probe of this coupling, we further studied the electrical conductivity as a function of temperature, by including the scattering effects with the local electromagnetic field configuration via the Kubo linear response formalism. We applied our theoretical results to model the electromagnetic coupling in heterostructures made of different TIs (PbTe, Bi2Te3, PbSe, PbS, Bi2Se3, TlBiSe2, TbPO4). Our analytical and numerical results suggest that, among the properties of the TIs, the dielectric permittivity ε1 is the most relevant at tuning the electronic transport in the coupled graphene monolayer. On the other hand, we also observed that the topological effects arising from the presence of the MEP coefficient θ are comparatively very small even at zero temperature.

References

[1] D. Bonilla, J. Castaño-Yepes, A. Martín-Ruiz, E. Muñoz, Physical Review B 107, 245103 (2023).

Figures

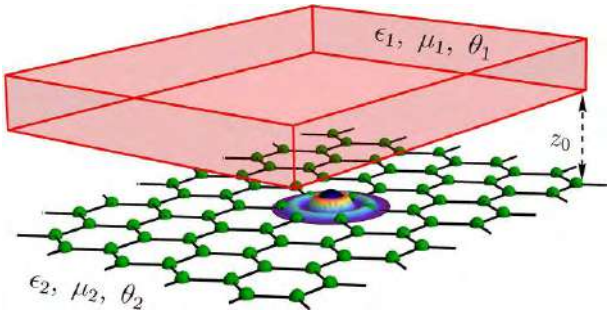


Figure 1: Graphene-TI heterostructure considered in this work

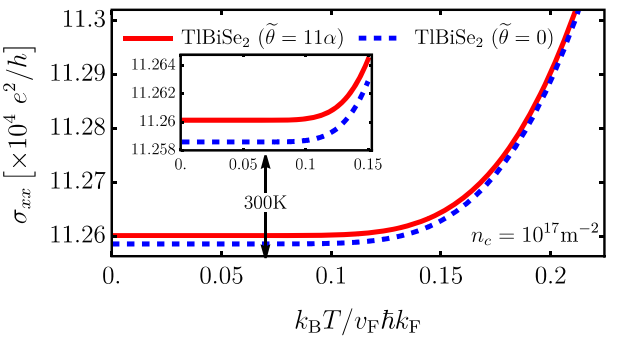


Figure 2: Electrical conductivity in the graphene monolayer as a function temperature

Experimental realization of the cumulant expansion of the Lanczos Method for the calculation of Green's functions

David Muñoz Ramo
Gabriel Greene-Diniz, Kentaro Yamamoto, Nathan Fitzpatrick, Rei Sakuma, Evgeny Plekhanov

Quantinuum PLC, Terrington House,13-15 Hills Road, Cambridge, UK

David.munozramo@quantinuum.com

In this work, we present a quantum computational method to calculate the many-body Green's function matrix in a spin orbital basis. We apply our approach to finite-sized fermionic Hubbard models and related impurity models within Dynamical Mean Field Theory, and demonstrate the calculation of Green's functions on Quantinuum's H1-1 trapped-ion quantum computer. Our approach involves a cumulant expansion of the Lanczos method, using Hamiltonian moments as measurable expectation values. This bypasses the need for a large overhead in the number of measurements due to repeated applications of the variational quantum eigensolver (VQE), and instead measures the expectation value of the moments with one set of measurement circuits. From the measured moments, the tridiagonalised Hamiltonian matrix can be computed, which in turn yields the Green's function via continued fractions. While we use a variational algorithm to prepare the ground state in this work, we note that the modularity of our implementation allows for other (non-variational) approaches to be used for the ground state.

Figures

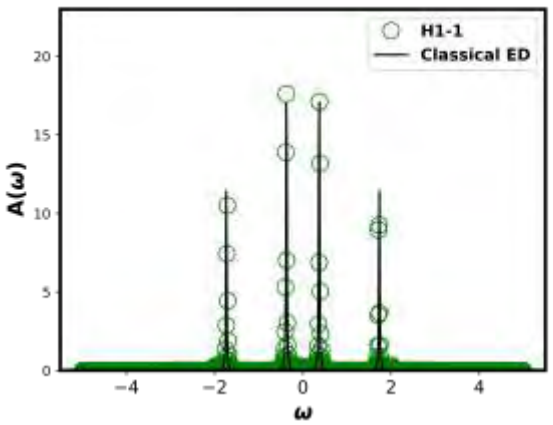


Figure 1: Spectral function for a Hubbard dimer obtained with the H1 Quantinuum ion trap device, compared with classical results

QAOA ansatz and differential evolution for quantum molecular comparison

Mariamo Mussa Juane[1]
Antón Rodríguez Otero[2], María Paredes-Ramos[3], Jochem Nelen[4], Alejandro Borrallo Rentero[2], José Manuel López Vilariño[3], Andrés Gómez Tato[1]

[1]*Galicia Supercomputing Center, Avenida de Vigo s/n, 15705 Santiago de Compostela*
[2]*Fujitsu International Quantum Centre, Rúa da República Checa, 40, 15707 Santiago de Compostela*
[3]*Hijos de Rivera SAU, C/José María Rivera Corral 6, 15008 A Coruña*
[4]*UCAM Av. de los Jerónimos, 135, 30107 Guadalupe de Maciascoque, Murcia*

mmussa@cesga.es

Abstract

The perception of tastes and sensations: sweet, sour, bitter, acid, salty, umami, but also freshness, cold, warmth, and even carbonation, amongst others, is mediated by different receptors. With a virtual screening (VS) method implemented and refined for quantum gate-based computation, we can predict whether a molecule binds adequately to the freshness receptor, activating the transmission signal that indicates the freshness sensation to the brain. The aim is to design, before consumption, tailor-made food and beverage products.
The VS method used determines the maximum common substructure between molecules, mappable to the maximum-weighted set problem over a conflict graph, where the edges are conflicts to avoid. For this case, we implement a weighted variation of the original QAOA with (1+n) parameters per layer inspired by the ma-QAOA [1], being n the number of qubits. We choose differential evolution as the optimiser since it evades local minima [2]. With two layers, we find optimal configurations until 19 qubits through emulation with standard deviations of upper order 0.1 (Figure 1).

References

[1] Herrman, R., Lotshaw, P.C., Ostrowski, J. et al. Multi-angle quantum approximate optimization algorithm. Sci Rep 12, 6781 (2022).
[2] Faílde, D., Viqueira, J.D., Mussa Juane, M. et al. Using Differential Evolution to avoid local minima in Variational Quantum Algorithms. Sci Rep 13, 16230 (2023).

Figures

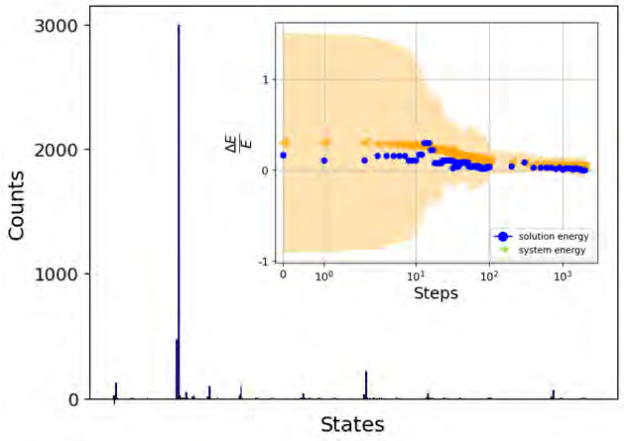


Figure 1: Final distribution with 3000 out of 10000 counts for the optimal configuration with 0 conflicts (molecule α-cedrene with 19 qubits). Embedded, energy evolution of the optimal configuration with its standard deviation and of the whole system.

Acknowledgements

This work was supported by MICINN through the European Union NextGenerationEU recovery plan (PRTR-C17.I1), and by the Galician Regional Government through the "Planes Complementarios de I+D+I con las Comunidades Autónomas" in Quantum Communication.

Bragg-spectroscopy of a dissipation-induced instability in an atom-cavity system

Gabriele Natale
Alexander Baumgärtner, Justyna Stefaniak, Simon Hertlein, David Baur, Dalila Rivero, Tobias Donner, and Tilman Esslinger

Institute for Quantum Electronics,
Otto-Stern-Weg 1, CH-8093 Zürich, Switzerland

gnatale@phys.ethz.ch

The study of collective excitations is a powerful tool to gain insight into a many-body system. By examining the low-lying energy spectrum and its modes, we can identify imminent phase transitions and better understand the nature of different phases. In our experiment, we load a Bose-Einstein Condensate (BEC) into a high-finesse cavity. The coupling of the BEC and the cavity produces long-range interactions, which can result in two roton-like excitation modes. These modes correspond to two exotic superradiant phases that have been previously observed and studied [1].
Due to inherent dissipation in our system, these two modes couple when their energies are close leading to a topological pump [2]. At this exceptional point, the eigenvalues and eigenvectors related to the two modes are expected to hybridize.
To measure these two low-lying excitations simultaneously, we use Bragg-spectroscopy. We observe the individual softening of the two modes as they approach their respective phases, along with a diverging susceptibility. By leveraging the full tunability of our non-Hermitian system, we explore a parameter regime where the two modes coalesce, causing an exceptional point and the associated dynamical instability.

References

[1] L. Xiangliang et al., Phys. Rev. Res. 3, L012024 (2021).
[2] D. Dreon et al., Nature 608, 494–498 (2022).

Limiting mechanisms for the lifetime and coherence of a hole-spin qubit strongly coupled to a cavity

Leo Noirot[1]
S. Zihlmann[1], C. X. Yu[1], J. C. Abadillo-Uriel[1], E. Dumur[1], B. Brun-Barrière[1], B. Bertrand[3], Y.-M. Niquet[2], S. De Franceschi, and R. Maurand[1]

[1]Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG-Pheliqs, Grenoble, France.
[2]Univ. Grenoble Alpes, CEA, IRIG-MEM-L Sim, Grenoble, France
[3]Univ. Grenoble Alpes, CEA, LETI, Minatec Campus, Grenoble, France.

leo.noirot@cea.fr

Spins in semiconductor quantum dots constitute a promising platform for scalable quantum information processing [1]. Coupling them strongly to the photonic modes of superconducting microwave resonators would enable fast non-demolition readout and long-range, on-chip connectivity, well beyond nearest-neighbor quantum interactions [2]. As the field of spin circuit quantum electro-dynamic (cqed) is growing, new experiments showed spin-photon coupling rates as high as 330 MHz and a 2-qubit gate mediated by a photonic interaction [3, 4]. However, up to now, all of the semiconductor spin-cqed devices have showed fast decoherence and relaxation times, mitigating the high fidelity control and readout usually achieved for spin qubits.

We present here an experimental study of a hole spin qubit embedded in a Si double quantum dot, strongly coupled to a microwave cavity thanks to the intrinsic spin-orbit interaction (SOI) of holes in Si. We measure relaxation (Γ_1) and decoherence (Γ_2) rates as a function of magnetic field, therefore controlling the qubit-cavity coupling as well as its energy through the magnetic-field dependence of the SOI. We span its energy over a range of 10GHz, crossing several cavity modes and identify photon emission (multimode Purcell effect) as one of the limiting mechanisms for the spin's lifetime. The decoherence shows signs of charge-noise induced dephasing as its magnetic-field dependence follows the second-order electrical susceptibility of the qubit. (Figure 2)

References

[1] Burkard G. et al, Rev. Mod. Phys. 95, 025003 (2021).
[2] Blais A. et al, Reviews of Modern Physics 93, 025005 (2021)
[3] Yu C.X. et al, Nature Nanotechnology volume 18, pages741–746 (2023)
[4] Dijkema J. et al, arXiv:2310.160805 (2023)

Figures

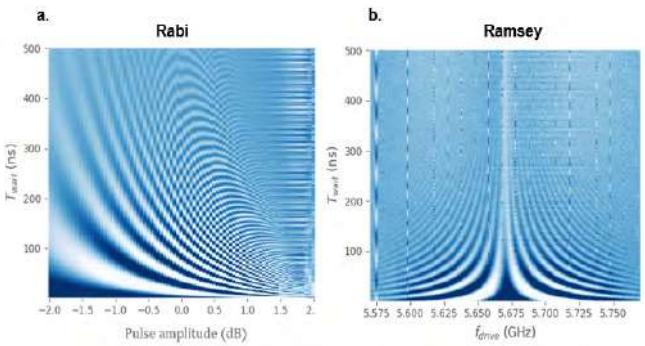


Figure 1: Power-dependence of Rabi oscillation and Ramsey interference of the spin state.

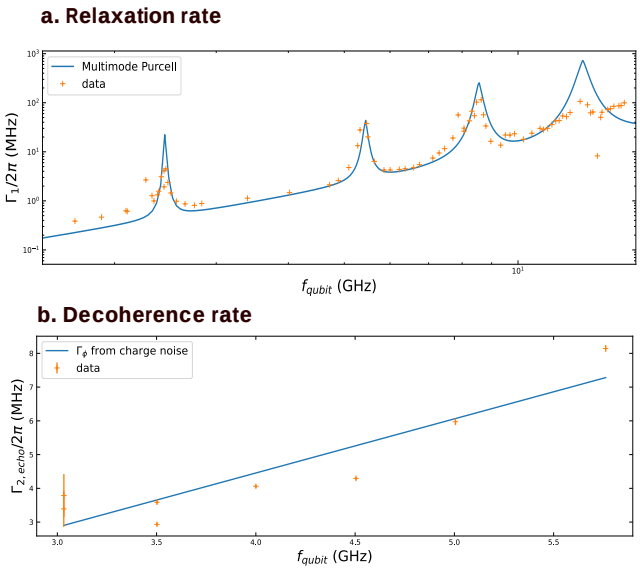


Figure 2: Energy dependence of the relaxation and decoherence rates of the spin state

Modelling Leakage with Perturbation Theory in Singlet-Triplet Spin Qubits

Oliva delMoral, Javier
Rubén M.Otxoa, Josu Etxezarreta Martinez and Pedro M. Crespo

Department of Basic Sciences, Tecnun – University of Navarra, 20018 Donostia-San Sebastian, Spain. Donostia International Physics Center (DIPC), 20018 Donostia-San Sebastian, Spain

jolivam@unav.es

Quantum computers are a promising technology poised to outperform classical computers in various problem domains. Despite their theoretical potential, qubits are susceptible to decoherence caused by interactions with their environment. These interactions sometimes lead to the population of higher energy levels, resulting in computational errors known as leakage errors. Recent research [1], has shown that quantum computers can prepare an initial state,, ρ_0 , more rapidly when more than two accessible levels are present. Consequently, leakage, instead of being a hindrance, could offer an advantage for quantum computing. We have conducted a study on how leakage induces dephasing in the time evolution, comparing scenarios with only two levels to those with more than two levels using perturbation theory, which elucidates the observed speedup.

In this poster, we will study the dynamics of Singlet-Triplet spin qubits (ST_0), which are qubits encoded in two electrons in two different quantum dots. These qubits are easier to control and suffer less dephasing due to interactions with the nuclei spins in their environment compared to single spin qubits. Spin qubits in quantum dots represent a promising technology for quantum computing. However, since these qubits have more than two accessible levels, they could populate levels outside of the computational basis ($|0\rangle$ and $|1\rangle$), making them a favourable scenario for experimental observation of this acceleration. We anticipate observing a trade-off between the acceleration caused by leakage and an increase in the decoherence experienced by the qubit.

References

[1] Asthana, Ayush et al., Phys. Rev. Appl., Vol. 19, issue 6, 2023.

Compressing neural networks by SVD in topological phase classification problem

Dmytro Oriekhov
Badr Zouggari, Guliuxin Jin, Eliska Greplova

Kavli Institute of Nanoscience, Delft University of Technology, 2628 CJ Delft, the Netherlands

d.oriekhov@tudelft.nl

Abstract
We study the efficiency of neural networks applied to classify topological phases in one-dimensional Su-Schrieffer-Heeger model [1]. We apply singular value decomposition (SVD) to the weight matrices of layers of a trained feed-forward neural network. It is shown that by selecting a small set of largest singular values, it is possible to compress the number of free parameters in weight matrices while maintaining high accuracy of the model. We compare the results with removing the weights by replacing values below threshold by zeros. The SVD approach demonstrates advantage in maintaining precision of while reducing the memory size required for the largest and several sequential layers. This agrees with a number of observations in literature about the essential info contained in the most important singular values [2,3]. We analyse how the weight vector corresponding to largest singular value transforms dataset and performs a selection of the 'important' elements in each dataset example. This approach can be applied for compressing models discussed in recent Refs.[4-6].

References

[1] Su, W. P.; Schrieffer, J. R.; Heeger, A. J. Physical Review Letters. 42 (25): 1698 (1979)
[2] Tukan et.al., Sensors, 21(16), 5599 (2021).
[3] C.-Y. Park and M. J. Kastoryano, Phys. Rev. Research 2, 023232 (2020)
[4] Lei Wang, PRB 94, 195105 (2016)
[5] D. Carvalho, et.al., PRB 97, 115453 (2018)
[6] P. Huembeli, et.al., PRB 97, 134109 (2018)

Figures

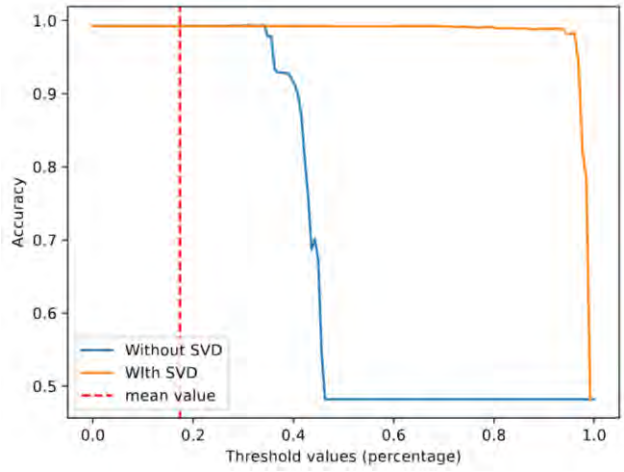


Figure 1: Performance of 3-layer feed-forward neural network with percentage of small weights weights or singular values (indicated in x-axis) being removed from the first layer. The network configuration used here is: input size 256 (all wave functions of length 16 SSH chain), output first layer 128, output second layer 64, output third layer 2. Only 8 singular values of first layer are important to maintain classification accuracy above the 95% level.

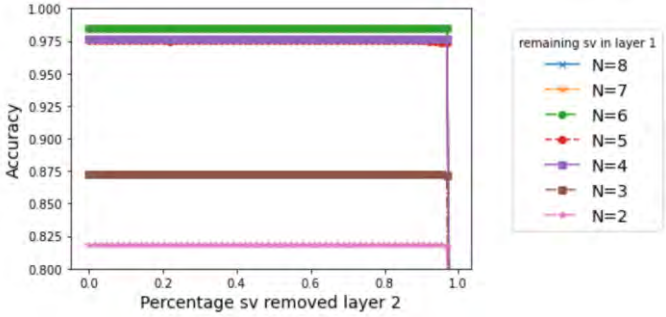


Figure 2: Accuracy of the network with few singular values left in first layer and percentage of singular values removed from second layer. Only 1 or 2 singular values in second layer store essential information for classification level of 95%. Curves correspond to number of singular values remaining in the first layer.

Addressing the scalability of quantum annealing of classical problems

Ana Palacios[1, 2]
Artur Garcia-Saez[1, 3], Marta P. Estarellas[1]

[1]*Qilimanjaro Quantum Tech, Carrer dels Comtes de Bell-Lloc, 161, 08014 Barcelona, Spain*
[2]*Departament de Física Quántica i Astrofísica, Universitat de Barcelona, Carrer de Martí i Franqués, 1, 08028 Barcelona, Spain*
[3]*Barcelona Supercomputing Center, Plaça Eusebi Güell, 1-3, 08034 Barcelona, Spain*

ana.palacios@qilimanjaro.tech

Quantum annealers are often presented as application-specific devices intended to harness quantum effects to solve classical optimisation tasks. This is due to the connection between the Ising model and QUBO (Quadratic Unconstrained Binary Optimisation) problems, to which several problems of interest can be mapped. However, the hard-wiring of a fully connected graph, a general requirement for these problems, is not scalable due to crosstalk and packing issues within the chip. We present a scalable architecture to embed an all-to-all connected Ising model within another Ising model defined on a graph of degree d = 3 containing exclusively 2-local interactions. This essentially amounts to an efficient braiding of logical chains of qubits which can be derived from a description of the problem in terms of triangles, naturally linking to a family of equivalent formulations of an Ising instance. We also devise strategies to address the challenges of scalable architectures, such as the faster shrinking of the gap due to the larger physical Hilbert space and the scaling of penalty strengths [1, 2], in the specific context of our architecture. These strategies consist on driver Hamiltonians that are more suited to the symmetries of the logical solution space, extending ideas from [3, 4]. The hereby proposed architecture opens an alternative route to scale up devices dedicated to classical optimization tasks within the quantum annealing paradigm.

References

[1] T. Albash, W. Vinci, and D. A. Lidar, Physical Review A 94, 022327 (2016).
[2] M. Lanthaler and W. Lechner, New Journal of Physics 23, 083039 (2021).
[3] I. Hen and F. M. Spedalieri, Physical Review Applied 5, 034007 (2016)
[4] I. Hen and M. S. Sarandy, Physical Review A 93, 062312 (2016).

Figures

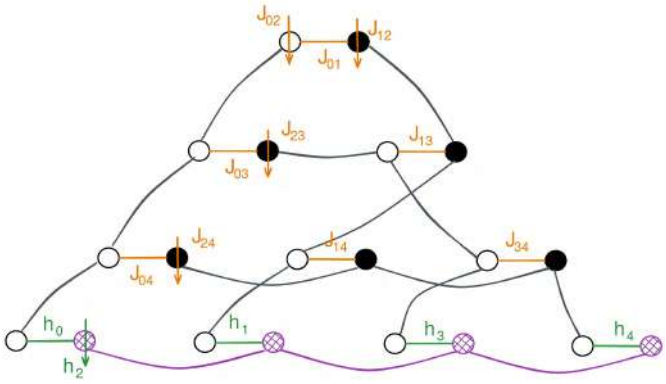


Figure 1: Schematic of the architecture for N=5 incorporating local fields.

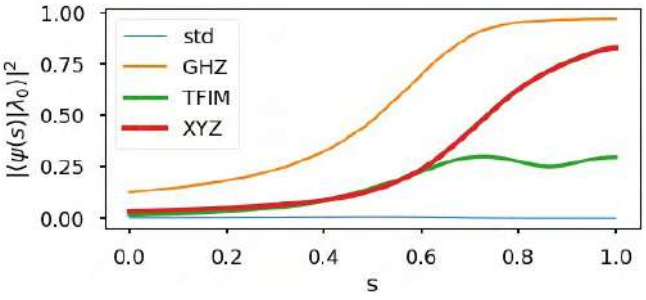


Figure 2: Success probability of finding the logical ground state along the anneal in a small example (3 logical variables, 9 physical qubits) for different driver Hamiltonians for an instance in which the logical ground state is in the (degenerate) 4th-excited manifold of the embedding Hamiltonian.

Efficient tensor network simulation of IBM's largest quantum processors

Siddhartha Patra [1,2]
Saeed S. Jahromi, [2]
Sukhbinder Singh, [2]
Román Orus [1,2]

1. *Donostia International Physics Center, Paseo Manuel de Lardizabal 4, E-20018 San Sebastián, Spain*
2. *Multiverse Computing, Paseo de Miram´on 170, E-20014 San Sebastián, Spain*
3. *Multiverse Computing, Spadina Ave., Toronto, ON M5T 2C2, Canada*
4. *Ikerbasque Foundation for Science, Maria Diaz de Haro 3, E-48013 Bilbao, Spain*

Contact: siddhartha.patra@dipc.org

Abstract

We show how quantum-inspired 2d tensor networks can be used to efficiently and accurately simulate the largest quantum processors from IBM, namely Eagle (127 qubits), Osprey (433 qubits) and Condor (1121 qubits). We simulate the dynamics of a complex quantum many-body system—specifically, the kicked Ising experiment considered recently by IBM in Nature 618, p. 500–505 (2023)—using graph-based Projected Entangled Pair States (gPEPS), which was proposed by some of us in PRB 99, 195105 (2019). Our results show that simple tensor updates are already sufficient to achieve very large unprecedented accuracy with remarkably low computational resources for this model. Apart from simulating the original experiment for 127 qubits, we also extend our results to 433 and 1121 qubits, and for evolution times around 8 times longer, thus setting a benchmark for the newest IBM quantum machines. We also report accurate simulations for infinitely-many qubits. Our results show that gPEPS are a natural tool to efficiently simulate quantum computers with an underlying lattice-based qubit connectivity, such as all quantum processors based on superconducting qubits.

References

[1] Patra et al, Phys. Rev. Research 6, 013326 (2024).
[2] Jahromi et al, Phys. Rev. B 99, 195105 (2019)

Figures

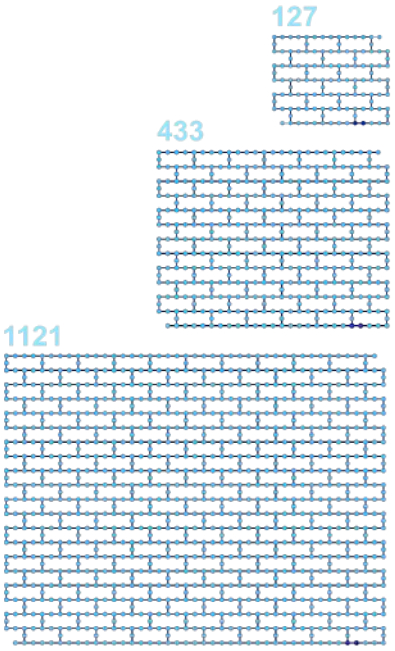


Figure 1: Different heavy-hexagon lattices, corresponding to the topology of qubit connectivity of three IBM quantum processors: (a) Eagle, with 127 qubits; (b) Osprey, with 433 qubits; (c) Condor, with 1121 qubits. Every dot in the lattices corresponds to a superconducting qubit, and every link corresponds to a qubit-qubit coupling.

Study of spectral spread in nitrogen vacancy centers in diamond for coherent spin control of electron and nitrogen nuclei ensembles

Ruben Pellicer-Guridi[1]
Jason Francis[1], Asier Mongelos[1], Angel Cifuentes[1], *Geza Giezke*[2,4], *Jorge Casanova*[3,5], *and* Gabriel Molina-Terriza[1,4]

[1]*Centro Física de Materiales, Donostia-San Sebastián, Spain;* [2]*Donostia International Physics Center,* [3]*Donostia-San Sebastián, Spain; EHU Quantum Center, Univeristy of the Basque Country UPV/EHU, Leioa, Spain;* [4]*IKERBASQUE, Basque Foundation for Science, Bilbao, Spain;* [5]*Department of Physical Chemistry, University of Basque Country UPV/EHU, Bilbao, Spain.*
ruben.pellicer@ehu.eus

Nitrogen Vacancy centers in diamond are a promising platform for a vast number of applications such as quantum sensing and quantum computing [1-3]. Many of these applications would also benefit from using spin ensembles to, for example, increase the signal-to-noise (SNR) in sensing applications, as the SNR increases proportionally to the square root of the number of Nvs [4]. The resonant frequency of different NV centers can vary within the same diamond crystal due to different variables such as strain. A large number of promising control protocols have been proven on single NVs, but these often rely on driving in resonance electron (Electron Spin Resonance - ESR) and/or nuclear spins (Nuclear Spin Resonance - NMR) through microwave and radio-frequency irradiation. Thereby, to be able to translate single NV protocols to exploit the benefit of NV ensembles, it is important to know the frequency spread in ensembles of NVs. In this work we assess the frequency spread existing in NV ensembles in sample of diamond grown via Chemical Vapour Deposition (CVD) containing about 4.5 ppm (0.79×10^{18} cm^{-3}) of NVs, which is about the highest density of NVs available in the market. We optically detected the ESR signal of an estimated population of ~0.79×10^{6} NVs within the active volume of our confocal instrument (~1 μm^3), which can be seen in Fig.1. This signal shows the typical ESR signature of one of the ESR peaks revealing the hyperfine coupling of the electron spin to the nuclear ^{14}N spin triplet conforming the NVs. Different power levels were employed to minimise the power broadening introduced by the MW pulses. The acquired image suggests that the spectral spread in the hundreds of thousands of NVs is small. These results suggest that sequences designed for simple NVs should be compatible with bulk sensing, paving the way to orders of magnitude sensitivity boosts.

References

[1] Crawford, Scott E., et al. "Quantum sensing for energy applications: Review and perspective." *Advanced Quantum Technologies* 4.8 (2021): 2100049.
[2] Mochalin, Vadym, et al. "The properties and applications of nanodiamonds." Nano-enabled medical applications (2020): 313-350.
[3] Casanova, J., Z-Y. Wang, and Martin B. Plenio. "Noise-resilient quantum computing with a nitrogen-vacancy center and nuclear spins." Physical review letters 117.13 (2016): 130502.
[4] Knowles, Helena S., Dhiren M. Kara, and Mete Atatüre. "Observing bulk diamond spin coherence in high-purity nanodiamonds." *Nature materials* 13.1 (2014): 21-25.

Figures

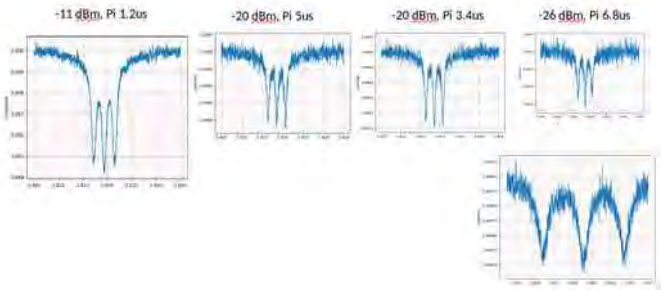


Figure 1: Optically detected ESR signal for different microwave power levels.

YBCO SQUIDs for High-Frequency Magnetic Particle Characterization

Jorge Pérez-Bailón[1]
Lorena Caswell Alonso[1], David García-Pons[1], Martin Hack[2], Reinhold Kleiner[2], Dieter Koelle[2], Javier Sesé[1], and María José Martínez-Pérez[1]

[1] *Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, Zaragoza, Spain and Departamento de Física de la Materia Condensada, Universidad de Zaragoza*
[2] *Physikalisches Institut, Eberhard Karls Universität Tübingen, Tübingen, Germany*

jorgepb@unizar.es

Exploring the characteristics of nanostructured magnetic materials is of great interest for investigating fundamental aspects of quantum magnonics and their application in cutting-edge quantum information technologies. To do this, the development of highly responsive magnetic sensors capable of handling radio frequency (RF) signals is needed. Such sensors, known as Superconducting Quantum Interference Devices (SQUIDs), have typically been used in DC applications due to specific amplification constraints limiting signal frequencies. However, the potential for SQUID utilization in RF signals exists, given the persistence of the Josephson effect at these frequencies. Here, we propose the fabrication of SQUIDs designed for high-frequency operation, particularly for their application in quantum magnonics experiments.

To this end, we propose the fabrication of SQUIDs based on grain boundary Josephson junctions in YBCO, a high-temperature superconductor, on a MgO substrate. These SQUIDs present exceptional sensitivity, low inductance, minimal noise, and a high critical current density.

References

[1] M. J. Martínez-Pérez et al 2017 Supercond. Sci. Technol. 30 024003.

Acknowledgements

This work was partly funded and supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (948986 QFaST) and the Juan de la Cierva 2022 grant of the Agencia Estatal de Investigación (AEI) of the Spanish Ministry of Science, Innovation and Universities.
Authors would like to acknowledge the use of Laboratorio de Microscopias Avanzadas-LMA and Servicio General de Apoyo a la Investigación-SAI, Universidad de Zaragoza.

Figures

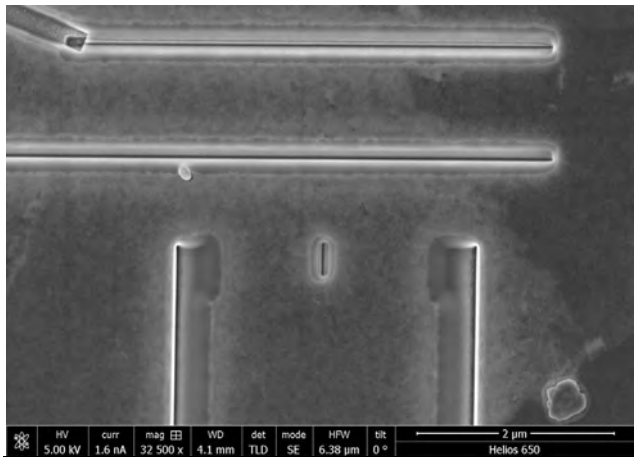


Figure 1: Detail of a YBCO SQUID with external flux line).

On classical advice, sampling advise and complexity assumptions for learning separations

Jordi Pérez-Guijarro
Alba Pagès-Zamora
Javier R. Fonollosa

Universitat Politècnica de Catalunya, ES-08034 Barcelona, Spain

jordi.perez.guijarro@upc.edu

As machine learning gains widespread adoption, there is a growing focus on exploring the computational limits of these algorithms. In particular, this arises as a crucial condition to understand the possible applications of quantum computers in machine learning, as proving a quantum speed-up requires comparing the performance of these quantum algorithms with that of any classical one.

Notably, certain findings suggest the presence of quantum speed-ups in this domain [1,2]. However, as illustrated in [3], achieving a (computational) quantum speed-up for a function is not a sufficient condition for a learning separation. This discrepancy arises from the fact that access to a classical training set can simplify seemingly complex tasks. This insight prompts a deeper examination of classical algorithms' capabilities when supplied with a training set, leading to the definition of the class BPP/samp.

We demonstrate that BPP/samp is, in fact, equivalent to a more conventional class known as P/poly. Additionally, we explore scenarios where the distribution is fixed. In this context, we establish a strict inclusion, indicating that sampling advice from a fixed distribution is inherently weaker than arbitrary classical advice. This result also holds true when we consider quantum advice and a quantum generalization of the training set. Lastly, leveraging these results and their associated proof techniques, we identify sufficient and necessary complexity assumptions for the existence of concept classes that exhibit a quantum learning speed-up in the worst-case scenario, i.e., when accurate results are required for all inputs.

References

[1] Y. Lie, et al., Nature Physics, vol.17, no. 9, pp. 1013-1017, 2021.
[2] A. Abbas, et al., Nature Computational Science, vol. 1, no. 6, pp. 403–409, 2021.
[3] H. Y. Huang, et al., Nature Communications, vol. 12, no.1, pp. 1-9, 2021.

Figures

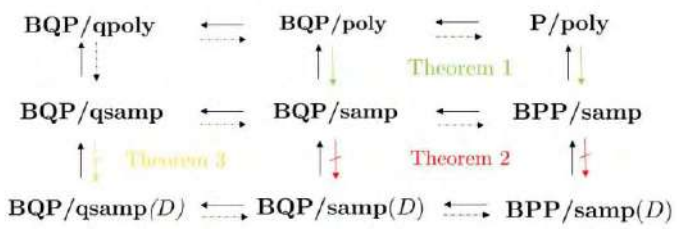


Figure 1: Relations between the different complexity classes studied. A solid arrow from A to B implies A ⊆ B. If the arrow is dashed, then it is unknown if that inclusion holds. Finally, if a bar is included, the inclusion does not hold

Control strategies for static ZZ coupling in flux-tunable transmon coupler systems

Simon Pettersson Fors
Jorge Fernández-Pendás
Anton Frisk Kockum

Department of Microtechnology and Nanoscience, Chalmers University of Technology, 412 96 Gothenburg, Sweden

simon.pettersson.fors@chalmers.se

Flux-tunable transmon couplers are widely used to implement two-qubit gates between superconducting qubits. However, connecting qubits through such couplers induces a ZZ coupling, an energy shift conditioned by the qubits' state which limits the performance of both one- and two-qubit gates. The performance limitation for two-qubit gates can be comparable to that from decoherence. In this talk, we present strategies to mitigate and control the ZZ coupling in devices based on fixed-frequency transmon qubits and flux-tunable transmon couplers. These strategies, which are based on numerical and analytical modeling, provide information on how to choose the frequencies, anharmonicities, and coupling strengths of the qubit systems [1]. This allows us to create several parameter regions with mitigated ZZ coupling that can be accessed by current technology without major redesigns. We also describe the underlying reasons for the existence of these regions inferred from new diagrammatic perturbation theory [2].

References

[1] S. P. Fors, J. Fernández-Pendás, A. F. Kockum, in preparation.
[2] S. P. Fors, J. Fernández-Pendás, A. F. Kockum, in preparation.

Figures

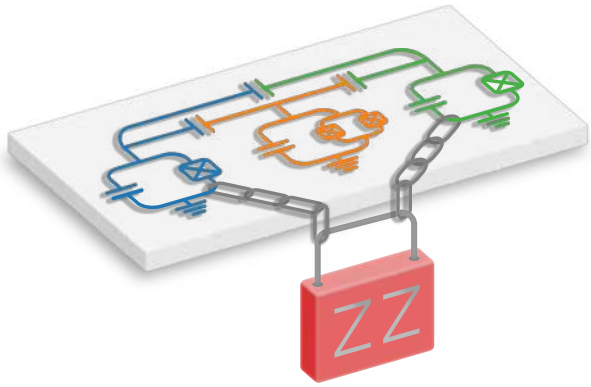


Figure 1: Circuit diagram for two fixed-frequency qubits (blue and green) coupled through both a direct capacitive coupling and a flux-tunable coupler (orange). The direct capacitive coupling and the coupler together generate an effective ZZ coupling between the qubits (symbolized as a red padlock) limiting the performance of one- and two-qubit gates.

Emergent quantum spin Hall phase in GeSn heterostructures on silicon

Presenting Author: Fabio Pezzoli[1]
Co-Authors: Beatrice Matilde Ferrari[1], Francesco Marcantonio[1], Felipe Murphy-Armando[2], Michele Virgilio[3]

[1]*Dipartimento di Scienza dei Materiali, Università di Milano-Bicocca, LNESS and BiQuTe, via Cozzi 55, 20125 Milano, Italy*
[2]*Tyndall National Institute, University College Cork, Cork T12R5CP, Ireland*
[3]*Dipartimento di Fisica, Università di Pisa, Largo Pontecorvo 3, I-56127 Pisa, Italy*

fabio.pezzoli@unimib.it

Topological phases of solid-state electron systems look poised to provide solutions that will revolutionize information technologies [1]. One of the challenges to translate topologically enriched devices from research lab to scale-up production remains the recurrent use of environmentally-polluting or resource-critical materials. To overcome this limitation, we propose a practical silicon-based architecture that spontaneously sustains topological properties, while being fully compatible with the high-volume manufacturing capabilities of modern microelectronic foundries [2]. Here we show how conventional semiconductors such as $Ge_{1-x}Sn_x$ alloys can be engineered into heterojunctions that demonstrate a broken gap alignment. We predict such basic building block undergo a quantum phase transition that can elegantly accommodate the existence of gate-controlled chiral edge states directly on Si (see the schematics in Fig. 1). This will enable the design of integrated circuits hosting quantum spin hall insulators, thus bringing topological functionalities a step closer to their use in future consumer electronics.

References

[1] J. E. Moore, Nature 464, 194 (2010).

[2] B. M. Ferrari, F. Marcantonio, F. Murphy-Armando, M. Virgilio, and F. Pezzoli Phys. Rev. Research 5, L022035 (2023).

Figures

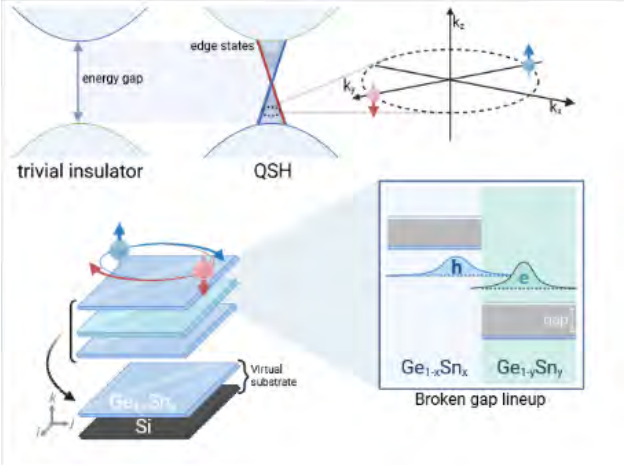


Figure 1: Quantum spin Hall (QSH) phase emergent in $Ge_{1-x}Sn_x/Ge_{1-y}Sn_y$ architectures. A strained $Ge_{1-x}Sn_x/Ge_{1-y}Sn_y$ heterostructure integrated on silicon through a $Ge_{1-s}Sn_s$ virtual substrate can host topologically protected edge states featuring spin-momentum locking. A quantum phase transition from a trivial to a quantum spin hall insulator can spontaneously occur in the system when the heterojunctions demonstrate a broken-gap alignment of the band offsets. This can lead to an inverted band structure with hole states higher in energy than the electron states, while giving rise to an interface electric dipole because of the accumulation of opposite charges at opposite sides of the junction.

Mo/Au TESs for Quantum Technologies

Carlos Pobes[a]
L.Fàbrega[b], *A.Camón*[a] , *P.Strichovanec*[a], *J. Bolea*[a], *J.L. García-Palacio*[a], *J.I. Rico*[a]
[a]*Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, Zaragoza 50009, Spain.*
[b]Institut de Ciència de Materials de Barcelona (ICMAB-CSIC)
cpobes@unizar.es

Abstract

We will present the development of Transition Edge Sensors (TESs) based on Mo/Au superconducting bilayers in Spain[1], optimized for different applications depending on the absorber design. These applications range from astrophysics and particle physics experiments (X-ray astronomy[2-3], Dark Matter direct detection) or material sciences, to photon counting in Quantum Technologies[4].

References

[1] L. Fàbrega, A. Camón, P.Strichovanec, C. Pobes, IEEE Trans. Appl.Supercond., 29(5) (2019) pp1-5. 2100405

[2] L.Ravera et al., Proceed. SPIE9144 (2014).

[3] C.Pobes et al., IEEE Trans. Appl.Supercond. 27(4) (2017) pp1-5. 2101505.

[4] Rodrigo, S. G., Pobes, C., Sánchez Casi, M., Martín-Moreno, L., & Camón Lasheras, A. Opt Express, 30(8) (2022) 12368-12377

Figures

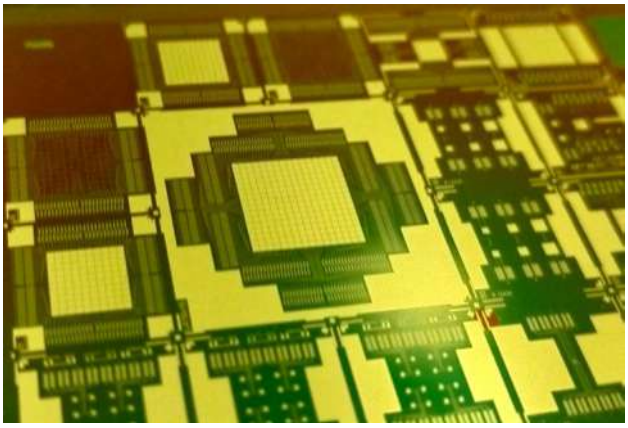


Figure 1: Partial picture of a wafer with Mo/Au TESs arrays and pixels of different designs. A 16x16 array with Au/Bi absorbers is highlighted at the center of the image.

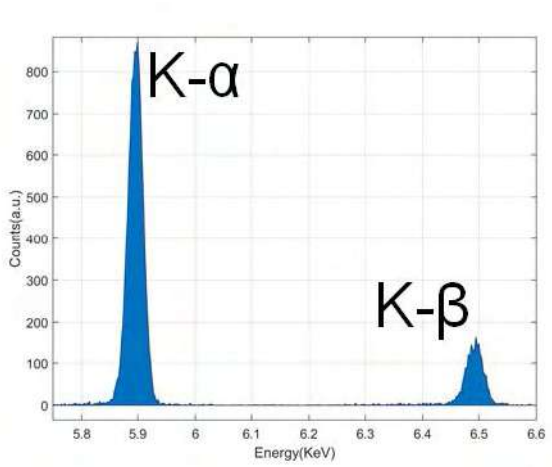


Figure 2: Preliminary Kα and Kβ peaks from a Fe55 source in a 250μm wide pixel.

Towards circular Rydberg qubits of calcium atoms

Claudia Politi
Wojciech Adamczyk, Silvan Koch, Pavel Filippov, Qianlong He, Daniel Kienzler, and Jonathan P. Home

Institute for Quantum Electronics, ETH Zürich, Otto-Stern-Weg 1, 8093 Zurich, Switzerland

cpoliti@phys.ethz.ch

Recently, neutral atoms excited to Rydberg states have emerged as a promising platform for quantum simulation and computation, owing to the high control and scalability of the system. Experiments mostly focused on excitations to low-angular momentum Rydberg states, which sets limits on achievable gate fidelity due to the short lifetime of these states. The lifetime can be extended up to several minutes for atoms excited to circular Rydberg states in a cryogenic environment with spontaneous-emission inhibition [1]. In this work, we present the latest results from our experiment, which focuses on trapping single alkaline-earth calcium atoms excited to circular Rydberg states. The primary objective of the experiment is to perform QND (Quantum Non-Demolition) readout of the qubit, employing the narrow-line transitions available in calcium for state-dependent shelving of the core electron [2,3]. We plan to cool and trap calcium atoms in an array of optical tweezers generated by a spatial light modulator. Following Rydberg excitation and circularization, the atoms will be transferred to an array of hollow bottle-beam traps, where control of the core electron will aid in the cooling, manipulation, and non-destructive readout of the circular qubit. To trap atoms in optical tweezers temperatures of about 100μK are desirable. Our experiment starts with a magneto-optical trap (MOT) operating on the broad $^1S_0$-$^1P_1$ dipole-allowed transition, resulting in a Doppler temperature of 0.8mK. Recently, we implemented a two-photon cooling scheme, previously demonstrated in magnesium [4], to achieve Sub-Doppler temperatures. This scheme, based on coupling the $^1P_1$ state to a higher lying narrower transition, offers a straightforward experimental implementation and can be used to achieve temperatures as low as 100μK. Finally, we outline our progress in the design of a cryogenic chamber, essential for preserving the extended lifetimes of circular Rydberg atoms.

References

[1] T. L. Nguyen et al., Towards Quantum Simulation with Circular Rydberg Atoms, Phys. Rev. X, 8, 011032 (2018)
[2] C. Fischer, Quantum non-demolition readout for optically trapped alkaline-earth Rydberg atoms, PhD Thesis, ETH Zürich (2022)
[3] A. Muni et al., Optical coherent manipulation of alkaline-earth circular Rydberg states, Nat.Phys.18,502 (2022)
[4] T. E Mehlstäubler et al, Observation of sub-Doppler temperatures in bosonic magnesium, Phys. Rev. A 77 (2008)

Nonlinear dynamics as a ground-state problem on a quantum computer

Albert J. Pool[1,2]
Alejandro D. Somoza[1,2], Michael Lubasch[3], Conor Mc Keever[3], Birger Horstmann[1,2,4]

[1] *Institute of Engineering Thermodynamics, German Aerospace Center (DLR), Wilhelm-Runge-Str. 10, 89081 Ulm, Germany*
[2] *Helmholtz Institute Ulm, Helmholtzstr. 11, 89081 Ulm, Germany*
[3] *Quantinuum, Partnership House, Carlisle Place, London SW1P 1BX, United Kingdom*
[4] *Department of Physics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm, Germany*

albert.pool@dlr.de

For the solution of time-dependent nonlinear differential equations, we present variational quantum algorithms (VQAs) that encode both space and time in qubit registers. The spacetime encoding enables us to obtain the entire time evolution from a single ground-state computation inspired by the Feynman—Kitaev Hamiltonian [1].
We describe a general procedure to construct efficient quantum circuits using quantum nonlinear processing units [2] for the cost function evaluation required by VQAs. To mitigate the barren plateau problem during the optimisation, we propose an adaptive strategy. The approach is illustrated for the nonlinear Burgers equation. We classically optimise quantum circuits to represent the desired ground-state solutions, run them on IBM Q System One, and demonstrate that current quantum computers are capable of accurately reproducing the exact results.

References

[1] Barison, S. et al. Phys. Rev. Res. 4 (2022), 043161
[2] Lubasch, M. et al. Phys. Rev. A 101 (2020), 010301(R)

Figures

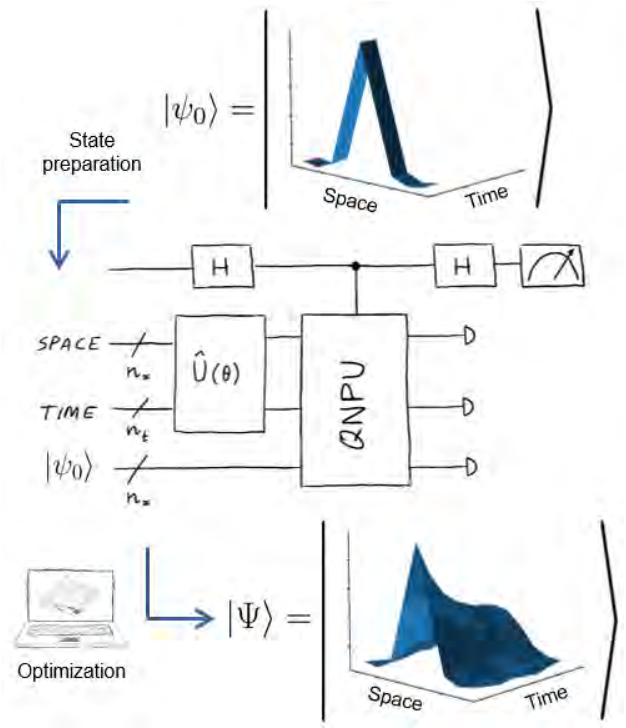


Figure 1: Summary of the procedure

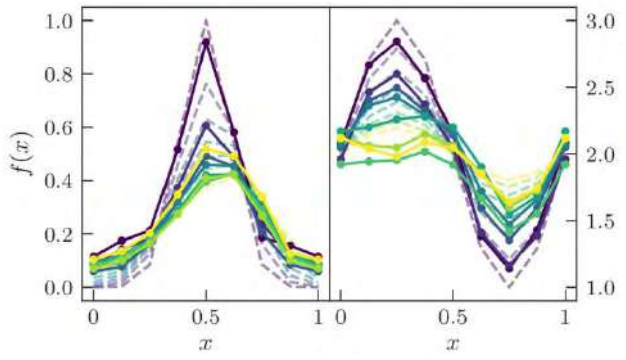


Figure 2: Solutions to the Burgers and diffusion equations on $3+3$ qubits ($2^3 = 8$ points in time and space) plotted using IBMQ Ehningen (solid lines) and a noiseless simulator (dashed lines). The lighter colours represent increasing time.

Discrete Abelian lattice gauge theories on a ladder and their dualities with quantum clock models

Sunny Pradhan
Andrea Maroncelli, Elisa Ercolessi

University of the Basque Country, Barrio Sarriena s/n, Leioa, Spain

sunny.pradhan@ehu.eus

Abstract

We study a duality transformation from the gauge-invariant subspace of a Z_N lattice gauge theory on a two-leg ladder geometry to an N-clock model on a single chain.
The main feature of this mapping is the emergence of a longitudinal field in the clock model, whose value depends on the super-selection sector of the gauge model, implying that the different sectors of the gauge theory can show quite different phase diagrams.
In order to investigate this and see if confined phases might emerge, we perform a numerical analysis for $N = 2, 3, 4$, using both exact diagonalization and DMRG.

References

[1] S. Pradhan, A. Maroncelli, and E. Ercolessi, Phys. Rev. B 109, 064410 (2024)

A Superconducting Platform for Quantum Information Processing

Lucien Quebaud
Ian Yang, Desislava Atanasova, Stefan Oleshko, Teresa Hoenigl-Decrinis, Gerhard Kirchmair

(1) Institute for Quantum Optics and Quantum Information, 6020 Innsbruck, Austria
(2) Institute for Experimental Physics, University of Innsbruck, 6020 Innsbruck, Austria
lucien.quebaud@uibk.ac.at

Abstract

In the pursuit of advancing quantum information processing, high-Q coaxial cavities have emerged as a potential avenue to realize interactions in multi-qubit systems. In this work, we present such a platform involving transmon qubits coupled to a high-purity niobium $\lambda/4$ coaxial seamless design.
A modular magnetic hose is introduced for implementing fast magnetic flux control within the superconducting cavity, crucial for fast frequency changes of tunable transmon qubits. The magnetic hose offers a solution to the longstanding challenge of achieving high-coherence 3D cQED systems with fast magnetic flux control.
In order to achieve fast and accurate qubit readout, which is typically limited by the Purcell effect in the dispersive regime, we propose a novel Purcell filter design replacing the conventional readout pin. This design incorporates a modular band-pass filter centred at the resonator frequency, allowing fast qubit measurements while mitigating the impact of the Purcell effect on qubit lifetime.
All these quantum engineering tools enable the construction of a robust superconducting platform for quantum information processing applications.

References

[1] M. Reagor et al., Phys. Rev. B 8, 014506 (2016)
[2] O. Gargiulo, S. Oleschko et al., Appl. Phys. Lett. 118, 012601 (2021)
[3] E. A. Sete, J. M. Martinis and A. N. Korotkow, Phys. Rev. A 92, 012325 (2015)
[4] A. Sanchez and N. Bort-Soldevilla, J. Appl. Phys. 130, 163901 (2021)

Figures

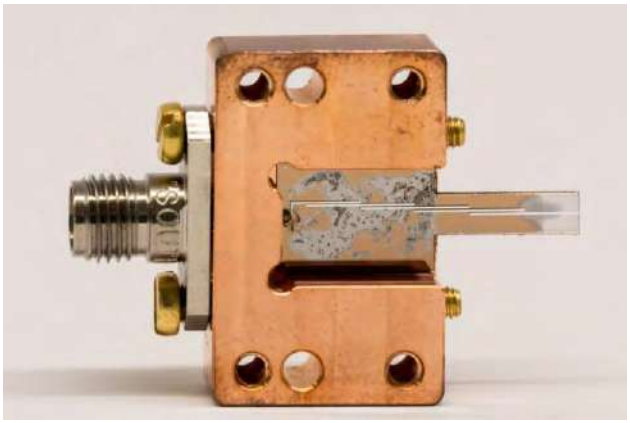


Figure 1: Picture of the Purcell filter

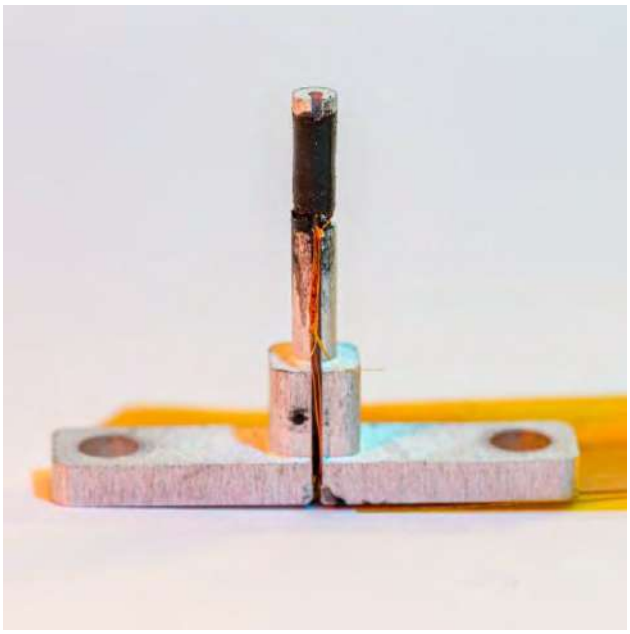


Figure 2: Picture of the flux hose

Heisenberg-Limited Quantum Lidar for Joint Range and Velocity Estimation

Maximilian Reichert

University of the Basque Country, Bilbao, Spain

maximilian.reichert1995@gmail.com

We propose a quantum lidar protocol to jointly estimate the range and velocity of a target by illuminating it with a single beam of pulsed displaced squeezed light. In the lossless scenario, we show that the mean-squared errors of both range and velocity estimations are inversely proportional to the squared number of signal photons, simultaneously attaining the Heisenberg limit. This is achieved by engineering the multi-photon squeezed state of the temporal modes and adopting standard homodyne detection. To assess the robustness of the quantum protocol, we incorporate photon losses and detuning of the homodyne receiver. Our findings reveal a quantum advantage over the best-known classical strategy across a wide range of round-trip transmissivities. Particularly, the quantum advantage is substantial for sufficiently small losses, even when compared to the optimal---potentially unattainable---classical performance limit. The quantum advantage also extends to the practical case where quantum engineering is done on top of the strong classical coherent state with watts of power. This, together with the robustness against losses and the feasibility of the measurement with state-of-the-art technology, make the protocol highly promising for near-term implementation.

References

[1] Maximilian Reichert, Quntao Zhuang, Mikel Sanz, arXiv:2311.14546

Figures

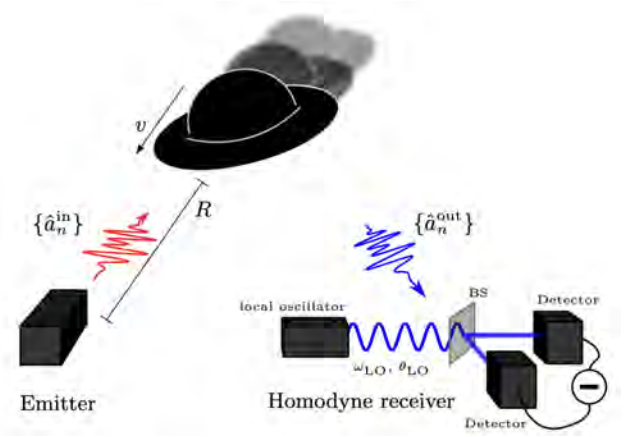


Figure 1: Quantum Lidar protocol

Approximate quantum adiabatic Hamiltonian simulation on quantum computers

Hannu Reittu
Eino Yrjö-Koskinen
VTT Technical Research Centre of Finland, Quantum algorithms and software, TT3 Tietotie 3 Espoo, Finland
hannu.reittu@vtt.fi eino.yrjo-koskinen@vtt.fi

Quantum evolution of a state is described by the Schrödinger equation: $i\partial_t|\psi(t)\rangle = H(t)|\psi(t)\rangle, |\psi(0)\rangle = |\psi_0\rangle$, in which $H(t)$ is a time-dependent Hamiltonian operator. Formal solution of this problem is written as: $|\psi(t)\rangle = \mathcal{T}exp(-i\int_o^t H(t')dt')\,|\psi_0\rangle$, in which $\mathcal{T}exp$ is the so called T-exponent, resulting in a complicated iterative formula. Quantum adiabatic evolution (QAE) happens when $H(t)$ is a slowly varying function. QAE preserves an eigenstate. This can be used in quantum annealing for solving hard classical problems (see [4] and refs. therein), in holonomic quantum computing for manipulating qubits [2] or solving molecular and other electronic problems in material science [1].

We suggest a way to approximate QAE using piecewise constant Hamiltonians, see Fig. 1, the corresponding approximation (=AQAE) converges to the true QAE in the limit of small step-size. Such approximation can be implemented on a quantum gate computer. We made tests on solving the classical QUBO problem (e.g. number partitioning) and simulated the exotic quantum holonomy effect. Classical computers cannot effectively simulate QAE of large quantum systems and a quantum computer is needed as well as a gate implementation of the corresponding AQAE. Such capacity would be useful in simulating control of qubits in holonomic quantum computers and other quantum devices. For electronic structure simulations we suggest to use Hamiltonian matrices, which tend to be sparse and thus has an effective quantum gate implementation of AQAE. All concepts are tested on a small-scale using quantum gate computers like VTT's 5-qubit Helmi machine.

References

[1] W.Rodrigues, et al. Comput. Electron., 14(2015), 593-603
[2] P. Zanardi and M Rasetti, Physics Letters A, 264(1999), 94-99.
[3] T. Cheon, et al., Physics Letters A, 2(2009), 144-149
[4] H. Reittu, et al., In Proc. 2019 IEEE International Conf. on Big Data, Big Data 2019, 2457-2464

Figures

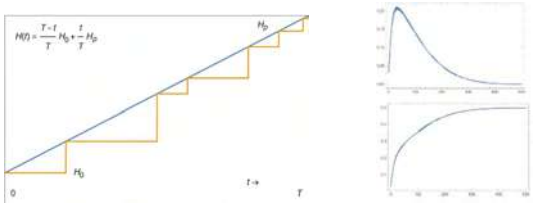


Figure 1: Left: QAE from H_0 to H_p, the blue line. The yellow line: a sequence of piecewise constant Hamiltonians approximating QAE (AQAE). AQAE can be effectively implemented as a sequence of quantum gates. AQAE for a QUBO – probability of a false state (top) vs of a solution (bottom).

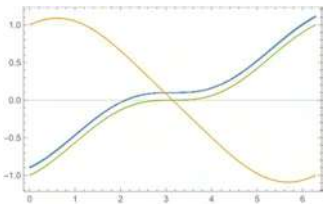


Figure 2: Exotic quantum holonomy in a two-level system [3], energies of two levels green and orange lines as a function of a parameter. Blue dots: energy found using QAE, points lie on the green line (a constant was added to each AQAE point to separate the plots).

Magneto-optical properties of Fourier-limited Tin-Vacancy centers in diamond

Jeremias Resch[1]
Ioannis Karapatzakis[1], Marcel Schrodin[1], Philipp Fuchs[3], Michael Kieschnick[4], Jan Meijer[4], Christoph Becher[3], Wolfgang Wernsdorfer[1,2], David Hunger[1, 2]

[1]*Physikalisches Institut, Karlsruhe Institute of Technology, Karlsruhe, Germany*
[2]*Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany*
[3]*Department of Physics, Saarland University, Saarbrücken, Germany*
[4]*Felix-Bloch-Institute for Solid State Physics, University of Leipzig, Leipzig, Germany*

jeremias.resch@kit.edu

Scalable quantum information processing requires spectrally stable interfaces between fiber-coupled photons and solid-state qubits. For remote entangling, bright and indistinguishable photons are necessary and thus high demands on the optical transitions of the spin-photon interfaces are compulsory. Group-IV color centers in diamond offer by symmetry a first-order insensitivity to charge noise, making them promising candidates for scalable integration. By an optimized spectroscopy method, we identify charge-state and spectrally stable Tin-Vacancy (SnV) centers with Fourier-limited optical linewidths using resonant excitation. We implement a 3D vector magnet in a confocal microscope setup to analyze the magneto-optical properties of the SnV electron spin at cryogenic temperatures. We determine long spin relaxation times as predicted by the larger spin-orbit splitting of the SnV center compared to other Group-IV defects. By rotating the magnetic field with respect to the symmetry axis, we determine the angle dependent splitting of the electron spin ground and excited states. This allows a full fit to the electron spin Hamiltonian and determination of the orbital quenching factors as previously derived in DFT calculations [1].

References

[1] Thiering & Gali, Phys. Rev. X, 8 (2018), 021063

Figures

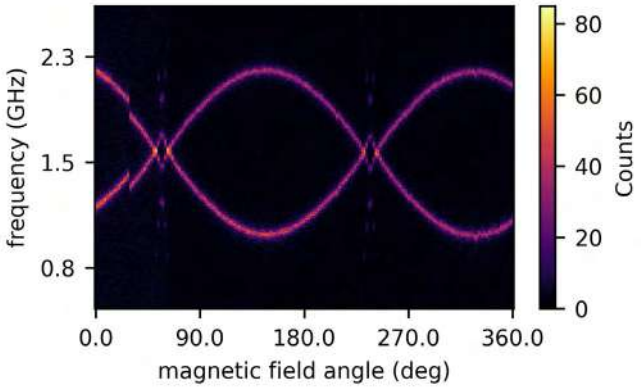


Figure 1: Fourier-limited PLE spectrum of a Tin-Vacancy center under magnetic field rotation.

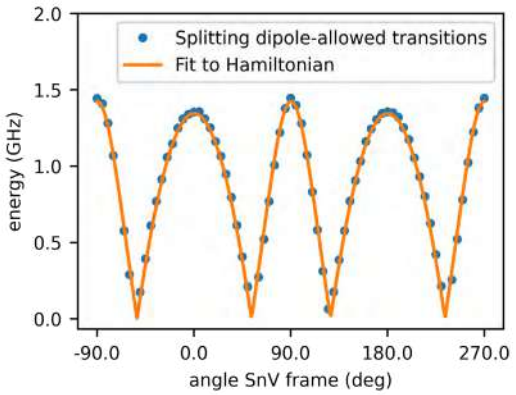


Figure 2: Full fit of the dipole-allowed transitions to the electron spin Hamiltonian in the local defect frame.

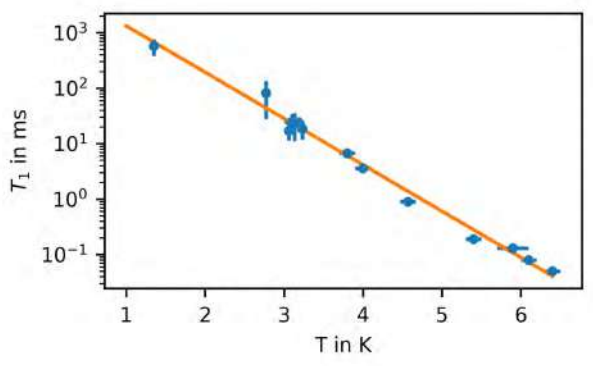


Figure 3: Electron spin lifetime under varying temperatures exceeding 0.5s at 1.3K.

Coherent control of a carbon nanotube-based gatemon qubit

H. Riechert, S. Annabi, M. Hantute, H. Duprez, A. Peugeot, E. Arrighi, J. Griesmar, J.-D. Pillet, L. Bretheau

Laboratoire PMC, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France

hannes.riechert@polytechnique.edu

The standard transmon qubit may be modified by using a Josephson junction with few well-transmitted channels. Via a gate the junction's transmission and thus qubit properties become tuneable. Previous works have shown coherent measurements in such gatemon qubits with nanowire or graphene-based junctions. We present a qubit design using ultraclean single carbon nanotubes as junction material. Measurements of the resonance frequency show signatures of charge parity change in the quantum dot formed by the carbon nanotube. We measured Rabi oscillations demonstrating coherent control. We currently work on a microwave design to reduce energy relaxation.

Figures

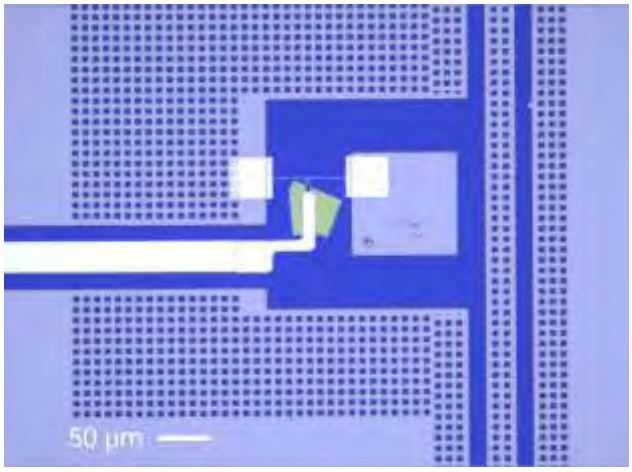


Figure 1: Optical microscope picture of transmon qubit coupled to a coplanar waveguide (on the right). The carbon nanotube (not visible) is covered by hexagonal boron nitride (green) and a top gate (towards the left).

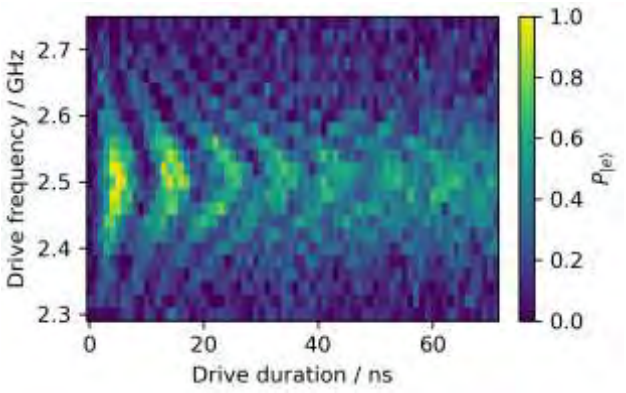


Figure 2: Rabi oscillations measured at various drive frequencies. The qubit frequency is at 2.5 GHz.

Fermionic quantum computation with Cooper pair splitters

Antonio L. R. Manesco[1]
Kostas Vilkelis[1,2]
Juan Daniel Torres[1,2]
Sebastian Miles[1,2]
Michael Wimmer[1,2]
Anton Akhmerov[1]

[1]*Kavli Institute of Nanoscience, Delft University of Technology, Delft 2600 GA, The Netherlands*
[2]*Qutech, Delft University of Technology, Delft 2600 GA, The Netherlands*

am@antoniomanesco.org

Abstract

We showed that Copper pair-splitting devices with tunable capacitors (Fig. 1) make up a building block of a fermionic quantum computer [1]. We derived the low-energy Hamiltonian and showed that it contains all the necessary processes to build a universal set of gate operations. Moreover, we showed how to use experimentally controllable parameters to implement the gate operations. We find that the presence of Zeeman splitting in the superconducting island complicates the implementation of gates and necessitates additional steps. Based on the low-energy theory, we also studied optimal regimes for the device operation. While our design was mostly inspired by recent experiments, we also discussed how to avoid foreseeable limitations such as (i) the use of neutral fermions to suppress charge noise; (ii) a floating superconducting island to simplify the layout; (iii) control of the superconducting gap to simplify gate operations.

References

[1] Kostas Vilkelis, Antonio Manesco, Juan Torres, Sebastian Miles, Michael Wimmer, Anton Akhmerov, arXiv:2310.15293 (2023)

Figures

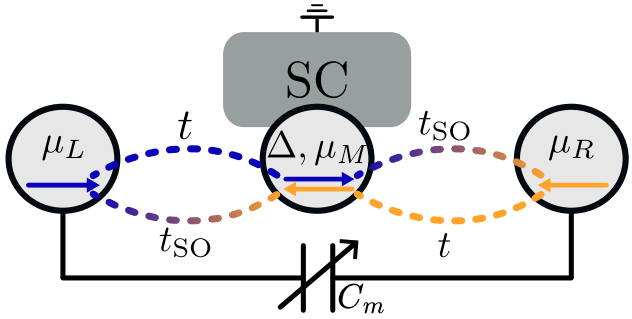


Figure 1: Schematics of the device. Two singly occupied spin-polarized quantum dots host the local fermionic modes. Two tunnel barriers enable normal and spin-dependent hopping. A middle superconducting island mediates superconducting correlations between the two local fermionic modes. An external mutual capacitor allows Coulomb interactions between the sites.

Simulating battery properties using IBM quantum processors

Marina Ristol Roura[1]
Sebastián V. Romero[2,3,4], Aitor Moreno Fdez. de Leceta[5]

[1]*i3B, Torre Barcelona, Gran Via de les Corts Catalanes, 130-136, 2ª planta, 08038 Barcelona, Spain*
[2]*Kipu Quantum, Greifswalderstrasse 226, 10405 Berlin, Germany*
[3]*Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, 48080, Bilbao, Spain*
[4]*TECNALIA, Basque Research and Technology Alliance (BRTA), 48160, Derio, Spain*
[5]*i3B, Unidad de Inteligencia Artificial, Avenida de los Huetos, Edificio Azucarera, 01010 Vitoria, Spain*

mristol@ayesa.com

The need to develop and implement rechargeable batteries with higher capacity, faster charging, and, ideally, lower production costs is a case of particular interest at the present time. While well-established classical computing techniques for simulating batteries already exist, they often struggle to obtain accurate and reliable results. However, quantum computing emerges as a potential framework to outperform them. Inspired by a previous work through the collaboration between Mercedes-Benz and IBM [1], we investigate key properties of battery-related compounds for their design and subsequent manufacture. We study the energy spectrum and the multipolar moments for different molecules using the variational quantum eigensolver (VQE) on simulators and IBM quantum processors. We exploit point-group symmetries [2] and meaningful active spaces to significantly reduce the amount of quantum resources required, which is highly valuable during the NISQ era.

References

[1] J. E. Rice et al., The Journal of Chemical Physics 154, 134115 (2021)
[2] D. Picozzi, and J. Tennyson, Quantum Science and Technology 8, 035026 (2023)
[3] M. Ristol et al. *Simulating battery properties using IBM quantum processors*. (in preparation)

Figures

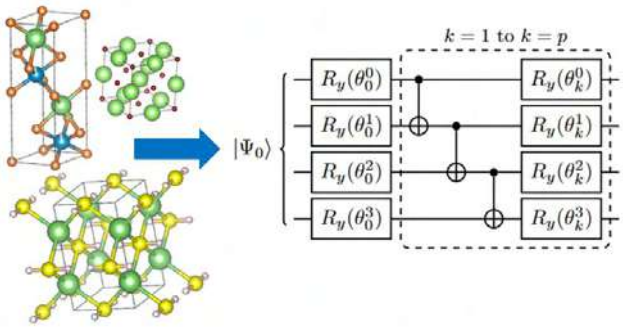


Figure 1: Diagram illustrating the representation of molecules in their ground state using a parametric quantum circuit, or ansatz, with k layers and 4 qubits. In our study, the initial state $|\Psi 0\rangle$ used is the Hartree-Fock state.

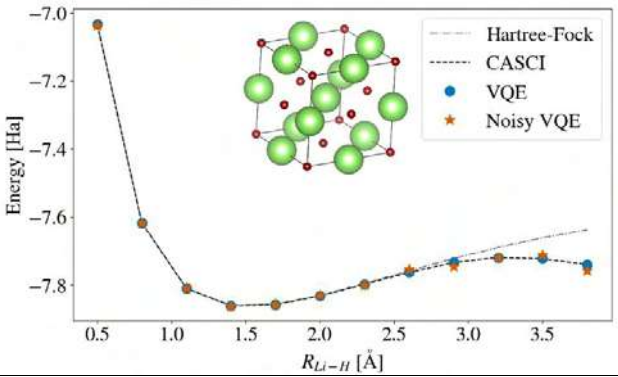


Figure 2: LiH ground state computation for different bond lengths and its unit cell. Results computed simulating the ideal VQE (blue dots) and the noisy VQE (orange stars) are compared against the Hartree-Fock approximation (black line) and the CASCI classical computation (grey line).

Design and numerical simulation of Josephson traveling-wave parametric amplifier using new circuit simulator

E. Rizvanov[1]
S. Kern[1]
P. Neilinger[1,2]
M. Grajcar[1,2]

[1]*Comenius University, Šafárikovo námestie 6, Bratislava, Slovakia*

[2]*Institute of Physics, Slovak Academy of Sciences, Dúbravská cesta, Bratislava, Slovakia*

emil.rizvanov@fmph.uniba.sk

Superconducting traveling wave parametric amplifier (TWPA) is essential in quantum sensing and quantum computers. Although standard coupled-mode theory can explain the amplification of the signal, it fails to describe complex behavior beyond the approximations utilized by the theory. In order to simulate a response of TWPA model, it is necessary to solve a system comprising many nonlinear equations numerically. The most common program that allows a simulation of such systems is WRspice. This program has already been successfully used to design some amplifiers [1],[2]. In this work, we used the new program JoSIM [3], which uses a different numerical scheme for solving Josephson junctions circuits.

We developed a novel Josephson Junction Resonantly phase-matched TWPA design based on the already known one [4] using a nonlinear resonant element instead of a linear one. Our innovations allow us to achieve high gain and make our designs realistic for manufacturing. The impedance matching of the amplifier is ensured by a novel taper consisting of Josephson Junctions. We showed that such a taper suppresses ripples in the gain profile. The design was modeled using JoSIM and WRspice programs,
considering realistic Josephson Junctions critical current spread in TWPA. Both programs provide similar gain magnitude, although slightly different gain profile. However, JoSIM simulates circuits much faster than WRspice.

References

[1] V. Gaydamachenko, C. Kissling, R. Dolata, and A. B. Zorin, *J. Appl. Phys.*, 2022 132, 154401 .
[2] C. Kissling, V. Gaydamachenko, F. Kaap, et al., IEEE Trans. Appl. Supercond., 2023 vol. 33, no. 5, pp. 1–6.
[3] J. A. Delport, K. Jackman, P. I. Roux, and C. J. Fourie, IEEE Transactions on Applied Superconductivity, 2019 vol. 29, no. 5, pp. 1–5.
[4] K. O'Brien, C. Macklin, I. Siddiqi, and X. Zhang, Phys. Rev. Lett., 2014 vol. 113, no. 15, p. 157 001

Algorithmic method to decompose unitary operators in local terms.

Constantino Rodriguez-Ramos
Andrés Gómez

Galicia Supercomputing Center (CESGA), Edificio Cesga s/n, Avenida de Vigo, 15705 Santiago de Compostela, Spain.

tinorodram@gmail.com

The number of qubits is a scarce resource in current quantum computers. Recent works propose techniques to execute large quantum circuits in Quantum Processing Units (QPUs) with fewer qubits [1, 2]. Those techniques belong to a larger class of algorithms known as hybrid quantum algorithms in which specific quantum resources are simulated at the expense of a classical overhead. When cutting a circuit into two parts, the simulated resource is bipartite entanglement. In this case, the simulation overhead grows with the degree of entanglement between the parts of the cut.

In this work, we present a method to execute arbitrary unitary operations in two separated QPUs using quasi-probability simulation. To achieve this, we employ a novel algorithm that finds local decompositions of arbitrary unitary channels. First, we construct a family of local quantum channels by reformulating the family of the local states introduced in [3]. Second, we create an algorithm which obtains a quasi-probability decomposition of the original unitary channel which minimises the overhead over all possible combinations of the elements of the local channel family. Our algorithm allows discarding those local channels with low contribution to the final channel. This permits the reduction of the circuit versions in the final execution obtaining an approximation to the original operator with high fidelity.

We test the algorithm for two-qubit gates and the Quantum Fourier Transform (QFT) operator of arbitrary dimension. For two-qubit gates, our algorithm obtains decompositions with optimal overheads as given by [4]. For the QFT operator, the algorithm obtains decompositions with overheads which are close to theoretical low. We observe that for some operators, our algorithm produces decompositions including non-unitary elements. The execution of these channels requires the use of extra ancillas. Further work will explore modifications to the original algorithm minimising the required ancillas.

References

[1] Sergey Bravyi, Graeme Smith, and John A. Smolin, Trading Classical and Quantum Computational Resources, Phys. Rev. X 6.2, p. 021043.
[2] Tianyi Peng, Aram W. Harrow, Maris Ozols, and Xiaodi Wu, Simulating Large Quantum Circuits on a Small Quantum Computer, Phys. Rev. 125.15, p. 150504.
[3] G. Vidal and R. Tarrach, Robustness of entanglement, Phys. Rev. A 59, 141.
[4] C. Piveteau and D. Sutter, Circuit knitting with classical communication, IEEE Trans. Inf. Theory, 1.

Acknowledgements

This work has been financially supported by the Ministry of Economic Affairs and Digital Transformation of the Spanish Government through the QUANTUM ENIA project call – Quantum Spain project, and by the European Union through the Recovery, Transformation and Resilience Plan – NextGenerationEU within the framework of the Digital Spain 2026 Agenda.

Training iterated protocols for distillation of GHZ states with variational quantum algorithms

Áron Rozgonyi[1,2]
Gábor Széchenyi[1], Orsolya Kálmán[2], Tamás Kiss[2]

[1] Eötvös Loránd University
[2] HUN-REN Wigner RCP

rozgonyi.aron@wigner.hu

Abstract

Since the pioneering work [1] there has been considerable effort devoted to the theory of distilling multipartite entangled states [2] and, especially, GHZ states. We present optimized distillation schemes for preparing GHZ states. Our approach relies on training variational quantum circuits with white noise affected GHZ states as inputs.

Optimizing for a single iteration of the scheme, we find that it is possible to achieve an increased fidelity to the GHZ state, although further iterations decrease the fidelity. The same scheme, acting on coherently distorted pure-state inputs, is effective only in certain special cases.

We show that radically different results can be achieved, however, when one optimizes for the output after two iterations of the protocol. In this case, the obtained schemes are more effective in distilling GHZ states from inputs affected by white noise. Moreover, they can also correct several types of coherent pure-state errors.

Published article:
https://doi.org/10.1016/j.physleta.2024.129349

References

[1] M. Murao et al, Multiparticle entanglement purification protocols, Physical ReviewA 57 (6) (1998)
[2] W. D¨ur, H. Aschauer, H.-J. Briegel, Multiparticle entanglement purification for graph states, Phys. Rev. Lett. 91 (2003) 107903.

Figures

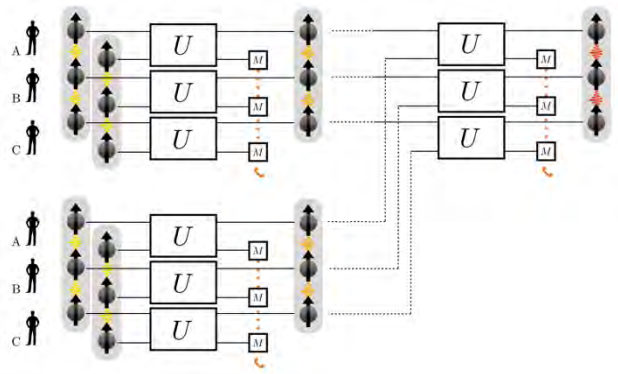


Figure 1: A schematic diagram illustrating the nonlinear protocol employed for GHZ distillation, considering a scenario involving two iterations. Three parties share two noisy GHZ states on which they perform local operations (denoted by the unitary operator *U*) and subsequent measurements (*M*). They communicate through classical channels to post-select the states by a consensus process for the next iteration.

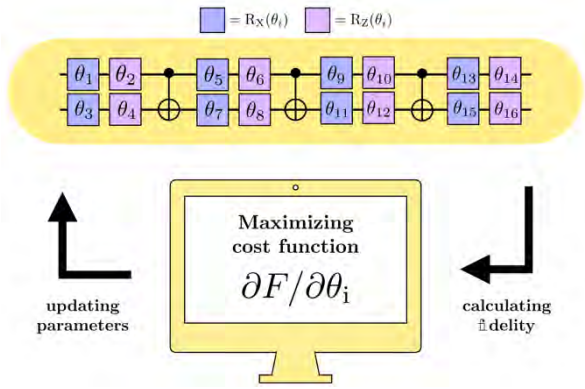


Figure 2: A schematic view of the variational algorithm consisting of a quantum circuit constructed by tuneable parametric gates of R_X and R_Y rotations, as well as CNOT gates. The circuit encircled in the yellow box (representing the unitary *U*) is employed by each party independently at their location. Once each protocol step has been executed by the parties, the cost function (i.e., the fidelity to the GHZ state) is computed. Subsequently, a classical gradient ascent algorithm is employed to calculate the derivatives of the fidelity with respect to the parameters. The parameters are then updated according to the derivatives and the variational algorithm is run until the output fidelity converges to a final value.

The Bethe Ansatz as a Quantum Circuit

Roberto Ruiz
Alejandro Sopena, Max Hunter Gordon, Germán Sierra, Esperanza López

Instituto de Física Teórica, C/ Nicolás Cabrera 13-15, Campus de Cantoblanco, 28049, Madrid, Spain

roberto.ruiz@ift.csic.es

The Bethe ansatz is an analytical method to address exactly solvable models in quantum mechanics. It has been shown that the states of the Bethe ansatz can be prepared by a deterministic quantum circuit whose quantum gates were determined numerically [1]. We report our progress in recasting the Bethe ansatz as a deterministic quantum circuit [2]. We present the analytical expressions of the quantum gates. Formulae rely upon diagrammatic rules that define the wave functions of the Bethe ansatz by matrix-product states. Based on the analytical expressions, we prove the unitarity of the quantum gates. We use our results to clarify on the equivalence between the coordinates and algebraic Bethe ansatze in light of matrix-product states.

References

[1] Alejandro Sopena, Max Hunter Gordon, Diego García Martín, Germán Sierra, Esperanza López, Quantum, 6 (2022) 796

[2] Roberto Ruiz, Alejandro Sopena, Max Hunter Gordon, Germán Sierra, Esperanza López (2023)

Figures

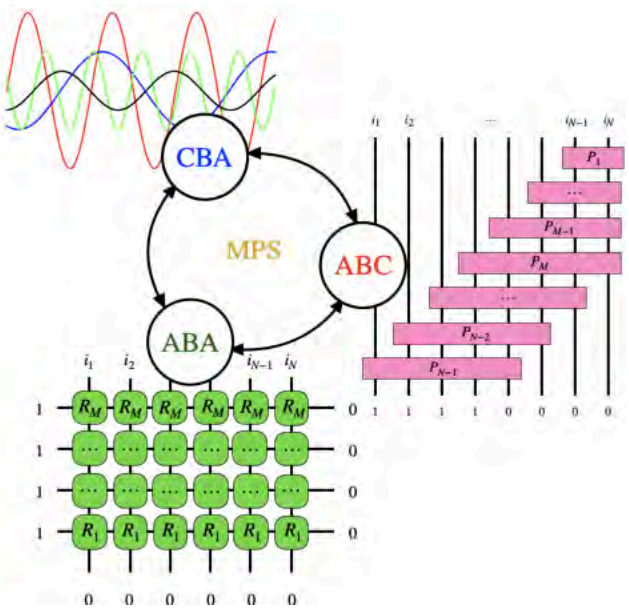


Figure 1: Realisations of the Bethe ansatz: CBA, ABA, and ABC. MPS lie at the core of the trio of equivalences.

Unraveling Timing Noise-Induced Decoherence in Single-Electron Sources

Sungguen Ryu[1]
Rosa López[1], Llorenç Serra[1], David Sánchez[1], and Michael Moskalets[1,2]

[1]*Institute for Cross-Disciplinary Physics and Complex Systems IFISC (UIB-CSIC), E-07122 Palma de Mallorca, Spain*
[2]*Department of Metal and Semiconductor Physics, NTU "Kharkiv Polytechnic Institute", 61002 Kharkiv, Ukraine*
sungguen@ifisc.uib-csic.es

Understanding decoherence in electronic excitations is pivotal for advancing solid-state devices in quantum technologies. The single-electron sources (SESs), which generate narrow nonequilibrium electron excitations as potential flying qubits, are particularly sensitive to external noise. Previous experiment using high-energy SES [1] has shown that the electron excitations suffer a strong decoherence, measuring the quantum purity low as 0.04. This cannot be explained by traditional mechanisms such as electron-electron or electron-phonon interactions, because the high-energy excitations are effectively isolated from the Fermi sea and the phonons [2].

We propose timing noise [3] as a universal model, consistent with Ref. [1], to explain strong decoherence of ultrafast SES pulses, without resorting to any specific microscopic mechanism. The timing noise generates a stochastic ensemble of wave packets which are temporally translated, see Fig.1. The timing noise induces pure dephasing effect in energy basis. Namely, the coherence in energy components is suppressed when the time uncertainty of the noise is much larger than that of the wave packet, see Fig.2. We also propose a protocol to identify the timing noise, i.e., to decide whether a SES involves timing noise and to obtain its noise distribution. Finally, we show that an energy filtering can recover the coherence when the time elongation due to the filtering is larger than the time uncertainty of the timing noise. Our theory and protocol are applicable for any SESs with ultrafast voltage pulses.

References

[1] J. D. Fletcher et al., Nat. Commun. 10, 5298 (2019)
[2] N. Johnson et al., Phys. Rev. Lett. 121, 137703 (2018)
[3] S. Ryu et al., arXiv:2310.03728.

Figures

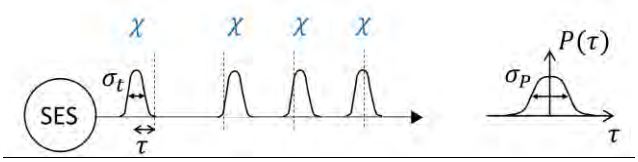


Figure 1: Single-electron sources with timing noise. At each emission (dashed lines), electron state χ is temporally translated by random timing shift τ, governed by probability distribution P(τ).

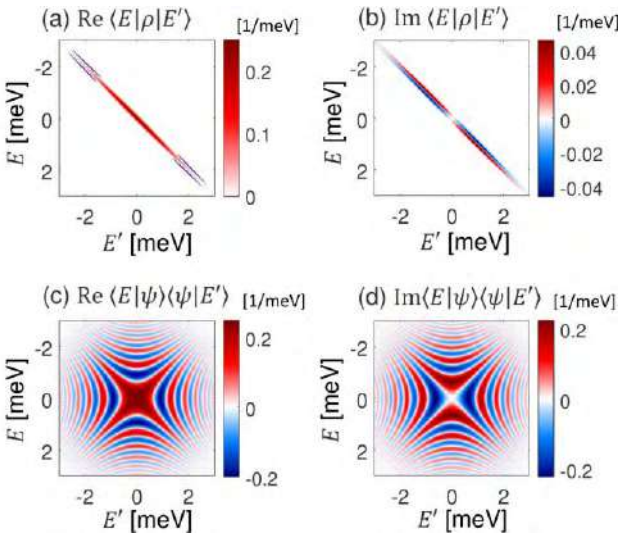


Figure 2: Timing noise identification. (a)–(b) The density matrix in energy basis for the state detected in Ref. [1]. Our protocol shows that this state is the result of noisy SES emitting pure-state wave packet ψ, (c)–(d).

The Fermionic Tonks-Girardeau gas: composite boson formation and a novel formulation of the ground state wave function

Francesc Sabater
Abel Rojo-Francàs, Grigori E. Astrakharchik, Bruno Juliá-Díaz

Departament de Física Quàntica i Astrofísica, Facultat de Física, Universitat de Barcelona, E-08028 Barcelona, Spain

francescsabater11@gmail.com

Attractive p-wave one-dimensional fermions are studied in the fermionic Tonks-Girardeau regime in which the diagonal properties are shared with those of an ideal Bose gas. We study the off-diagonal properties and present analytical expressions for the eigenvalues of the one-body density matrix. One striking aspect is the universality of the occupation numbers which are independent of the specific shape of the external potential [1]. We show that the occupation of natural orbitals occurs in pairs, indicating the formation of composite bosons, each consisting of two attractive fermions. The formation of composite bosons sheds light on the pairing mechanism of the system orbitals, yielding a total density equal to that of a Bose-Einstein condensate [2]. Additionally, we propose an alternative form of the Fermionic Tonks-Girardeau ground state.

Figures

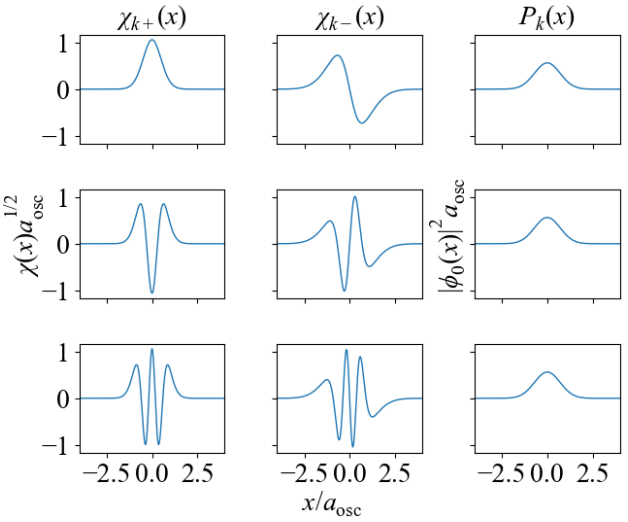


Figure 1: Fermionic natural orbitals and composite boson density profile in a harmonic trap potential for an even number of particles. First and second columns, the first six natural orbitals, $\chi_k+(x)$ and $\chi_k-(x)$, respectively, corresponding to the three largest doubly degenerate eigenvalues k =1,2,3 of the OBDM. Third column, the first three composite boson density profiles $P_k(x)$.

References

[1] P. Kóscik and T. Sowínski, Phys. Rev. Lett. 130, 253401 (2023)
[2] Sabater, F., Rojo-Francàs, A., Astrakharchik, G. E., & Juliá-Díaz, B. (2023) arXiv preprint arXiv:2309.03606 (Accepted in Phys. Rev. Lett)

Mean Field Theory Investigation of Spin Magnetizations in $MoTe_2/WSe_2$ Systems

Palash Saha, Michał Zegrodnik

AGH University of Science and Technology, Academic Centre for Materials and Nanotechnology AGH, A. Mickiewicza Av. 30, 30-059 Krakow, Poland

psaha@agh.edu.pl
michal.zegrodnik@agh.edu.pl

Abstract

We study the magnetic and topological properties of the $MoTe_2/WSe_2$ moiré heterostructure by applying the tight binding model derived in Ref. [1] and supplemented with the onsite Coulomb repulsion terms. Through the use of mean field theory [2], we show the appearance of in-plane and out-of-plane spin magnetizations. The in-plane magnetic ordering realizes the 120 antiferromagnetic pattern. We analyse the evolution of magnetic states with changing carrier concentration and displacement field as well as study the emergence of topological features of the model in proper parameter regime. We discuss our results in the view of the Quantum Anomalous Hall effect reported recently by the experiment [3] as well as the Kondo lattice scenario proposed theoretically last year [4].

References

[1] Louk Rademaker, Phys. Rev. B, 105,19, 2022, 195428
[2] Michał Zegrodnik and Jozef Spałek, Phys. Rev. B, 86,1, 2012, 014505
[3] Li, T., Jiang, S., Shen, B. et al. Yang Zhang, Trithep Devakul and Liang Fu, Nature 600, 2021, 641–646
[4] Daniele Guerci et al, Science Advances, 9, 11, 2023, eade7701

Minimal quantum dot based Kitaev chain with only local superconducting proximity effect

William Samuelson
Viktor Svensson, Martin Leijnse

Division of Solid State Physics and NanoLund, Lund University, Lund, Sweden
william.samuelson@ftf.lth.se

The possibility to engineer a Kitaev chain in quantum dots coupled via superconductors has recently emerged as a promising path toward topological superconductivity and possibly nonabelian physics [1,2]. In this talk, I will discuss how some of the main experimental hurdles on this path can be avoided by using only local proximity effect on each quantum dot in a geometry resembling a two-dot version of the proposal in Ref. [3]. There is no need for narrow superconducting couplers, additional Andreev bound states, or spatially varying magnetic fields; it suffices with spin-orbit interaction and a constant magnetic field, in combination with control of the superconducting phase to tune the relative strengths of elastic cotunneling and an effective crossed-Andreev-reflection-like process generated by higher-order tunneling. We use a realistic spinful, interacting model and show that high-quality Majorana bound states can be generated already in a double quantum dot [4].

References

[1] T. Dvir, et. al. ''Realization of a minimal Kitaev chain in coupled quantum dots'', Nature 614, 445 (2023).

[2] Athanasios Tsintzis, Rubén Seoane Souto, Karsten Flensberg, Jeroen Danon, and Martin Leijnse, ''Majorana qubits and non-Abelian physics in quantum dot–based minimal Kitaev chains'', PRX Quantum 5, 010323 (2024).

[3] I. C. Fulga, A. Haim, A. R. Akhmerov, and Y. Oreg, ''Adaptive tuning of Majorana fermions in a quantum dot chain'', New J. Phys. 15, 045020 (2013).

[4] W. Samuelson, V. Svensson, and M. Leijnse, ''Minimal quantum dot based Kitaev chain with only local superconducting proximity effect'', Phys.Rev.B 109, 035415 (2024).

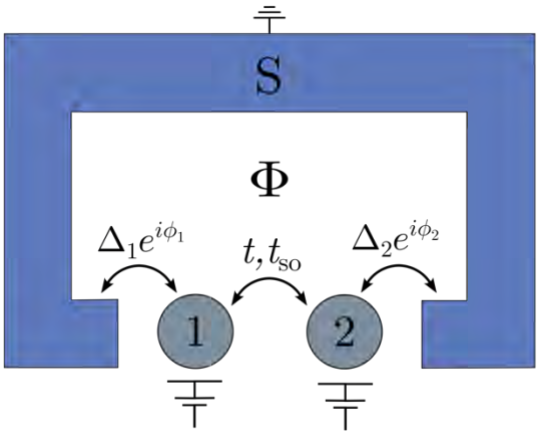


Figure 1 Setup consisting of two coupled quantum dots (1,2) with superconductivity induced by local tunneling to a bulk superconductor (S). Tuning the magnetic flux Φ drives the system to a Majorana sweet spot.

Electric Dipole Forces on a Binary System of Atoms

Julio Sánchez-Cánovas,
Manuel Donaire
Departamento de Física Teórica, Óptica y Atómica, University of Valladolid, Paseo Belén 7, 47011 Valladolid, Spain
julio.sanchez.canovas@uva.es

Dispersion forces between neutral atoms are the result of the coupling of the quantum fluctuations of the electromagnetic field in its vacuum state with the fluctuations of the atomic charges in (meta)stable states. In the electric dipole approximation, these forces are known as van der Waals (vdW) forces.

In recent decades renewed interest has been drawn to the interaction between excited atoms. From a practical perspective, this is the kind of interaction between Rydberg atoms which makes possible the coherent manipulation of their quantum states, facilitating the entanglement between separated quantum systems as well as the storage of quantum information [1]. On the other hand, from a fundamental perspective, the attention has focused on different aspects of the interaction, namely, its scaling behaviour with the distance, its inherent time dependence, and the net forces induced by parity and time-reversal violation on a binary system [2,3].

Here we address this problem on a system made of two two-level identical atoms. Following a fully Hamiltonian and time-dependent approach we show that, once the system is released with one of the atoms initially excited, two kinds of forces are involved in the interatomic interaction. On the one hand, conservative forces act along the interatomic axis. These forces are different on each atom, resulting in a net force upon the whole system. This apparent violation of the action-reaction principle is explained by the excess of linear momentum carried by the virtual photons which mediate the interaction. On the other hand, there exist nonconservative forces as a consequence of the time variation of the so-called Röntgen momentum which possess components orthogonal to the interatomic axis producing a net torque in the atomic system [4,5].

In the context of atomic arrays, both kinds of interactions might have implications on the improvement of coherence time and the directionality of the excitation transfer along the arrays, both determining the optimization of the scalability of multiple atom qubits [6,7].

References

[1] J. M. Raimond, G. Vitrant, and S. Haroche, J. Phys. B 14, L655 (1981).
[2] M. Donaire, R. Guérout, and A. Lambrecht, Phys. Rev. Lett. 115, 033201 (2015).
[3] M. Donaire, Phys. Rev. A 94, 062701 (2016).
[4] J. Sánchez-Cánovas, M. Donaire, Phys. Rev. A 104, 052814 (2021).
[5] J. Sánchez-Cánovas, M. Donaire, Phys. Rev. A 106, 032805 (2022)
[6] Daniel Barredo, Sylvain de Léséleuc, Vincent Lienhard, Thierry Lahaye, and Antoine Browaeys. Science, 354(6315), (2016).
[7] L. Pause et al., Optica 11, 222-226 (2024)

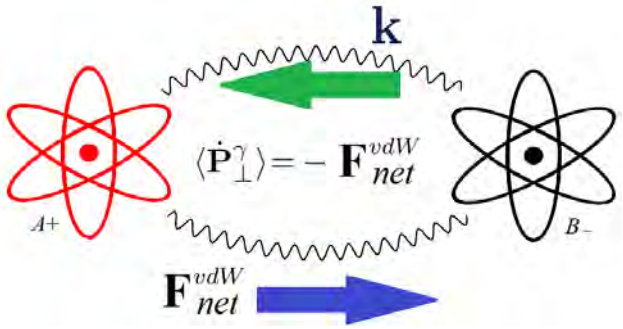


Figure 1: Conservative Net Force on the system

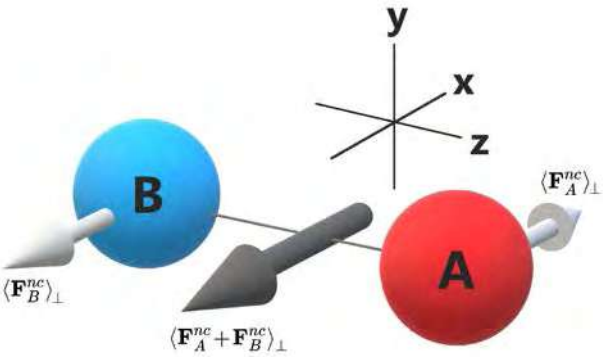


Figure 2: Non-Conservative Orthogonal Forces

Integration of maximum likelihood estimation for reducing the variance of ZNE

Olatz Sanz Larrarte (1,*)
Javier Oliva del Moral (1,2), Reza Dastbasteh (1), Ruben M. Otxoa (2,3), Pedro M. Crespo (1) and Josu Etxezarreta Martinez (1)

1. Department of Basic Sciences, Tecnun - University of Navarra, 20018 San Sebastian, Spain
2. Donostia International Physics Center, 20018 San Sebastian, Spain
3. Hitachi Cambridge Laboratory, J. J. Thomson Avenue, Cambridge, CB3 0HE, United Kingdom

* osanzl@unav.es

Quantum Error Mitigation (QEM) [1] strategies are critical for dealing with noise in quantum computing systems in the Noisy-Intemediate Scale Quantum (NISQ) era. Especially, zero noise extrapolation (ZNE) is one of the most promising QEM techniques for computing noise free expectation values [2]. However, conventional ZNE methods usually require a significant sampling overhead [1, 3], as a result of the increased estimation variance that arises from the extrapolation to the zero noise limit.

In this study, we propose to leverage Maximum Likelihood (ML) estimation techniques to deal with this problem by accounting for sample variance in extrapolation. By integrating ML estimation into the ZNE framework, we aim to improve both the accuracy and efficiency of error mitigation strategies in noisy quantum systems. The main idea revolves around making a priori guesses of the sampling variance of the noisy measurements so that the function fitting protocol takes into account such variability by means of an ML estimator.

References

[1] Z. Cai, R. Babbush, S. C. Benjamin, S. Endo, W. J. Huggins, Y. Li, J. R. McClean, and T. E. O'Brien. (2023). Quantum error mitigation. Reviews of Modern Physics, 95, 045005.DOI:10.1103/RevModPhys.95.045005.

[2] Y. Kim et al. (2023). Evidence for the utility of quantum computing before fault tolerance. Nature 618, 500-505.

[3] Lu, D., Liu, Y., Li, Y., Hu, X., Guo, Y., Han, S., & Feng, G. (2022). A survey of quantum error mitigation. Npj, Quantum Information, 8(1), 1-15. DOI: 10.1038/s41534-022-00618-z

Current-phase relation in Fibonacci Josephson junctions

Ignacio Sardinero[1],
Jorge Cayao[2], Keiji Yada[3], Yukio Tanaka[3] and Pablo Burset[1]

[1]Department of Theoretical Condensed Matter Physics, Condensed Matter Physics Center (IFIMAC) and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, 28049 Madrid, Spain. – [2]Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden. – [3]Department of Applied Physics, Nagoya University, Nagoya 464-8603, Japan

ignacio.sardinero@uam.es

Quasicrystals (QCs), lattices displaying long-range order without translational periodicity, have been shown to be topologically nontrivial [1]. They feature energy gaps linked to topological invariants, harbouring edge modes under specific conditions [2]. The Fibonacci quasicrystal (FQC), a prototypical example of a one-dimensional QC, comprises an aperiodic sequence of two alternating parameters.

We consider Josephson junctions where superconductors with a finite phase difference are subjected to chemical potentials arranged in a Fibonacci sequence. The FQC arrangement, which may be implemented using local gates, introduces gaps and edge modes above the superconducting energy gap (Fig. 1a). We show that these edge modes develop superconducting correlations, with an intriguing dependence on the superconducting phase difference (Fig. 1b). This effect gives rise to a finite Josephson current which can even dominate the contribution from common Andreev bound states (ABS), see Fig. 2.

The interplay between FQCs and the Josephson effect opens new avenues for exploring exotic phenomena with important consequences in topological superconductivity.

References

[1] Kraus et al., Phys. Rev. Lett. **109**, 2012
[2] Jagannathan, Rev. Mod. Phys. **93** 2021

Figures

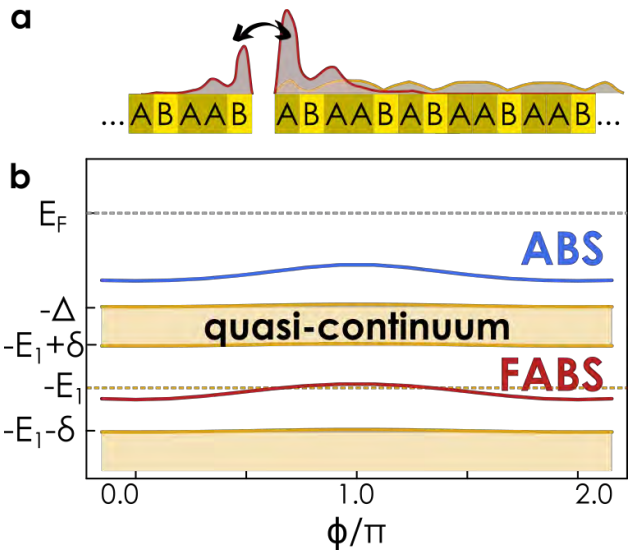


Figure 1: a Sketch of a one-dimensional FQC Josephson junction, showing a delocalized quasicrystal mode (yellow) and a localized Fibonacci-Andreev bound state (FABS) (red). **b** Energy levels as a function of the superconducting phase ϕ.

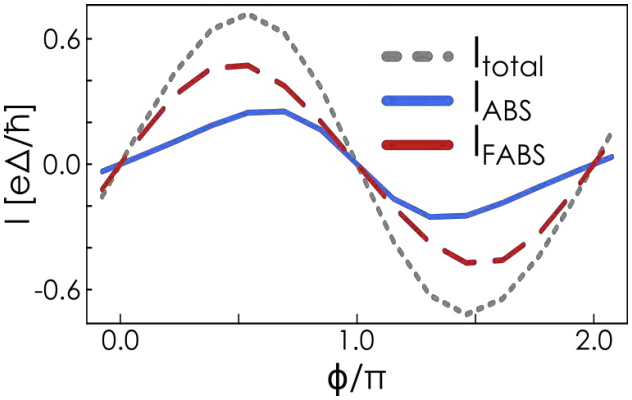


Figure 2: The FABS contribution to the supercurrent can dominate over the conventional ABS one.

Fully autonomous tuning of a spin qubit

Jonas Schuff
David L. Craig
Barnaby van Straaten
Brandon Severin

Department of Materials, University of Oxford, Oxford OX1 3PH, United Kingdom

Federico Fedele
Natalia Ares

Department of Engineering Science, University of Oxford, Oxford OX1 3PJ, United Kingdom

Miguel J. Carballido
Simon Svab
Pierre Chevalier Kwon
Rafael S. Eggli
Taras Patlatiuk
Dominik Zumbühl

Department of Physics, University of Basel, 4056 Basel, Switzerland

Madeleine Kotzagiannidis
Juan Carlos Calvo
Marco Caselli
Jacob Rawling
Nathan Korda

Mind Foundry Ltd, Summertown, Oxford OX2 7DD, United Kingdom

jonas.schuff@materials.ox.ac.uk

Spanning over two decades, the study of qubits in semiconductors for quantum computing has yielded significant breakthroughs [1–3]. However, the development of large-scale semiconductor quantum circuits is still limited by challenges in efficiently tuning and operating these circuits. Identifying optimal operating conditions for these qubits is complex, involving the exploration of vast parameter spaces [4]. This presents a real 'needle in the haystack' problem, which, until now, has resisted complete automation due to device variability and fabrication imperfections [5]. In this study, we present the first fully autonomous tuning of a semiconductor qubit, from a grounded device to Rabi oscillations, a clear indication of successful qubit operation. We demonstrate this automation, achieved without human intervention, in a Ge/Si core/shell nanowire device. Our approach integrates deep learning, Bayesian optimization, and computer vision techniques. We expect this automation algorithm to apply to a wide range of semiconductor qubit devices, allowing for statistical studies of qubit quality metrics. As a demonstration of the potential of full automation, we characterise how the Rabi frequency and g-factor depend on barrier gate voltages for one of the qubits found by the algorithm. Twenty years after the initial demonstrations of spin qubit operation, this significant advancement is poised to finally catalyze the operation of large, previously unexplored quantum circuits.

References

[1] D. Loss and D. P. DiVincenzo, Phys. Rev. A, vol. 57, no. 1, p. 120 (1998)

[2] J. R. Petta, A. C. Johnson, J. M. Taylor, E. A. Laird, A. Yacoby, M. D. Lukin, C. M. Marcus, M. P. Hanson, and A. C. Gossard, Science, vol. 309, no. 5744, pp. 2180–2184 (2005)

[3] X. Xue, M. Russ, N. Samkharadze, B. Undseth, A. Sam- mak, G. Scappucci, and L. M. Vandersypen, Nature, vol. 601, no. 7893, pp. 343–347 (2022)

[4] S. Neyens, O. Zietz, T. Watson, F. Luthi, A. Nethwewala, H. George, E. Henry, A. Wagner, M. Islam, R. Pillarisetty, *et al.*, arXiv preprint arXiv:2307.04812 (2023)

[5] H. Moon, D. Lennon, J. Kirkpatrick, N. van Esbroeck, L. Camenzind, L. Yu, F. Vigneau, D. Zumbühl, G. A. D. Briggs, M. Osborne, *et al.*, Nat. Commun., vol. 11, no. 1, pp. 1– 10 (2020)

A fermion-parity qubit in a double quantum dot

R. Seoane Souto[1,2,4]
M. Geier[2], J. Schulenborg[2,3], S. Asaad[2], M. Leijnse[2,4], and K. Flensberg[2]

[1]*Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC), Spain*
2Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Denmark.
[3]*Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Gothenburg (Sweden).*
[4]*Division of Solid State Physics and NanoLund, Lund University, 22100 Lund, Sweden.*

Ruben.seoane@csic.es

Quantum dots (QDs) allow to control and manipulate the quantum mechanical properties of individual electrons using external potentials and electromagnetic fields. Their exquisite tunability as well as their long coherence times give them a central role in the development of quantum technologies, being the base for charge and spin qubits. However, QD states decohere due to charge fluctuations and random magnetic fields coming from the environment, limiting their use for applications. On the other hand, superconductors have played a central role in the development of quantum technologies, thanks to their macroscopic quantum properties.

In this presentation, I will introduce a new qubit type based on the combination of quantum dots and superconductors, exploiting some of the advantages of both platforms. Bound states that appear in quantum dots coupled to superconductors can be in a coherent superposition of states with different electron number but with the same number parity. Electrostatic gating can tune this superposition to a sweet spot, where the quantum dot has the same mean electric charge independent of its electron-number parity [1]. Here, we propose to encode quantum information in the local fermion parity of two tunnel-coupled quantum dots embedded in a Josephson junction [2]. At the sweet spot, the qubit states have zero charge dipole moment. This protects the qubit from dephasing due to electric field fluctuations. Depending on the strength of the tunnel coupling between the dots, the system is further protected towards either relaxation (weak tunneling) or dephasing (strong tunneling) from noise coupling separately to each quantum dot. We describe initialization and readout as well as single-qubit and two-qubit gates by pulsing gate voltages.

References

[1] E. J. H. Lee, X. Jiang, M. Houzet, R. Aguado, C. M. Lieber, and S. De Franceschi, Nat. Nanotechnol. **9**, 79 (2014).
[2] M. Geier, R. Seoane Souto, J. Schulenborg, S. Asaad, M. Leijnse, and K. Flensberg, arXiv: 2307.05678 (2024)

Figures

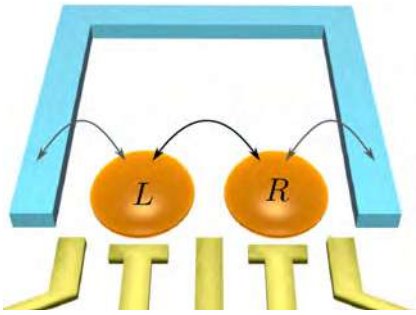


Figure 1: Sketch of the proposed parity qubit, where two QDs (orange) couple to a superconductor (blue). The loop allows for phase control.

Quantum-anomalous-Hall current patterns and interference in thin slabs of chiral topological superconductors

Llorenç Serra[1,2]
Daniele Di Miceli[1,3]

[1]*Institute for Cross-Disciplinary Physics and Complex Systems IFISC (CSIC-UIB) 07122 Palma, Spain.*
[2]*Department of Physics, University of the Balearic Islands, 07122 Palma, Spain*
[3]*Department of Physics and Materials Science, University of Luxembourg, 1511 Luxembourg, Luxembourg*

llorens.serra@uib.es

The chiral topological superconductor, which supports propagating nontrivial edge modes while maintaining a gapped bulk, can be realized hybridizing a quantum-anomalous-Hall thin slab with an ordinary s-wave superconductor. We show that by sweeping the voltage bias in a normal-hybrid-normal double junction, the pattern of electric currents in the normal leads spans three main regimes. From single-mode edge-current quantization at low bias, to double-mode edge-current oscillations at intermediate voltages and up to diffusive bulk currents at larger voltages. Observing such patterns by resolving the spatial distribution of the local current in the thin slab could provide additional evidence, besides the global conductance, on the physics of chiral topological superconductors.

References

[1] D. Di Miceli, L. Serra, Scientific Rep. **13**:19955 (2023); arXiv:2311.09664
[2] D. Di Miceli et al, Phys. Rev. B **108**, 035424 (2023); arXiv:2303.16261

Figures

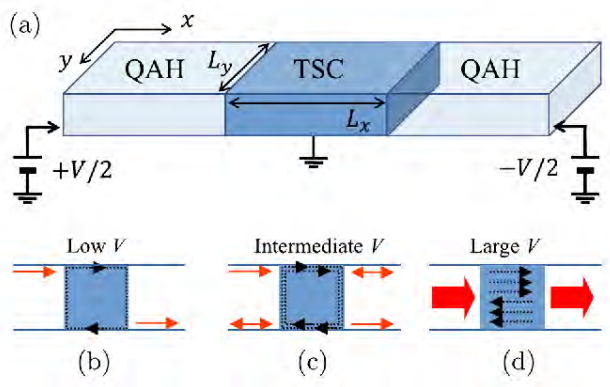


Figure 1: (a) Sketch of the QAH slab with a TSC hybrid sector proximitized by a superconductor (not shown). (b,c,d) Sketches of the currents (red arrows) for low, intermediate and large applied voltages. The dotted black lines represent the TSC quasiparticle modes.

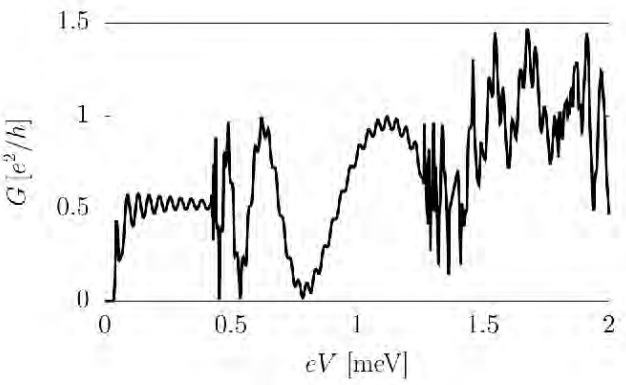


Figure 2: Electric conductance G in the normal leads of a NSN junction as a function of the total bias V . We assumed a magnetic TI thin slab of width Ly = 1 μm with a central sector long Lx = 20 μm. The superconducting pairings are Δ1 = 1.5 meV and Δ2 = 0, and the other parameters of the effective Hamiltonian are the same as in Fig. 2.

Neural network decoding of quantum error correction experiments using soft measurement information

Marc Serra-Peralta
Barbara M. Terhal

Qutech, Lorentzweg 1, Delft, Netherlands.
Delft Institute of Applied Mathematics (DIAM), Mekelweg 4, Delft, Netherlands.

m.serraperalta@tudelft.nl

In recent years, there has been interest in small-scale quantum error correction experiments such as scaling a surface code from distance d=3 to d=5 for superconducting qubits [1]. Neural network decoders can offer an alternative to conventional decoders, such as minimum-weight-perfect-matching (MWPM) and variants, and can provide an advantage when dealing with non-conventional errors, such as leakage and crosstalk. Until recently, neural network decoders have only been applied to simulated data with Pauli errors. In our work, we apply a recurrent neural network to decode experimental data from several superconducting experiments. For experiments on d=3 and d=5 surface codes, with a decoder trained on simulated data but applied to experimental data, we show performance close to a Belief-Matching decoder, see Figure 1. We also show a decoding advantage in using soft measurement data [4]. For experimental data of a Surface-13 (only correcting bit-flip errors) experiment, we train and apply the neural network decoder with experimentally available soft measurement information and outperform MPWM with either soft or hard information, see Figure 2. We also show that the neural network decoder can use leakage information to improve its performance. Finally, we discuss how this method of decoding can be used for decoding logical gates and larger distance codes.

This talk is based on the work carried out in Ref. [2] and Ref. [3].

References

[1] Google Quantum AI. Nature 614 (2023) 676-681
[2] Boris M. Varbanov et al., arXiv (2023) 2307.03280
[3] Hany Ali et al., (in preparation)
[4] Christopher A. Pattison et al., arXiv (2021) 2107.13589

Figures

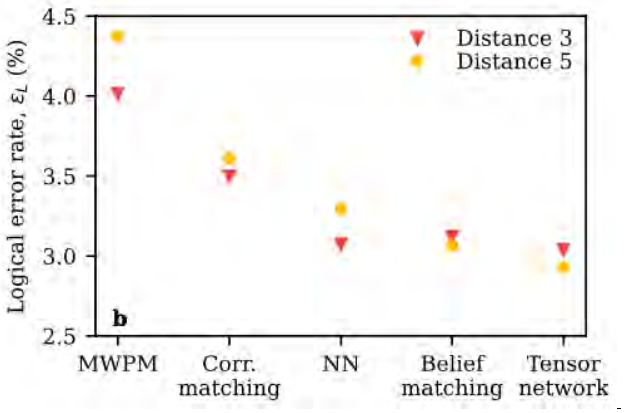


Figure 1: Logical error rate for different decoders, including the neural network, evaluated on experimental data from d=3 and d=5 surface codes [2]

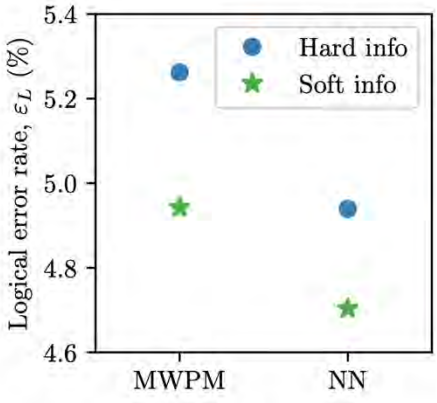


Figure 2: Logical error rate for the neural network and MWPM decoders evaluated on experimental data using soft and hard measurement information from a Surface-13 code [3]

Study of non-linear dynamics of a nanomechanical resonator with single-electron tunnelling

Sofia Sevitz[1]
Kushagra Aggarwal[2], Federico Cerisola[3], Juliette Monsel[4], Gerard J. Milburn[5], Janet Anders[1,3], and Natalia Ares[6]

[1] *University of Potsdam, Institute of Physics and Astronomy, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany*
[2] *Department of Engineering Science, University of Oxford, Oxford OX1 3PJ, United Kingdom*
3 *Physics and Astronomy, University of Exeter, Exeter EX4 4QL, United Kingdom*
[4] *Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, S-412 96 Göteborg, Sweden*
[5] *School of Mathematics and Physics, The University of Queensland, St Lucia QLD 4072, Australia*
[6] *Department of Engineering Science, University of Oxford, Oxford OX1 3PJ, United Kingdom*

sofia.sevitz@uni-potsdam.de

Devices that present non-linear behaviour are of much interest for their broad applications ranging from thermodynamics, chaos to metrology. A promising platform is a suspended Carbon Nanotube (CNT) containing an electrostatically defined quantum dot. The electronic transport couples to the mechanical degrees of freedom of the CNT. When the coupling is in the ultrastrong regime, the CNT experiences a pronounced back-action that leads to non-linear dynamics [1,2]. When the CNT is driven weakly, this nonlinearity is presented as a softening of the resonance frequency of the CNT. However, when the CNT is subjected to a strong driving, intrinsic non-linearities of the mechanics take over. The main feature is the emergence of arch-like resonances in the electronic transport [3].

In this talk, we describe our physical model that captures the combined interplay between the intrinsic non-linearities of the mechanics (modeled as a Duffing oscillator) and the electromechanical coupling under different driving regimes [4]. Finally, we show that our model is in good agreement with our experimental electron transport measurements.

References

[1] Steele, G. A. et al. Science, 325 (2009) 1103–1107.
[2] Vigneau, F. et al. Phys. Rev. Research, 4 (2022) 043168.
[3] Wang, X. et al. Nano Res., 14 (2021) 1156–1161.
[4] Aggarwal, K., Sevitz, S., et al. *Manuscript in preparation.*

Quantum subspace expansion in the presence of hardware noise

Prachi Sharma[1]
Joao C. Getelina[2], Thomas Iadecola[2,3], Peter P. Orth[1,2,3], Yong-Xin Yao[2,3]

[1.] *Department of Physics, Saarland University, 66123 Saarbrücken, Germany*
[2.] *Ames National Laboratory, U.S. Department of Energy, Ames, Iowa 50011, USA*
[3.] *Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA*

prachi.sharma@uni-saarland.de

Finding ground state energies on current quantum processing units (QPUs) using algorithms like the variational quantum eigensolver (VQE) continues to pose challenges. Hardware noise severely affects both expressivity and trainability of parametrized quantum circuits, limiting them to shallow depths in practice. Here, we demonstrate that both issues can be addressed by synergistically integrating VQE with a quantum subspace expansion, allowing for an optimal balance between quantum and classical computing capabilities and costs. We perform a systematic benchmark analysis of the iterative quantum-assisted eigensolver of [1] in the presence of hardware noise. We determine ground state energies of 1D and 2D mixed-field Ising spin models (MFIM) on noisy simulators and on the IBM QPUs ibmq_quito (5 qubits) and ibmq_guadalupe (16 qubits). To maximize accuracy, we propose a suitable criterion to select the subspace basis vectors according to the trace of the noisy overlap matrix. Finally, we show how to systematically approach the exact solution by performing controlled quantum error mitigation based on probabilistic error reduction (PER) on the noisy backend fake_guadalupe.

Figures

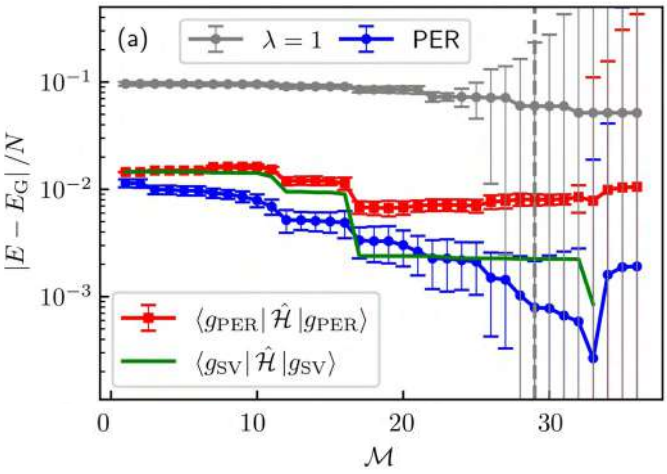


Figure 1: Paired iterative quantum-assisted eigensolver calculations on fake_guadalupe using PER quantum error mitigation. Energy error per site as a function of subspace dimension for a 16-site MFIM.

References

[1] K. Bharti and T. Haug, Phys. Rev. A 104, L050401 (2021)

Preparation of Emerging 2D Materials and their Heterostructures by Electrochemistry

Huanhuan Shi
Xinliang Feng, Dirk Fuchs, Matthieu Le Tacon
Karlsruher Institut für Technologie, Hermann-v.-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen, Germany
Huanhuan.Shi@kit.edu

Abstract

2D materials and their heterostructures have attracted tremendous research interest Since their unique mechanical, electrical and optical properties hold great potential in novel applications for electronics and optoelectronics. High-yield production of 2D materials and their vdWHs with high quality is a key to fundamental studies and especially industrial applications. Electrochemical intercalation has been proved a very promising approach that can delaminate the layered materials with high yield. Here we will show preparation of high-quality emerging 2D materials and their vdWHs by using electrochemical intercalation. At the end, the emerging trends, challenges, and opportunities in electrochemical intercalation are also highlighted.

References

[1] **H. Shi**, M. Li, A. S. Nia, M. Wang, S. Park, Z. Zhang, M. R. Lohe, S. Yang, X. Feng, *Adv. Mater.* **2020**, 32, 1907244.
[2] **H. Shi**, M. Li, S. Fu, C. Neumann, X. Li, W. Niu, Y. Lee, M. Bonn, H.I. Wang, A. Turchanin, A. Shaygan Nia, S. Yang, X. Feng, *Angew. Chem. Int. Ed.*, **2023**, 62, e202303929.
[3] **H. Shi**, D Fuchs, M Le Tacon, **2024**, unpublished.

Figures

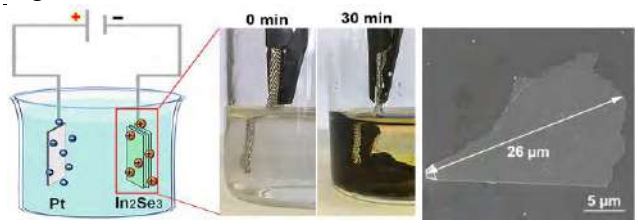


Figure 1: Ultrafast electrochemical synthesis of defect-free In_2Se_3 flakes.

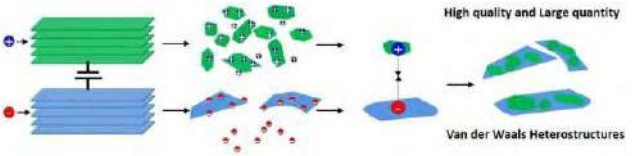


Figure 2: High-throughput synthesis of van der Waals heterostructures through electrochemistry.

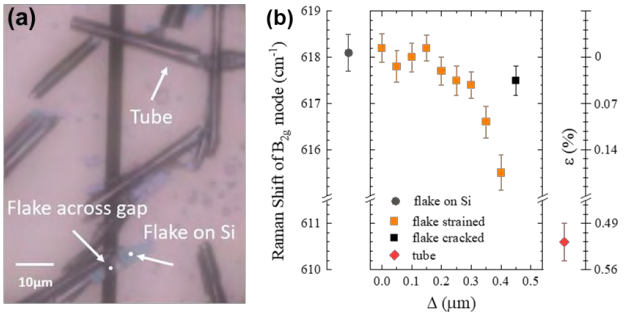


Figure 3. Strain induced Raman Shift of B_{1g} mode in $TbMnO_3$ membranes.

Ultrastrong coupling between Andreev bound states and a high impedance lumped-element resonator

Oleg Shvetsov[1]
A. Ankit[1], V. Buccheri[1], I. Cools[1], T. Kanne[2], J. Nygård[2], A. Geresdi[1]

[1]*Quantum Device Physics Laboratory, Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE 41296 Gothenburg, Sweden*

[2]*Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark*

shvetsov@chalmers.se

Josephson junctions in Al/InAs nanowires host Andreev bound states[1] (ABSs) and can be considered as a platform for realization of gate-tunable Andreev qubits[2-4]. An acute challenge of such architecture is to improve the coupling between an ABS and a microwave resonator.
Here, we report microwave characterization of an Al/InAs nanowire weak link embedded in a superconducting loop with a lumped-element resonator patterned from a thin NbTiN film with high kinetic inductance. We demonstrate that our approach offers a compact geometry, a high resonator impedance above 12 kOhm and remarkably large coupling rates between ABSs and the resonator mode reaching the value of 1.2 GHz. This result provides a basis for exploration of strongly correlated light–matter states in cQED.

References

[1] A. Furusaki and M. Tsukada, Phys. Rev. B 43, 10164 (1991).
[2] A. Zazunov et al, Phys. Rev. Lett. 90, 087003 (2003).
[3] M. Hays et al, Phys. Rev. Lett. 121, 047001 (2018)
[4] C. Metzger et al, Phys. Rev. Res. 3, 013036 (2021).

Figures

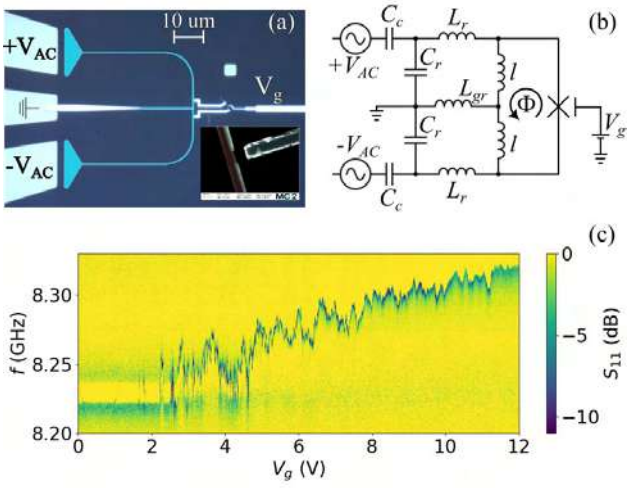
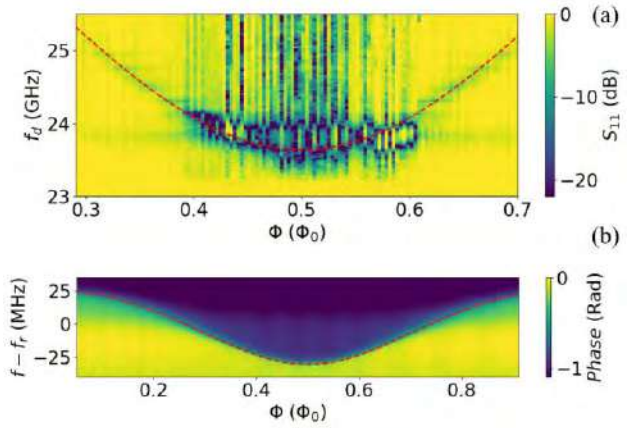


Figure 1: (a) Differentially driven lumped element resonator coupled to a nanowire weak link. Inset: SEM picture of the nanowire Josephson junction. (b) Circuit equivalent of the device. (c) Gate-tunable microwave response.



Channel	Δ (GHz)	τ	δ_{zp} (Rad)
1	13.95	0.282	0.121
2*	15.5	0.2	0.121

Figure 2: (a) Two-tone spectrum in dispersive regime. (b) Corresponding single-tone spectrum. Dashed lines show the fitted spectra. Table: parameters for a 2-channel fitting (Δ – ABS energy gap, τ – channel transmission, δ_{zp} – zero-point phase fluctuations in the weak link). *The second channel is introduced to account for all the higher energy states.

Time series prediction with photonic quantum memristor

Michał Siemaszko[1]
Mirela Selimović[2], Iris Agresti[2], Philip Walther[2], Francesco Ceccarelli[3] and Roberto Osellame[3]

[1] University of Warsaw, Faculty of Mathematics, Informatics, and Mechanics,
Stefana Banacha 2, 02-097 Warszawa, Poland
[2] University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology, Boltzmanngasse 5, Vienna A-1090, Austria
[3] Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche (IFN-CNR), piazza L. Da Vinci 32, 20133 Milano, Italy

mm.siemaszko2@uw.edu.pl

Time series prediction is a crucial task for many human activities e.g. weather forecasts or predicting stock prices. One solution to this problem is to use the Reservoir Computing paradigm [1]. The purpose of the reservoir is to map the input data into a computational space using fixed and non-linear dynamical systems (Fig. 1). In recent years, various quantum dynamical systems have been proposed to serve as reservoirs which can potentially improve the prediction capability over the classical reservoirs [2].

In our work we utilize the photonic quantum memristor [3] to build a quantum reservoir. We show that the photonic quantum memristor is the source of a temporal memory and non-linearity in the reservoir. We evaluate the performance of the reservoir using the standard task of NARMA prediction [4], which contains a quadratic temporal dependance. Our findings indicate that a single memristor is sufficient for the network to effectively learn the NARMA task, maintaining an average relative error of less than 5% (Fig. 2).

References

[1] Du, C., Cai, F., Zidan, M.A. *et al.* Nat Commun 8, 1, (2017) 2204
[2] Fujii, K. & Nakajima, K., Phys. Rev. Applied 8, 2, (2017) 024030
[3] Spagnolo, M. et al. Nat Photon 16, 4, (2022) 318–323
[4] Appeltant, L. et al. Nat Commun 2, 1, (2011) 468.

Figures

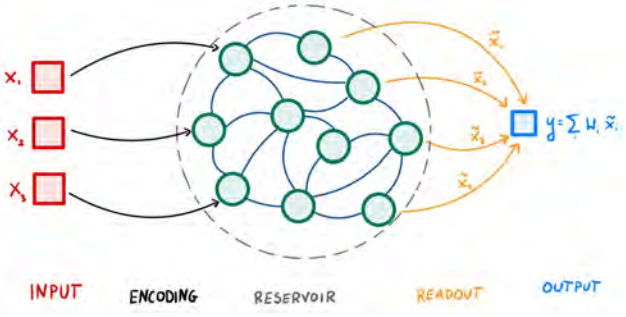


Figure 1: Visualization of the reservoir computing

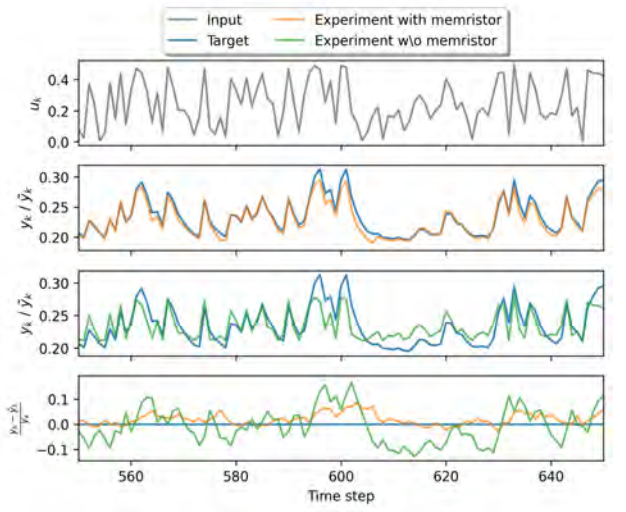


Figure 2: Results of the NARMA prediction. Top row is the input fed to the quantum circuit (gray). Second and third row shows the target sequence (blue) and the prediction of the reservoir with (orange) and without (green) memristor. Bottom row presents the relative errors of corresponding predictions.

Strain-induced topological edge states in few layers of SnTe

Orlando J Silveira
Liwei Jing, Mohammad Amini, Adolfo Fumega, Jose L Lado, Adam S Foster, Peter Liljeroth, Shawulienu Kezilebieke

Department of Applied Physics, Aalto University, Aalto, FI-00076 Finland

orlando.silveirajunior@aalto.fi

2D topological crystalline insulators (2D-TCI) represent an exotic quantum state of matter characterized by metallic edges states (MES) residing within a bulk band gap [1]. Unlike 2D topological insulators where the MES are protected by time-reversal symmetry, the edge states of a 2D-TCI are protected by crystal symmetries and are characterized by the Chern mirror topological invariant. The 3D SnTe is already a known 3D-TCI [1], hosting topological protected surface states instead of edge states, but it behaves as a trivial insulator when reduced to the few layers limit (less than 10 layers) [2]. In this work we show through DFT calculations that slowly compressing the few layers of SnTe leads to a gap-closing transition, and SnTe already starts behaving as a 2D-TCI on moderate compression of 2-3%, where a clear band inversion is observed. The intrinsic ferroelectric properties of the SnTe are also investigated within this regime, where the possibility of topological and ferroelectric phases coexisting is considered. We show that such compression can be achieved when bilayers of SnTe are grown on a $NbSe_2$ substrate due to the incommensurability between their square and hexagonal cells. The topologically protected MES are clearly observed in dI/dV scans taken over the step edges of a bilayer to monolayers SnTe, where very clear and symmetric islands are obtained. This work opens the possibility for the engineering of such topological states by controlling the number of layers of SnTe, and y using different kinds of substrate, where its lattice parameter can then be tuned.

References

[1] Hsieh, T., Lin, H., Liu, J. et al. Topological crystalline insulators in the SnTe material class. Nat Commun 3, (2012) 982

[2] Araújo, A.L., Ferreira, G.J. & Schmidt, T.M. Suppressed topological phase transitions due to nonsymmorphism in SnTe stacking. Sci Rep 8 (2018) 9452

Avoiding decoherence with giant atoms in a 2D structured environment

Ariadna Soro
Emil Raaholt Ingelsten
Anton Frisk Kockum

Chalmers University of Technology, Department of Microtechnology and Nanoscience, 412 96 Gothenburg, Sweden

soro@chalmers.se

Giant atoms [1] are quantum emitters that can couple to light at multiple discrete points, as has been demonstrated in recent experiments using superconducting qubits and microwaves [2-4]. Besides many other remarkable features, giant atoms have been shown to interact without decohering via a one-dimensional waveguide [2]. Here [5], we study how giant atoms behave when coupled to a two-dimensional square lattice of coupled cavities, an environment characterized by a finite energy band and band gaps. In particular, we describe the role that bound states in the continuum (BICs) play in how giant atoms avoid decoherence. By developing numerical methods, we investigate the dynamics of the system and show the appearance of interfering BICs within a single giant atom, as well as oscillating BICs between many giant atoms. In this way, we find the geometric arrangements of atomic coupling points that yield protection from decoherence. These results on engineering the interaction between light and matter may find applications in quantum simulation and quantum information processing.

References

[1] AF Kockum, International Symposium on Mathematics, Quantum Theory, and Cryptography, pp 125-146 (2021)
[2] B Kannan et al., Nature 583, pp 775-779 (2020)
[3] AM Vadiraj et al., Phys. Rev. A 103, 023710 (2021)
[4] C Joshi et al., Phys. Rev. X 13, 021039 (2023)
[5] ER Ingelsten, AF Kockum, and A Soro, arXiv:2402.XXXX (2024).

Figures

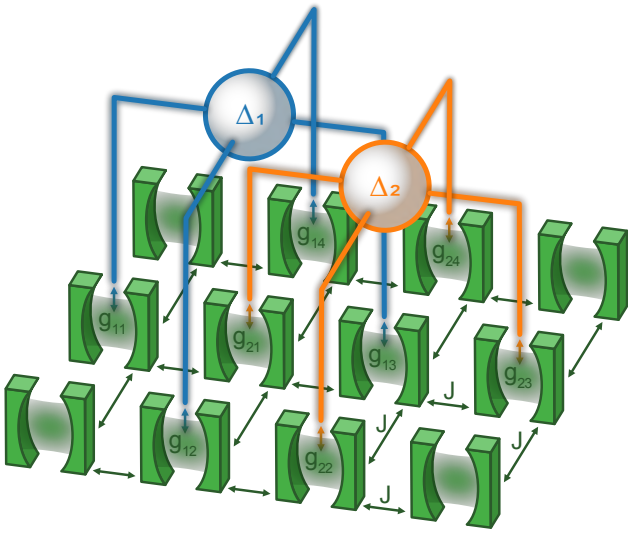


Figure 1: Sketch of the setup studied in this work. In particular, this shows two giant atoms in a braided configuration coupled to a 2D structured bath. The bath is modeled as a lattice of *NxN* cavities with nearest-neighbor coupling strength *J*. The atoms are two-level systems that are coupled to the cavities with strength g_{ip} at each coupling point, where *i* refers to the atom, and *p* to the connection point. The atomic transition frequencies are detuned from the bath frequency (i.e., from the middle of the band) by Δ_i.

Fragile Discolation Modes

Rodrigo Soto Garrido
Gabriel Malavé, Jorge Schifferli, Pedro A. Orellana and Vladimir Juricic

Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Santiago, Chile

rodsoto@uc.cl

Abstract (Century Gothic 11)

We introduce the notion of fragile dislocation modes, confined to a specific portion of a topological phase while otherwise extending into the bulk continuum. As demonstrated in this work, these dislocation modes appear in the two-dimensional Su-Schrieffer-Heeger model. Nevertheless, their presence is confined to a finite region characterized by an indirect gap at high energy. The dislocation modes appear as chiral pairs at finite energies, enjoying protection through a combination of chiral (unitary particle-hole) and point group (C4v) symmetries. Within this parameter range, we affirm the stability of these defect modes by tracking their localization and introducing a mild chemical potential disorder explicitly. Consequently, our findings bear significance for the experimental detection of such modes in engineered topological crystals and classical metamaterials

References

[1] G. Malavé, J. Schifferli, R. Soto-Garrido, P. A. Orellana and V. Juricic. arXiv:2310.10779.
[2] W. A. Benalcazar and A. Cerjan, Phys. Rev. B 101, 161116 (2020).

Figures

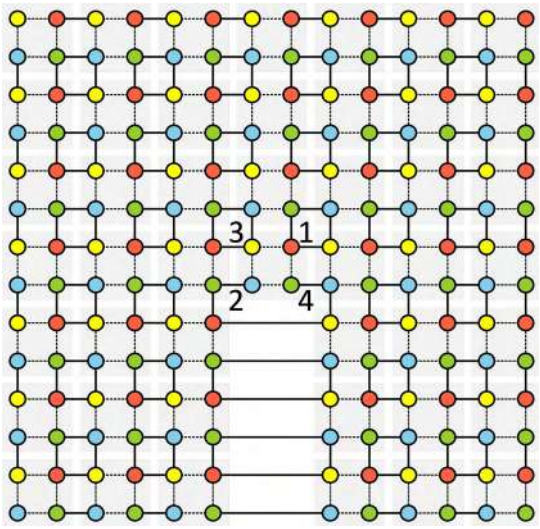


Figure 1: Two-dimensional (2D) Su-Schrieffer-Heeger (SSH) model with a single dislocation.

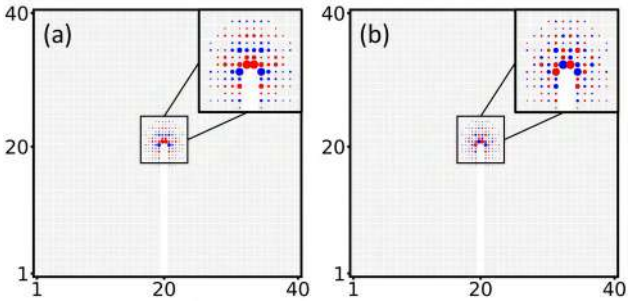


Figure 2: Two chiral pairs of the fragile dislocation bound states in the topological phase. (a) E = 0.72 and (b) E = −0.72

Revisiting quantum superpositions: Insights from the Generalized Lorentz Transformation

Jędrzej Stempin
Andrzej Grudka, Jan Wójcik, Antoni Wójcik
Faculty of Physics, Adam Mickiewicz University, 61-614 Poznań, Poland

jedste@st.amu.edu.pl

Abstract

The quantum description of reality is still an intriguing and bizarre topic for many scientists because of its rich structure. In tackling the most fundamental questions within this domain, researchers often try to incorporate unconventional methods to explain some essential features acquired by quantum systems. Recently, Dragan and Ekert [2] postulated that considering the generalized Lorentz transformation, including a valid description of superluminal observers, may imply the emergence of multiple quantum mechanical trajectories. As a counterargument, we show that rigorous analysis of the generalized Lorentz transformation does not imply any correspondence between the classical concept of a definite path and the multiple paths of quantum mechanics. Furthermore, we point out that a comprehensive analysis of the structure of subluminal and superluminal reference frames leads to the conclusion that the absorption process is indistinguishable from the emission process as far as the superluminal reference frame is concerned. We indicate the preceding argument as the major cause of the illusory emergence of multiple quantum trajectories.

References

[1] Grudka, A., Stempin, J., Wójcik, J., & Wójcik, A. (2023). Superluminal observers do not explain quantum superpositions. *Physics Letters A*, *487*, 129127.

[2] Dragan, A., & Ekert, A. (2020). Quantum principle of relativity. *New Journal of Physics*, *22*(3), 033038.

Figures

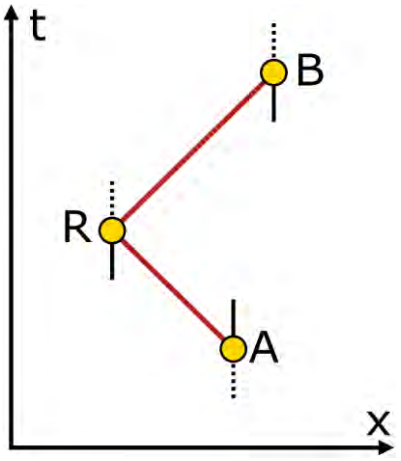


Figure 1: Minkowski diagram presents an experiment in which a single photon is emitted by a source A, reflected by a mirror R, and absorbed by an atom B as seen from a subluminal reference frame

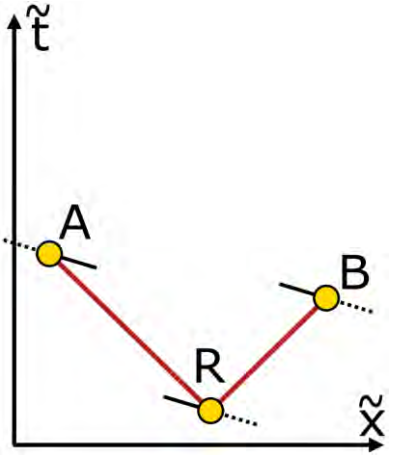


Figure 2: The experiment from Fig.1 seen from the superluminal reference frame

Spectral Properties of Random Clifford Circuits

Dominik Szombathy[1,2]
A.Valli[1,3], P.Moca[1,4], T.Rakovszky[5], G.Zaránd[1,3]

[1]Department of Theoretical Physics, Institute of Physics, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest (Hungary)
[2]Nokia Bell Labs, Nokia Solutions and Networks Kft, Bókay János u. 36-42, 1083 Budapest (Hungary)
[3]HUN-REN–BME Quantum Dynamics and Correlations Research Group, Budapest University of Technology and Economics, H-1111 Budapest, Hungary
[4]Department of Physics, University of Oradea, 410087, Oradea (Romania)
[5]Department of Physics, Stanford University, Stanford, CA, 94305 (USA)

szombathy.dominik@gmail.com

Abstract

The Clifford group plays a fundamental role in modern quantum computation and quantum information, because it can be efficiently simulated on classical hardware, and can be augmented to a universal quantum computer by just using additional T-gates [1]. We investigate the spectral properties of random Clifford circuits, U, and that of the corresponding Liouvillian, $L_U \ldots = U \ldots U^+$ [2]. The spectrum of U is in one-to-one correspondence with that of L_U. The latter is in direct relation with the structure and distribution of periodic orbits, i.e., so-called Pauli strings S that are transformed into themselves – apart from a possible sign, the parity of the orbit – after L interations, $(L_U)^n S = \tau S$.
We build random brick-wall circuits, and sample the closed trajectories (periodic orbits), and determine the distribution of the eigenvalues $\lambda = e^{i\theta}$ on the unit circle. The distribution $P(\theta) \equiv \langle P_U(\theta) \rangle_U$ can be identified as the autocorrelation of the phases of the eigenvalues of U, and displays peculiar properties: extreme degeneracies as well as some level-repulsion, and has features reminiscent of a fractal pattern.

To investigate the stability of orbits, we introduce $\pi/4$ phase shift gates (T-gates). We find that even a single T-gate completely changes the properties of the circuit [3]. By increasing the number of T-gates, the correlation function rapidly approaches the random matrix theory result, characteristic of random unitary circuits. Nevertheless, some statistically significant fraction of non-trivial orbits persists at low T-gate densities [2].

References

[1] D. Gottesman, Phys. Rev. A **57**, 127 (1998)
[2] D. Szombathy et.al., in preparation (2024)
[3] S. Zhou et.al., SciPost Physics **9**, 087(2020)

Figures

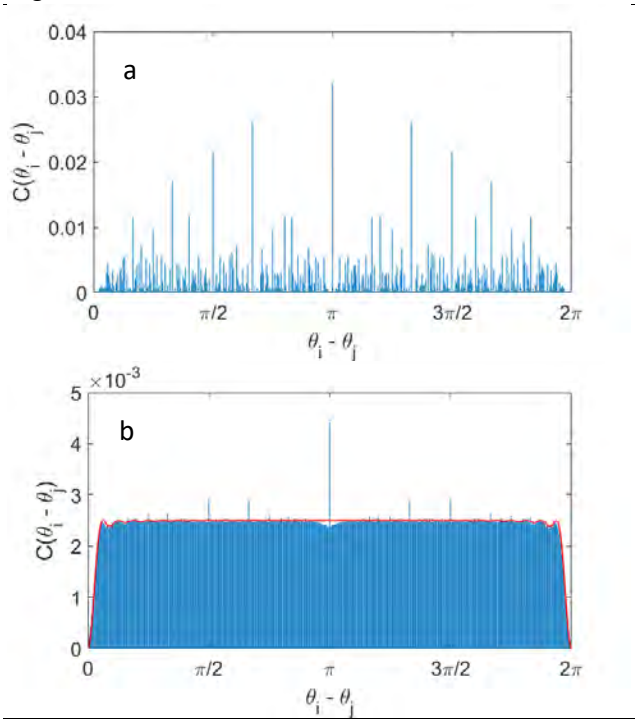


Figure 1: Correlation function of eigenvalue phases $C(\theta_i - \theta_j)$ for random Clifford circuits (a) without and (b) $N_T = 4$ T-gates inserted. The red line corresponds to the analytical result for unitary matrices.

Thermal and electronic properties of twisted bilayer ZnO

B. Tanatar,
M. Seyedmohammadzadeh, and A. Mobaraki

Department of Physics, Bilkent University, Ankara 06800 Turkey

tanatar@fen.bilkent.edu.tr

Abstract

ZINC oxide (ZnO) based materials are the foremost metal oxides in technological utilization, with both monolayer and bilayer configurations experimentally verified. In this work, we developed interatomic potentials for studying the lattice thermal conductivity of monolayer and bilayer ZnO. We show that the structural parameters of the monolayer and bulk wurtzite can accurately be described by Stilinger-Weber (SW potential). Kolomogrov-Crespi potential is optimized for capturing the interlayer interaction of the bilayer system. We also show that the resulting potentials can be used to investigate structural relaxation in twisted bilayer ZnO. We studied the effect of twist angle on the thermal conductivity of the bilayer ZnO.

Figures

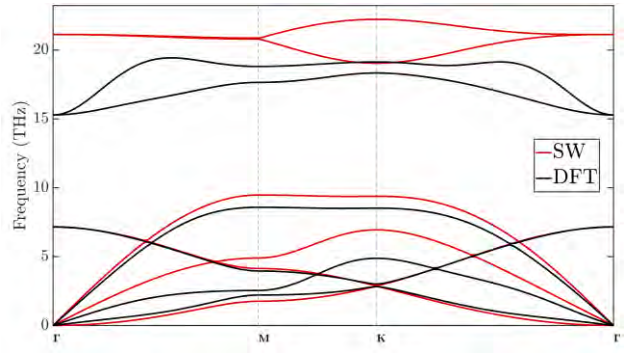


Figure 1: Phonon dispersion curves obtained using the DFT (black lines) and SW potential (red lines).

Certifying asymmetric configuration of three qubit states in the prepare-and-measure scenario

Abdelmalek TAOUTIOUI
Gábor Drótos and Tamás Vértesi

MTA Atomki Lendület Quantum Correlations Research Group, HUN-REN Institute for Nuclear Research, P.O. Box 51, H-4001 Debrecen, Hungary

Abdelmalek.taoutioui@atomki.hu

We consider a prepare-and-measure communication scenario, where Alice prepares a qubit state with an untrusted device chosen from a set of three states and sends it to Bob, who probes the state with an uncharacterized measurement device. We prove that an asymmetric configuration of the Bloch vectors associated with the qubit trine states can be certified in this prepare-and-measure setup. To achieve this, we construct a linear functional W on the observed measurement probabilities based on a generalization of the biased $2\to1$ quantum random access code (b-QRAC). Namely, our witness W is defined as the sum of three suitable $2\to1$b-QRAC functionals. We compute a bound on this witness W that holds for any mirror symmetric configuration of the Bloch vectors of the prepared trine states. Besides, the overall maximum of the witness is also given, which is reached by preparing a specific set of states which we call target states. The difference between the above mirror symmetric witness value and the overall maximum witness value defines a so-called witness gap, which can only be zero if the Bloch vectors of the target trine states possess a mirror-symmetric configuration. The latter gap is used as a measure of the degree of asymmetry of the target trine states. By optimizing over the witness gap, we found that the most asymmetric three-qubit configuration defines a scalene right triangle inscribed in the Bloch sphere. In addition to the theoretical analysis, we have implemented our prepare-and-measure scenario on two publicly accessible quantum processors of different quantum technologies, where we found a violation of the mirror symmetric witness bound certifying an asymmetric configuration of trine states on both quantum processors.

The Qube: a lattice of vertically and laterally coupled quantum dots

Hanifa Tidjani
Hanifa Tidjani[1], Alexander Ivlev[1], Alberto Tosato[1], Jann Hinnerk Ungerer[1], Michael Chan[1], Stefan Oosterhout[2], Lucas Stehouwer[1], Giordano Scappucci[1], and Menno Veldhorst[1]

[1]*QuTech and Kavli Institute of Nanoscience, Delft University of Technology, PO Box 5046, 2600 GA Delft, The Netherlands*

[2]*QuTech and Netherlands Organisation for Applied Scientific Research (TNO), Delft, The Netherlands*

h.tidjani@tudelft.nl

Quantum dots defined in quantum wells in semiconductor heterostructures are a promising platform for realizing quantum computers. To explore what more the platform has to offer, we investigate the properties when electrostatic top gating is used to define quantum dots on bilayer quantum wells [1]. In doing so, we realize a vertically coupled double quantum dot, measured both in transport across a single hole transistor, then in charge sensing. We tune up to the single hole regime under a single plunger and find the (1,1) charge filling. We demonstrate virtualization of the double dot using surrounding barrier gates and find good evidence for the dots being vertically coupled by triangulation of the coupling to the surrounding gates, and electrostatic simulations.

We demonstrate a vertical 2 x 2 array of quantum dots by accumulating under a second plunger, tuning to the (1,1,1,1) regime. By extending this to a four-plunger gate design, we form four vertically coupled double quantum dots. We obtain charge stability diagrams of four dots through the variation of two top plunger gates at a time, on both sides of the device at the same voltage point, resulting in a 2x2x2 quantum dot lattice. This is an exciting opportunity to extend the framework of gate-defined semiconductor quantum dots beyond planar implementations, for the development of quantum computation and simulation.

References

[1] 1] A High-Mobility Hole Bilayer in a Germanium Double Quantum Well, A. Tosato, B. Ferrari, G. Scappucci et al Advanced Quantum Technologies, 2022.

Figures

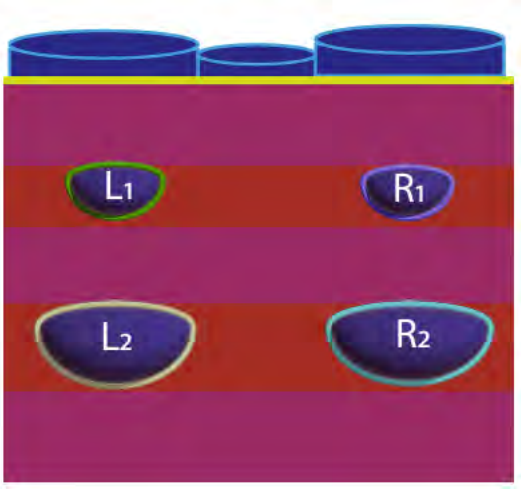


Figure 1: Schematic of a heterostructure with two quantum wells, with two plunger gates. Beneath each plunger gate there is a vertically coupled double quantum dot accumulated.

LatMatcher - AI-Powered Tool for 2D Material Stacking and Property prediction.

Andrei Voicu Tomut [1]
Stephan Roche [12]
Jose Hugo Garcia Aguilar [1]

[1]*Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and The Barcelona Institute of Science and Technology, Campus UAB, 08193 Bellaterra, Catalonia, Spain.*
[2]ICREA — Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain
andrei.tomut@icn2.cat
josehugo.garcia@icn2.cat

Open science databases like C2DB Jarvis and others provide access to thousands of 2D structures. Using this material as fundamental building blocks in creating new materials by stacking allows development of amazing new materials with properties that may be completely different from those of the components.
However exploring the new space comes with two bottlenecks. Firstly, the new space of combinations is vast since the resulting stacked material's properties depend not only on the constituent materials but also on the stacking method. Secondly, evaluating the properties of new materials is challenging with classical methods such as DFT and other techniques. As a first step in addressing this problem, we created Latmatcher, a tool that allows you to stack 2D structures while minimising the supercell size and predicting the properties of the new material using a set of machine learning algorithms. Such a tool can be further integrated into other machine learning pipelines, such as genetic algorithms or reinforcement learning, to expedite the evaluation step.

References

[1] Haastrup et. all, 2D Materials, 5 (2018) page (Century Gothic 11) Indicate references with sequential

Figures

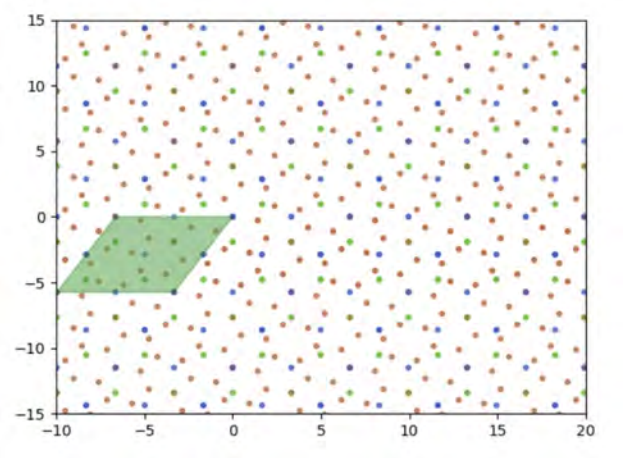


Figure 1: Supercell generated by stacking elements WSe2 on top of graphene, with the supercell delimited with green .

Acknowledgements

ICN2 is funded by the CERCA programme / Generalitat de Catalunya, and is supported by the Severo Ochoa Centres of Excellence programme, Grant CEX2021-001214-S, funded by MCIN / AEI / 10.13039.501100011033. This work is also supported by MICIN with European funds-NextGenerationEU (PRTR-C17.I1) and by Generalitat de Catalunya.

Coarse Graining of Quantum Cellular Automata

Presenting Author: Lorenzo Siro Trezzini
Co-Authors: Paolo Perinotti, Alessandro Bisio.

University of Pavia, Via Bassi, 6, Pavia, Italy

lorenzosiro.trezzini01@universitadipavia.it

Quantum Cellular Automata [1] (QCA) are local dynamics over lattices of quantum systems with discrete time steps. They have many applications, from foundations of quantum mechanics [2] to Many Body Physics. Most notably, they are proven to be a universal model of parallel quantum computation [3]. In particular, they offer promising architecture for the simulation of quantum field theories, as exemplified by the successful implementation of cold atoms on optical lattices or integrated quantum optic simulations.

Given the universality of QCA in computation, a coarse graining procedure would find applications in designing experimental-accessible apparatuses for quantum simulation and computation. Indeed, by neglecting irrelevant degrees of freedom, computation can focus solely on those pertinent for the problem at hand, reducing computational and experimental efforts. We propose a procedure of Coarse Graining largely inspired by Israeli and Goldenfeld's method for classical cellular automata [4].

The main idea is to restrict the dynamics of N steps of a QCA to a subset of 'relevant' degrees of freedom: if this restriction is expressible as a single step of a QCA over the chosen subset, we say that the new automaton is a coarse graining of the original one. This allows us to describe the evolution neglecting irrelevant degrees of freedom. However, with this definition, not all QCA can undergo coarse graining; in general, is not always possible to choose a map that implements the restriction in such a way that what we get behaves like a QCA. We derive a necessary and sufficient condition for a general QCA to be coarse grained relating the original evolution and the restriction map. We then focus on the case of QCA over one dimensional lattices, leveraging a characterization of such QCA in terms of a local topological invariant called the index [5]. This allows to formulate the coarse graining conditions in terms of the structure of the original evolution, facilitating the analysis. Finally, we focus on the case of one-dimensional qubits QCA. This QCA are completely classified [5]. Exploiting this classification, we find all the possible qubit QCA that can be coarse grained. Those are particularly simple, and do not show interesting behavior. However, we have strong reasons to believe that this conclusion is an artifact of the limited number of subspaces within a qubit's cell. Indeed, this strongly constrains the way we can select degrees of freedom.

While this procedure aims to an exact coarse graining, it can also serve as starting point for non-exact methods. Relaxing conditions to allow small simulation errors extends the tool's applicability to general scenarios. Furthermore, beyond practical application, this procedure can shed light on more theoretical questions, as the relation between the renormalization of the simulated field theories and the coarse graining of the underlying computational devices.

References

[1] Farrelly, T., *Quantum*, 4 (2020),369.
[2] Bisio, A., D'Ariano, G.M., Perinotti, P. *et al.* Weyl, Dirac and Maxwell Quantum Cellular Automata. *Found Phys* **45** (2015), 1203–1221
[3] Watrous, J., *Proceedings of IEEE 36th Annual Foundations of Computer Science*, (1995) p. 528-537
[4] N. Israeli, N. Goldenfeld, Phys. Rev. Lett. 92, 074105 (2004)
[5] Gross, D *et al.*, Communications in Mathematical Physics, 310, 2 (2012) p. 419–454
[6] B. Schumacher and R. F. Werner, *arXiv: Quantum Physic* (2004) quant-ph/0405174

Induced Superconductivity in Hybrid Nanowires: Hysteretic Magnetotransport and Intrinsic Magnetic Fields

Nermin Trnjanin[1]
Bekmurat Dalelkhan [1], Yu Liu [2], Jesper Nygård [2], Thilo Bauch [1]

[1] *Chalmers University of Technology, Kemivägen 9, 412 58 Göteborg, Sweden*

[2] *Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark*

nermin@chalmers.se

Strong spin-obit semiconducting nanowires (NWs) in proximity to a conventional superconductor have for some time now been the focus of research in the field of topological superconductivity. These topological states require strong Zeeman fields to emerge which puts constraints on device design and operation. A new set of NWs with such properties, in addition to a ferromagnetic insulator layer offer a possible relaxation of these constraint as they provide an intrinsic magnetic field inside the material. We report magneto transport measurements of Josephson devices implementing these hybrid NWs consisting of an InAs core with a ferromagnetic insulator EuS layer (covered by a protective Aluminium oxide cap) and contacted by two Al electrodes. This geometry shows a hysteretic behaviour in transport with respect to the axial applied magnetic field direction and bias current polarization. The hysteresis of the transport map suggests a significant effective Zeeman field in the material.

References

[1] Lutchyn, Roman M., et al. "Majorana zero modes in superconductor–semiconductor heterostructures." Nature Reviews Materials 3.5 (2018): 52-68.

[2] Sau, Jay D., et al. "Generic new platform for topological quantum computation using semiconductor heterostructures." Physical review letters 104.4 (2010): 040502.

[3] Vaitiekėnas, S., et al. "Zero-field topological superconductivity in ferromagnetic hybrid nanowires." arXiv preprint arXiv:2004.02226 (2020).

[4] Razmadze, D., et al. "Supercurrent reversal in ferromagnetic hybrid nanowire Josephson junctions." Physical Review B 107.8 (2023): L081301.

Figures

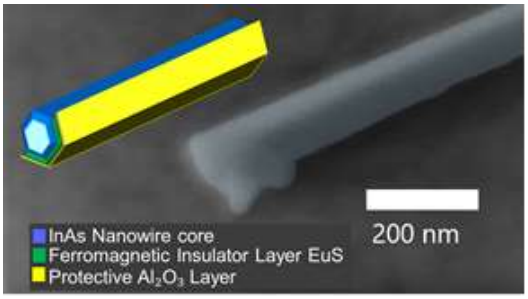


Figure 1: SEM image of a typical NW used in the experiment and an illustration of the nanowire and its constituents in the top left corner.

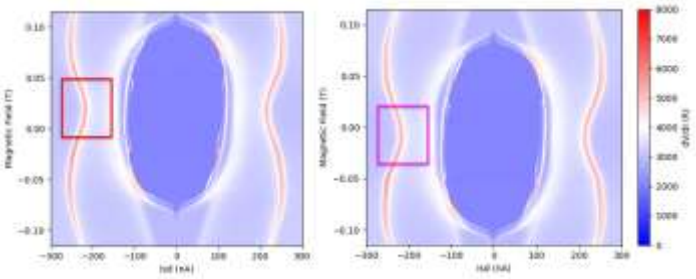


Figure 2: Differential resistance measurements of a InAs-EuS NW Josephson junction with the right panel representing the differential resistance after a 500 mT field was applied in positive direction along the nanowire axis and magnetic field is stepped from positive to negative values, vice versa for the left panel. Note the hysteresis of the map highlighted in the red and purple box.

Superconducting qubits at elevated frequencies

Ivan Tsitsilin[1]
N. Bruckmoser, L. Koch, J. Schirk, D. Bazulin, F. Haslbeck, C. Schneider, S. Filipp

[1]*Technical University of Munich & Walther-Meissner-Insitute, Walther-Meissner-Strasse 8, Garching, Germany*

ivan.tsitsilin@wmi.badw.de

Quantum processors based on superconducting qubits typically operate in a frequency range from 3 to 7 GHz. Raising the qubit frequencies beyond this well-established frequency range could result in significant advantages including reduced residual mode populations, enhanced anharmonicities and the potential for operation at elevated cryogenic temperatures [1]. In this work, we study the properties of transmon-type superconducting qubits based on niobium electrodes and standard Al/AlOx/Al junctions with resonance frequencies up to 20GHz. We observe a reduction in qubit lifetimes by two orders of magnitude for high-frequency qubits compared to standard devices operating around 4.5 GHz. To investigate the source of the additional losses we measure the behavior of niobium (Nb) resonators in the same range. We find that the quality factors of the Nb resonators are nearly constant as a function of frequency, suggesting that Josephson junctions, particularly AlOx [2], are responsible for losses at higher frequencies.

References

[1] A. Anferov et al., arXiv:2402.03031(2024)

[2] H.J. Mamin et al., Phys. Rev. Applied 16, 024023 (2021)

Figures

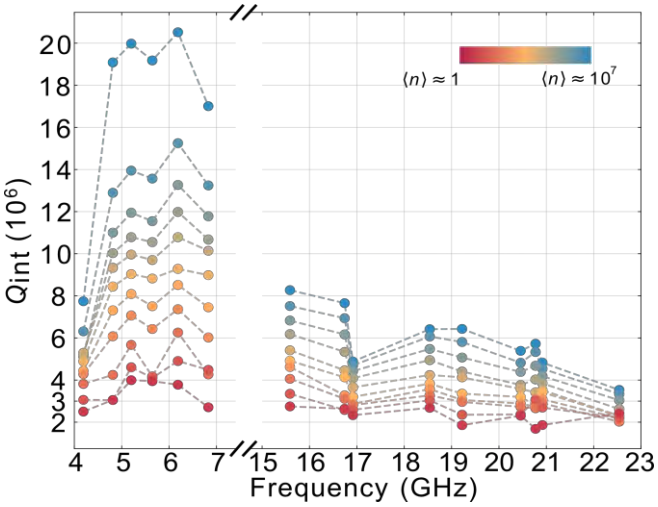


Figure 1: Comparison of low- and high-frequency resonators Q_{int} vs photon number.
Low frequency 4-7 GHz: Q_{int} ≈ 3.3M at n ≈ 1
High frequency 15-21 GHz: Q_{int} ≈ 2.4M at n ≈ 1

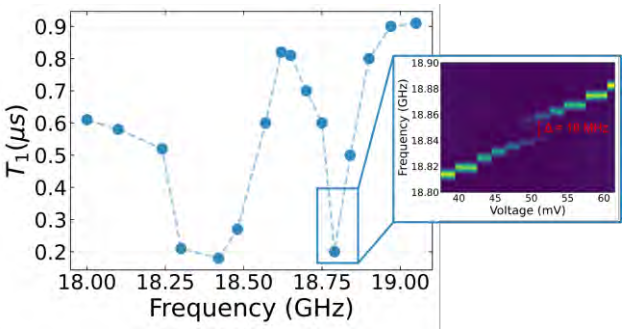


Figure 2: Relaxation time vs frequency of the planar on-chip flux-tunable transmon qubit. The inset shows spectroscopically resolvable interaction with low-coherent TLS.

Experimental quantification of measuring quantum entanglement and Bell's nonlocality of two-qubit states

Patrycja Tulewicz
Karol Bartkiewicz

Institute of Spintronics and Quantum Information, Adam Mickiewicz University, PL-61-614 Poznań, Poland

pattul@amu.edu.pl

Measuring nontrivial properties of quantum systems, such as entanglement measures and Bell inequality violations, poses significant challenges. The conventional method involves computing these metrics using the fully reconstructed density matrix of the system, necessitating comprehensive knowledge of the quantum system under investigation, whereas nonclasical correlations are invariant with respect to local unitary operations.

To reduce the need to complete system information, one can employ multiple copies of the system and conduct joint measurements. While this approach was once deemed impractical due to the complexities of preparing and controlling quantum-correlated systems, recent advancements have made it viable, albeit with challenges such as nonlinear amplification of experimental noise.

In our study, we successfully measured two-qubit quantum systems for Horodecki and Werner states, utilizing the multicopy approach outlined in [1,2]. We performed measurements, on noiseless simulators as well as on real IBMQ quantum processors [3], to determine the negativity and nonlocality values. Our analysis involved a comparison with the conventional tomography-based method.

To counteract the nonlinear approach's susceptibility to noise, we implemented a maximum likelihood method, leveraging physical constraints on jointly observed multicopy observables.

Furthermore, employing SHAP analysis [4], we identified the impact of specific singlet projections on entanglement witnesses. Based on these findings, we showed that it is possible to train a neural network model to quantify nonlocality and negativity.

Acknowledgments

This work was supported by the Polish National Science Centre from funds awarded through the Maestro Grant No. DEC-2019/34/A/ST2/00081.

References

[1] K. Bartkiewicz, G. Chimczak, and K. Lemr, Phys. Rev. A 95, 022331 (2017).
[2] K. Bartkiewicz and G. Chimczak, Phys. Rev. A 97, 012107 (2018).
[3] IBM Quantum, https://quantum-computing.ibm.com/, (2021).
[4] S. M. Lundberg and S.-I. Lee, Advances in Neural Information Processing Systems 30, Curran Associates, Inc., pp. 4765–4774 (2017).

Closed-loop optimisation of quantum states in a high Q bosonic mode

Vasilisa Usova[1, 2]
Ian Yang[1, 2]
Phila Rembold[4, 5, 6]
Marco Rossignolo[3]
Simone Montangero[4]
Gerhard Kirchmair[1, 2]

(1) Institute of Quantum Optics and Quantum Information, Technikerstraße 21a, 6020 Innsbruck, Austria
(2) University of Innsbruck, Innrain 52, 6020 Innsbruck, Austria
(3) *Qruise GmbH, D-66113 Saarbrücken, Germany*
(4) Dipartimento di Fisica e Astronomia "G. Galilei", Universit`a degli Studi di Padova & INFN, Sezione di Padova, I-35131 Italy
(5) Institute for Theoretical Physics, University of Cologne, D-50937 Cologne, Germany
(6) Technische Universität Wien, Karlsplatz 13, 1040 Wien, Österreich
Vasilisa.Usova@oeaw.ac.at

The generation of high-fidelity quantum states and multi-qubit gate operations is a fundamental requirement for quantum physics experiments. However, most experiments are guided by Hamiltonians containing terms that are either overlooked or imperfectly characterized. These imperfections are exacerbated by stochastic variations of the Hamiltonian or, more broadly, the instrument setup. Quantum optimal control methods offer a solution to mitigate these unwanted effects and achieve high-quality state preparation [1] and gate fidelities [2].
Closed-loop optimization for generating a quantum state necessitates measurements after each iteration. For bosonic modes, this can become prohibitively expensive, as it requires consideration of the entire phase space for state reconstruction. We demonstrate that full state reconstruction is not necessary to improve fidelity, provided that an appropriate figure of merit (FOM) and suitable measurements are chosen.
In our study, we utilize a high-Q Niobium cavity coupled to a superconducting transmon qubit to generate quantum states in a cavity mode. Employing a closed-loop optimization approach using the QuOCS library [3], we implement calibration techniques to maximize the fidelity of cat states (Fig. 1).

References

[1] Heeres, R. W., Reinhold, P., Ofek, N., Frunzio, L., Jiang, L., Devoret, M. H., Schoelkopf, R. J. Nature Communications 8, 94 (2017)
[2] Werninghaus, M., Egger, D. J., Roy, F., Machnes, S., Wilhelm, F. K., Filipp, S. npj Quantum Inf 7, 14 (2021)
[3] Rossignolo, M., Reisser, T., Marshall, A., Rembold, P., Pagano, A., Vetter, P. J., Said, R. S.,Müller, M. M., Motzoi, F., Calarco, T., Jelezko, F., Montangero, S. Computer Physics Communications, vol. 291 (2023), 108782.

Figures

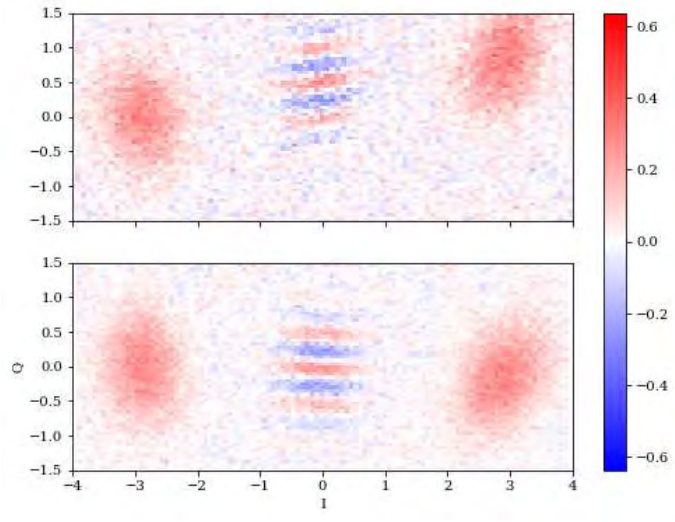


Figure 1: α = 3 cat before (top) and after (after) closed-loop optimization

Full counting statistics and cumulant evolution in infinite temperature quantum spin chains

Angelo Valli[1,2]
P.Moca[1,3], M.A.Werner[4], Ž.Krajnik[5], T.Prosen[6], G.Zaránd[1,2]

[1]*Department of Theoretical Physics, Budapest University of Technology and Economics, Műegyetem rkp. 3., 1111 Budapest (Hungary)*
[2]*HUN-REN–BME Quantum Dynamics and Correlations Research Group*
[3]*Department of Physics, University of Oradea, 410087 Oradea (Romania)*
[4]*Wigner Research Centre for Physics, 1525 Budapest (Hungary)*
[5]*Department of Physics, New York University, NY 10003 New York (USA)*
[6]*University of Ljubljana, Faculty for Mathematics and Physics, Jadranska 19, 1000 Ljubljana (Slovenia)*

valli.angelo@ttk.bme.hu

We investigate the spin-transfer statistics in one-dimensional anisotropic Heisenberg (XXZ) spin models. We introduce a novel tensor-network approach, with which we extract high-order cumulants directly from the generating function at unprecedently long times. We can validate our approach against quantum trajectory simulations – which give access to the full distribution but are limited to shorter times – allowing us to compare cumulants up to the sixth order for S=1/2 and S=1 spin chains.

S=1/2 spin chains are integrable, and at the isotropic point (Δ=1) the variance of the spin transfer is characterized by algebraic growth in time with a superdiffusive z=3/2 exponent as for a Kardar-Parisi-Zhang (KPZ) universal scaling. Fluctuations are weakly non-Gaussian (e.g., excess kurtosis ≠ 0) but incompatible with a Baik-Rains distribution, in agreement with recent experiments on quantum simulators [2] and with theoretical predictions for classical magnets [3]. In the easy-plane regime (Δ<1) transport is ballistic with asymptotically Gaussian distribution. In the XX limit (i.e., Δ=0), we can compare our simulations with exact results, obtained by fermionizing the spin chain. Remarkably, in the diffusive easy-axis regime (Δ>1), we find distinctively non-Gaussian fluctuations, and cumulants consistent with those obtained from Mainardi-Wright family distributions [3]. For non-integrable S=1 spin chains, we find a distinctively different scenario. The spin transfer in the easy-plane regime displays a ballistic-to-diffusive crossover. Interestingly, at the isotropic point, a resilient KPZ scaling is observed, suggesting near-integrability. The dynamical exponent drifts away from the universal value z=3/2 logarithmically in time, possibly towards a z=2 diffusive regime – although we cannot numerically rule out a z=5/3 Fibonacci-ratio exponent [4]. In all regimes, we find fluctuations asymptotically consistent with Gaussianity.

References

[1] Valli *et al.*, in preparation (2024)
[2] Google Quantum AI and Collaborators, arXiv:2306.09333 (2023)
[3] Krajnik *et al.*, PRL **132**, 017101 (2024)
[4] Popkov et al., PNAS **112** 12645 (2015)

Figures

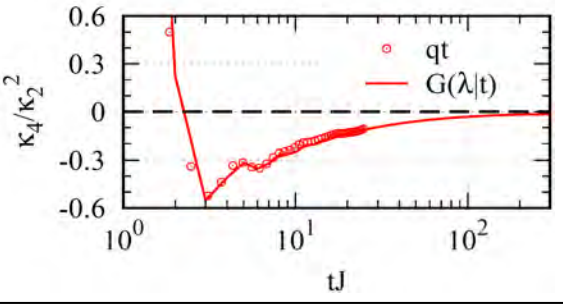


Figure 1: Excess kurtosis for S=1/2 XX chain (Δ=0): quantum trajectories and generating function.

Automatic Detection of Nuclear Spins at Arbitrary Magnetic Fields via Signal-to-Image AI Model [1]

B. Varona-Uriarte
C. Munuera-Javaloy, E. Terradillos, Y. Ban, A. Alvarez-Gila, E. Garrote, and J. Casanova

UPV/EHU, Sarriena Auzoa, 48940 Leioa, Biscay

borjavarona201@gmail.com

Abstract

Quantum sensors leverage matter's quantum properties to enable measurements with unprecedented spatial and spectral resolution. Among these sensors, those utilizing nitrogen-vacancy (NV) centers in diamond offer the distinct advantage of operating at room temperature [2, 3]. Nevertheless, signals received from NV centers are often complex, making interpretation challenging [4]. This is especially relevant in low magnetic field scenarios, where standard approximations for modeling the system fail. Additionally, NV signals feature a prominent noise component. In this work, we present a signal-to-image deep learning model capable to automatically infer the number of nuclear spins surrounding an NV sensor and the hyperfine couplings between the sensor and the nuclear spins. Our model is trained to operate effectively across various magnetic field scenarios, requires no prior knowledge of the involved nuclei, and is designed to handle noisy signals, leading to fast characterization of nuclear environments in real experimental conditions. With detailed numerical simulations, we test the performance of our model in scenarios involving varying numbers of nuclei, achieving an average error of less than $2\,\mathrm{kHz}$ in the estimated hyperfine constants.

Figures

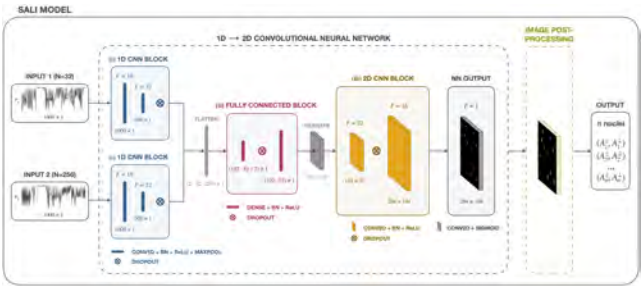


Figure 1: Schematic representation of SALI model, composed of a 1D → 2D Convolutional Neural Network (CNN) module for processing 1D string data of NV measurements into a 2D image output, along with an image post-processing module.

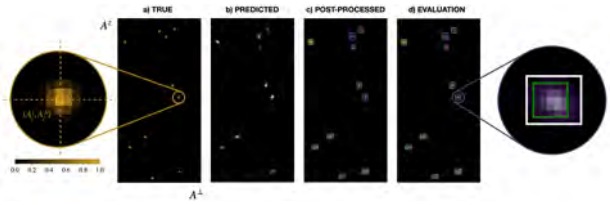


Figure 2: (a) True output of the neural network. (b) Output predicted by the neural network. (c) Output after the image post-processing. (d) Evaluation of the post-processed output.

References

[1] B. Varona-Uriarte, C. Munuera-Javaloy, E. Terradillos, Y. Ban, A. Alvarez-Gila, E. Garrote, and J. Casanova, arXiv: 2311.15037, (2023)
[2] S. Homura, H. Watanabe, and S. Kashiwaya, arXiv:2307.02089, (2023)
[3] K. Ohashi, T. Rosskopf, H. Watanabe, M. Loretz, Y. Tao, R. Hauert, S. Tomizawa, T. Ishikawa, J. Ishi-Hayase, S. Shikata, C. L. Degen, and K. M. Itoh, Nano Lett., 13 (2013) 4733
[4] Y. Chen, Y. Ban, R. He, J. M. Cui, Y. F. Huang, C. F. Li, G. C. Guo, and J. Casanova, Npj Quantum Inf., 8 (2022) 152

Spectroscopy and cavity-enhanced emission of Europium-based molecular systems

Evgenij Vasilenko[1]
Vishnu Unni C[2], Weizhe Li[2], Nicholas Jobbitt[2], Senthil Kumar Kuppusamy[3], Mario Ruben[3], David Hunger[2]

[1]*Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, Karlsruhe, Germany*
[2]*Physikalisches Institut, Karlsruhe Institute of Technology, Karlsruhe, Germany*
[3]*Institute of Nanotechnology & Institute of Inorganic Chemistry, Karlsruhe Institute of Technology, Karlsruhe, Germany*

evgenij.vasilenko@kit.edu

Rare-earth ions in solid-state hosts are a promising candidate for optically addressable spin qubits, owing to their excellent optical and spin coherence times. Recently, Eu^{3+}-based molecular materials have also been shown to possess excellent optical coherence properties [1]. However, Eu^{3+}-doped nanocrystals have a long optical lifetime of the $^5D_0$-$^7F_0$ transition ($T_{1,opt}$ ~ ms) and a low branching ratio (<1%) [2], limiting single-ion experiments. Both issues can be solved by enhancing the emission of Eu^{3+} with high-finesse fiber-based microcavities.

We study Eu^{3+}-doped molecular crystalline materials and powders, exhibiting long spin lifetimes and narrow homogeneous linewidths at 4.2K [1,3]. On a single, macroscopic molecular crystal of [Eu(Ba)4(pip)] [see Figure 2], we measure narrow inhomogeneous linewidths, hour-long spin T_1, and photon echoes at <1K. Steps to integrate molecular crystals into a fiber cavity in the form of a crystalline thin film are reported. Open-access Fabry-Pérot fiber cavities have been demonstrated to achieve high quality factors and low mode volumes, while simultaneously offering large tunability and efficient collection of the cavity mode [4]. The home-built cavity setup was successfully integrated into a cryostat and demonstrated high mechanical stability during operation, which is required for cavity-enhanced ensemble spectroscopy. The presented results are important steps towards single-ion readout and control being necessary for scalable quantum registers.

References

[1] Serrano et al., Nature, 603, 241–246 (2022)
[2] Bartholomew et al., Nano Lett., 17, 2, 778–787 (2017)
[3] Kuppusamy et al., J. Phys. Chem. C 127, 22 (2023)
[4] Hunger et al., New J. Phys 12, 065038 (2010)

Figures

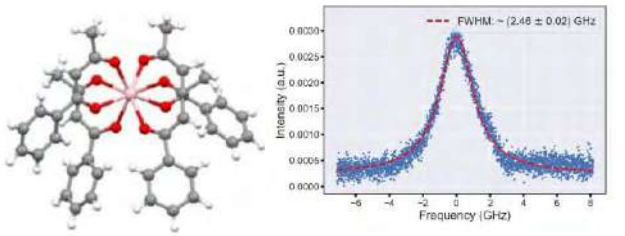


Figure 1: Left: Mononuclear Eu^{3+}-based molecular complex [1]. Right: Narrow inhomogeneous line of the $^5D_0$-$^7F_0$ transition measured in a powder sample.

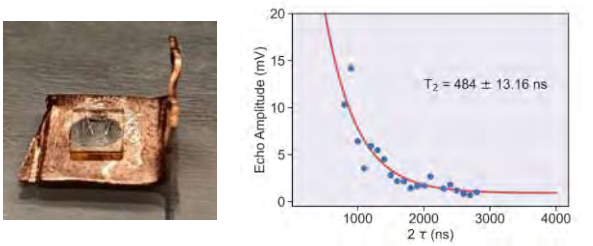


Figure 2: Left: Macroscopic molecular crystal on a copper holder was installed in a dilution refrigerator. Right: Measured two-pulse photon echo decay for the $^5D_0$-$^7F_0$ transition.

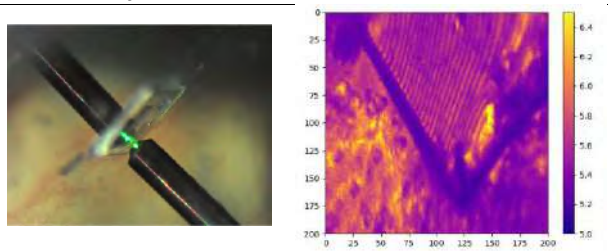


Figure 3: Left: Cavity integration of molecular crystals. Right: Single 2D – transmission raster scan of a crystalline region, carried out at room temperature. X- and Y-axes are pixel numbers.

Measurement-induced collective vibrational quantum coherence under spontaneous Raman scattering in a liquid

Valeria Vento
Santiago Tarrago Velez, Anna Pogrebna, Christophe Galland

Institute of Physics, École polytechnique fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland.

valeria.vento@epfl.ch

Abstract

Spontaneous vibrational Raman scattering is a ubiquitous form of light–matter interaction whose description necessitates quantization of the electromagnetic field. It is classically considered as an incoherent process because the scattered field lacks any predictable phase relationship with the incoming field [1]. When probing an ensemble of molecules, the question therefore arises: What quantum state should be used to describe the molecular ensemble following spontaneous Stokes scattering? We experimentally address this question by measuring time-resolved Stokes–anti-Stokes two-photon coincidences on a molecular liquid consisting of several sub-ensembles with slightly different vibrational frequencies (Figure 1) [2]. When spontaneously scattered Stokes photons and subsequent anti-Stokes photons are detected into a single spatiotemporal mode, the observed dynamics is inconsistent with a statistical mixture of individually excited molecules. Instead, we show that the data are reproduced if Stokes–anti-Stokes correlations are mediated by a collective vibrational quantum, i.e. a coherent superposition of all molecules interacting with light. Our results demonstrate that the degree of coherence in the vibrational state of the liquid is not an intrinsic property of the material system, but rather depends on the optical excitation and detection geometry. Our work nourishes the debate about the relation between optical coherence, quantum coherence and entanglement [3, 4].

References

[1] D. A. Long, *The Raman effect ...*, Wiley (2002).
[2] V. Vento, S. T. Velez, et al., Nat. Commun., 14 (2023) 2818
[3] K. Mølmer, Phys. Rev. A, 55 (1997) 3195
[4] L.-M. Duan, et al., *Nature*, 414 (2001) 413-318

Figures

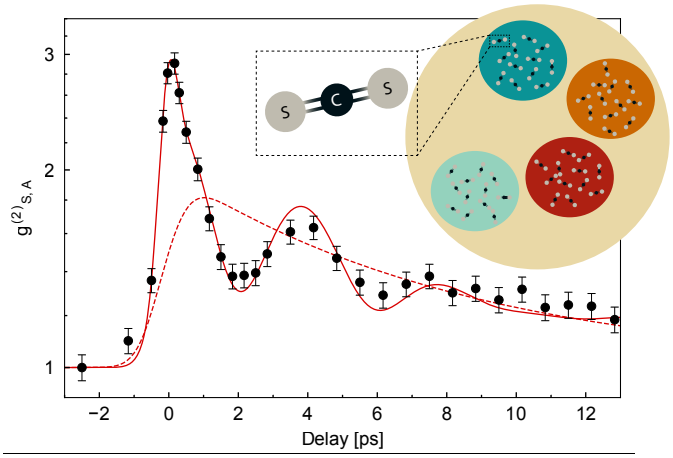


Figure 1: Time-resolved Stokes–anti-Stokes correlations. Full circles represent the measured data points while the solid red line indicates the model prediction. The observed quantum beats are consistent with a macroscopic quantum superposition of four sub-ensembles of CS2 molecules (inset) sharing a single quantum of vibration. The dotted red line represents the multi-exponential decay that would result from a statistical mixture of single vibrating molecules.

Dissipative Symmetry-protected topological order induced by Z_2 x Z_2 generators

Luan Martins Verissimo
Roman Orus

Donostia International Physics Center, Paseo Manuel de Lardizabal 4, E-20018 San Sebastián, Spain

luan.martins@dipc.org

Abstract

Topological phases of matter[1] have emerged last decades as an important research area in condensed matter physics owing to further paradigms on the classification of novel quantum phases of matter beyond the Landau-Ginzburg-Wilson theory. Also, the interplay of quantum physics and the environment opens the possibilities to interesting physics phenomena, where the role of dissipation on the topological order is important given the possibilities of applications in material science[2] and topological quantum computing[3]. In this work, we implement a tensor networks [4,5] algorithm to investigate the effects of dissipation on the symmetry-protected topological order. We've considered the Affleck-Kennedy-Tasaki-Lieb spin model coupled with an environment where the Lindbladian master equation describes dissipative dynamics. We numerically solve the Lindbladian master equation by adapting the infinite time-evolving block decimation method for mixed states [5]. We demonstrate that, for jump-operators described by the Z_2xZ_2 group generator elements we obtained a non-equilibrium steady state with typical properties of a symmetry-protected topological order[6]. We also bring counter-examples with jump operators as geral spin rotations are given, where no fingerprints of symmetry-protected topological order are observed.

References

[1] Haldane, Rev. Mod. Phys. 89, 040502 - (2017)
[2] M. Z. Hasan and C. L. Kane, Rev. Mod. Phys. 82, 3045 - (2010)
[3] Ville Lahtinen, Jiannis K. Pachos, SciPost Phys. 3, 021 (2017)
[4] Román Orús, Annals of Physics, 349, (2014)
[5] Michael Zwolak and Guifre Vidal, Phys. Rev. Lett. 93, 207205 – (2004)
[6] Luan M. Veríssimo, Marcelo L. Lyra, Román Orús, Phys. Rev. B, 107, L241104 - (2023)}

Figures

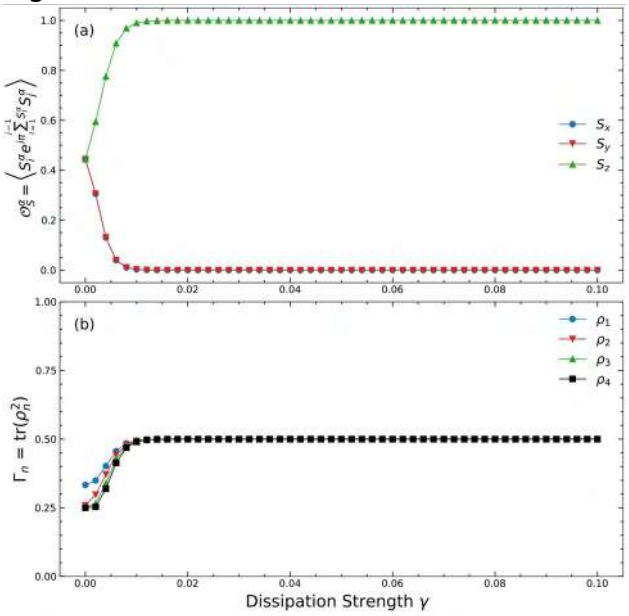


Figure 1: String Order parameter(a) and Purity(b) of the non-equilibrium steady state. In that case, the jump-operators are described by Z_2xZ_2 group generators.

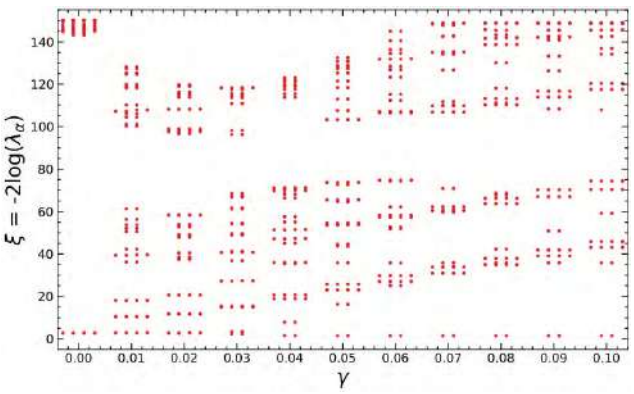


Figure 2: The Entanglement Spectrum of the non-equilibrium steady state. The typical degeneracy is a robust fingerprint of a symmetry-protected topological phase.

Magnon-mediated topological superconductivity in a quantum wire

Florinda Viñas Boström
Emil Viñas Boström

Division of Solid State Physics and NanoLund, Lund University, Box 118, S-221 00 Lund, Sweden

florinda.vinas_bostrom@ftf.lth.se

One-dimensional superconducting systems with *p*-wave pairing are known to reside in a topological class that can host non-trivial topological phases, with non-abelian anyons as topologically protected end states.[1-3] Superconductive *p*-wave pairing arises in systems where the effective electronic attraction favors Cooper pairs with a symmetric spin structure. In this work we show that superconductive *p*-wave pairing emerges as the result of interactions between electrons and magnons in a quantum wire and a helical magnet.[4] The magnon-mediated interaction favors *p*-wave superconductivity over a large magnetic phase space region, and stabilizes topological superconductivity over an extended region of chemical potentials. The superconducting gap depends exponentially on the spin-electron coupling, allowing it to be enhanced through material engineering techniques. In addition, the non-collinear magnetic order induces an effective spin-orbit coupling and a Zeeman field among the electrons, that allows to realize an effective single-band regime over a finite range of chemical potentials. Within the single-band regime, the system enters a topological phase, with unpaired Majorana bound states at each end of the wire. Crucially, both the size of the effective single-band regime and the superconducting gap are increasing functions of the spin-electron coupling *g*. Our proposal thereby identifies quantum wires in proximity to helical magnets as a promising platform to realize topological superconductivity, without the need to proximitize the wire to a conventional superconductor.

Figures

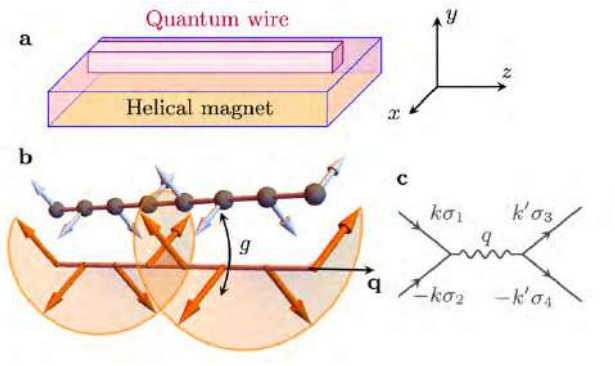


Figure 1: Principles of magnon-mediated superconductivity. **a,** Experimental setup with a quantum wire in proximity to a helical magnet. **b,** The helical magnetic order (orange arrows) induces an effective spin-orbit interaction and Zeeman splitting of the electronic bands via the spin-electron coupling *g*. Magnon fluctuations around the equilibrium magnetic order provide an effective attractive interaction among the electrons (blue arrows). **c,** Due to the non-collinear magnetic structure, magnon fluctuations mediate scattering between electrons with arbitrary spin projections σ_i.

References

[1] A. Altland and M.R. Zirnbauer, Phys. Rev. B 55 (1997) 1142
[2] A.Y Kitaev, Physics-Uspekhi 44 (2001) 131
[3] C.-K. Chiu, J. C. Y. Teo, A. P. Schnyder, and S. Ryu, Rev. Mod. Phys. 88 (2016) 035005
[4] F. Viñas Boström and E. Viñas Boström, "Topological superconductivity in quantum wires mediated by helical magnons" (2023), arXiv: 2312.02655

Quantifying entanglement with global variances

Giuseppe Vitagliano[1]
Shuheng Liu[2], Matteo Fadel[3], Ayaka Usui[4], Qiongyi He[2], Nicolai Friis[1], Marcus Huber[1], O. Gühne[5]

[1]Atominstitut, TU Wien, 1020 Vienna, Austria
[2] Peking University, Beijing 100871, China
[3] Department of Physics, ETH Zürich, 8093 Zürich, Switzerland
[4] Facultat de Fısica, Universitat de Barcelona, E08028 Barcelona, Spain
[5] Naturwissenschaftlich-Technische Fakultät Universität Siegen, D-57068 Siegen, Germany

giuseppe.vitagliano@tuwien.ac.at

We introduce witnesses of entanglement based on variances of collective operators, such as the collective spin of ensembles of atoms. These can be seen as generalizations of the well-known *spin-squeezing criterion* [1], which is connected to quantum-enhanced metrological schemes and is often used to quantify entanglement in many-body experiments [2].
We will show how such witnesses can be used for the quantification of entanglement via monotones. First in the case of monotones which can be expressed as minimizations over witnesses [3]. Afterwards, we focus on the so-called *Schmidt-number* or *entanglement dimensionality*, which has been identified as an important resource in quantum information processing, and also as a main obstacle for simulating quantum systems. Its certification is often difficult, and most widely used methods for experiments are based on fidelity measurements with respect to highly entangled states. Here, instead, we generalize the well-known Covariance Matrix Criterion (CMC) [4] to determine the Schmidt number of a bipartite system. This is potentially particularly advantageous in many-body systems, such as cold atoms, where the set of practical measurements is very limited and only variances of collective operators can typically be estimated.
Finally, we show that particular instances of such a general criterion can be evaluated with the use of correlations between measurements in randomized directions [5]. In particular, we find analytical boundary curves for the different entanglement dimensionalities in the space of second- and fourth-order moments of randomized correlations for all dimensions of a bipartite system.

We then show how our method works in practice, also considering a finite statistical sample of correlations, and we also show that it can detect more states than other entanglement-dimensionality criteria available in the literature, thus providing a method that is both very powerful and potentially simpler in practical scenarios.

References

[1] M. Kitagawa, M. Ueda, Phys. Rev. A 47, 5138 (1193)
[2] N. Friis, G. Vitagliano, M. Malik, M. Huber,
Nat. Rev. Phys. 1 (1), 72-87 (2019)
[3] M. Fadel, A. Usui, M. Huber, N. Friis, G. Vitagliano, Phys. Rev. Let. 127 (1), 010401 (2021)
[4] S. Liu, M. Fadel, Q. He, M. Huber, G. Vitagliano, Quantum 8, 1236 (2024).
[4] S. Liu, Q. He, M. Huber, O. Gühne, G. Vitagliano, PRX Quantum 4 (2), 020324 (2023)

Probing Integer and Fractional Quantum Hall States in GaAs with Microcavity Polaritons

Odysseas Williams
Stefan Faelt, Werner Wegscheider

ETH Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

owilliams@phys.ethz.ch

A MBE grown planar AlGaAs/AlAs microcavity can be monolithically integrated with a high-mobility 2-dimensional electron gas (2DEG) in the center anti-node of the cavity. Strong coupling can be achieved in this type of structure. Using a magnetic field, the spin polarization of quantum Hall states (QHS) can be directly measured by circular polarization resolved resonance spectroscopy of the polariton states [1,2]. Full spin polarization at $\nu = 1$ and rapid depolarization away from it was observed, consistent with the Skyrmionic nature of this state [2,3,4]. Current measurements of fractional states for $\nu < 2$ are under scrutiny, as well as plans for improved devices for more robust QHS.

References

[1] S. Ravets, et al., Phys. Rev. Lett., 120 (2018) 057401
[2] M. Lupatini, et al., Phys. Rev. Lett., 125 (2020) 067404
[3] E.H. Aifer, et al., Phys. Rev. Lett., 76 (1996) 680
[4] P. Plochocka, et al., Phys. Rev. Lett., 102 (2009) 126806

Figures

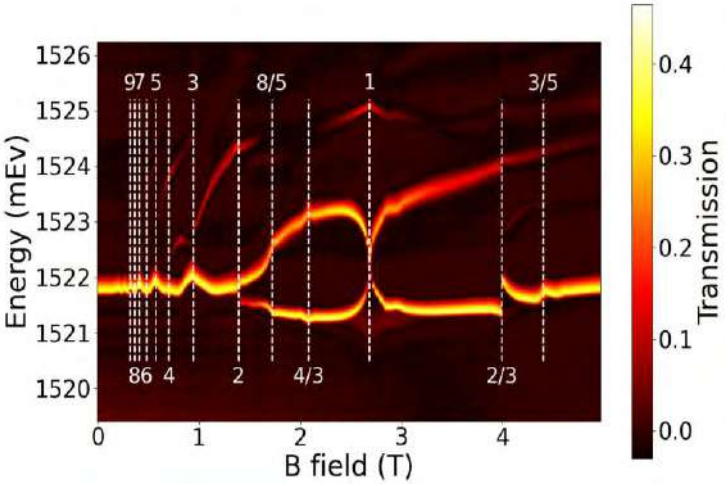


Figure 1: Transmission spectra of a microcavity with an integrated 2DEG as a function of applied perpendicular magnetic field. The cavity energy is fixed close to the energy of Landau Level 0 at filling factor $\nu = 1$. The white dashed lines indicate integer and fractional QHS. The change in polariton normal mode splitting comes from the change in oscillator strength.

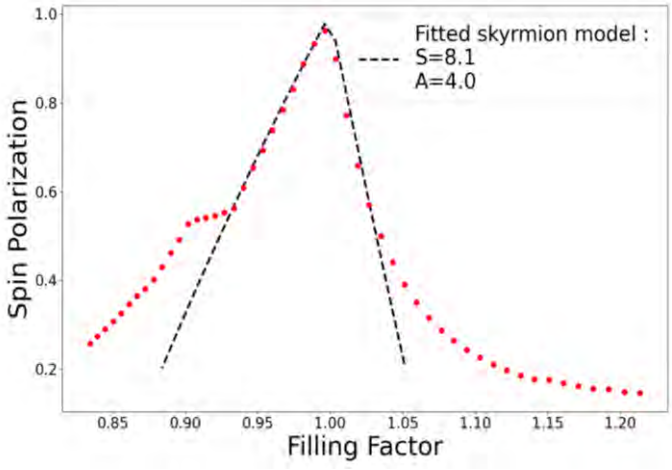


Figure 2: Spin polarization of the 2DEG around B = 2.67 T ($\nu = 1$). The red data points are extracted from spectral sweeps such as the one presented Figure 1. The black dotted line is a fit of a Skyrmion model with Skyrmion size S = 8.1 and Antiskyrmion size A = 4.0.

Normal state transport and induced superconductivity in SnTe nanowires

Femke Witmans[1]
Maarten Kamphuis[1], Ivana Bošnjak[1], Vince van de Sande[2], Matthijs Mientjes[2], Joost Ridderbos[1], Chuan Li[1], Erik Bakkers[2], Floris Zwanenburg[1], Alexander Brinkman[1]

[1]*University of Twente, 7500 AE, Enschede, The Netherlands*
[2]*Eindhoven University of Technology, 5600 MB, Eindhoven, The Netherlands*

f.j.witmans@utwente.nl

Tin telluride (SnTe) is a topological crystalline insulator [1] and hosts two-dimensional surface states. Moreover, SnTe is an acknowledged candidate as a higher order topological insulator (HOTI) [2]; this class of materials host hinge states on the boundary of two gapped surfaces, leading to conducting hinges and insulating bulk and surfaces. Thus far, HOTIs have not been experimentally confirmed , and detecting the 2D surface and 1D hinge states in this material is therefore an important fundamental advancement.
We employ both normal state and superconducting devices, to determine the effect of 1D and 2D states on the transport properties of SnTe nanowires. In the normal state, conductance oscillations as a function of source-drain and backgate voltage are attributed to Fabry-Pérot resonances, hinting at (quasi-) ballistic transport through a topological surface or hinge state [3]. Furthermore, we form Josephson junctions using superconducting electrodes to investigate Shapiro patterns and look at the supercurrent distribution in magnetic field. Using both experiments, a distinction between lower dimensional transport and trivial bulk transport can be made [4].

References

[1] Y. Tanaka et al., Nature Phys, 8 (2012) 800-803
[2] F. Schindler et al., Sci. Adv., 4 (2018) eaat0346
[3] A.V. Kretinin et al., Nano Letters, 10 (2010) 3439-3445
[4] C-Z. Li et al., Phys. Rev. B, 97 (2018) 115446

Figures

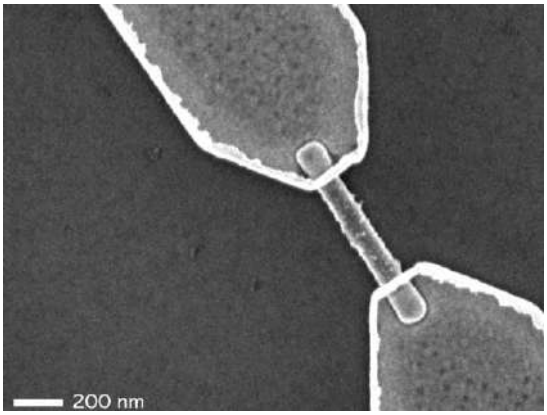


Figure 1: SEM image of the general device architecture, consisting of a SnTe nanowire and contacts. For normal contacts, Ti/Au is used, and for Josephson junctions, Nb/Pd is deposited.

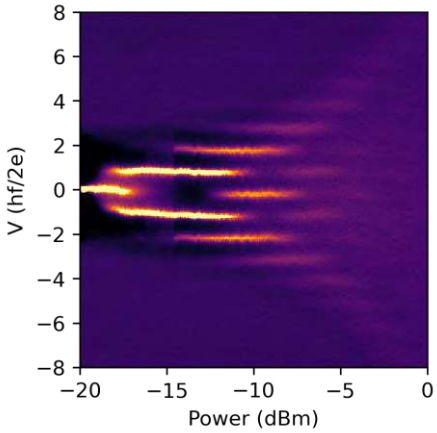


Figure 2: AC Josephson effect, showing at least 6 Shapiro steps, when irradiating the junction with 2.073 GHz microwaves.

Tuneable spin-to-charge interconversion and valley effects in ex-so-tic and twisted graphene-based VdW heterostructures

Anna Dyrdal
Izabella Wojciechowska

Faculty of Physics, ISQI, Adam Mickiewicz University in Poznan, ul. Uniwersytetu Poznanskiego 2, 61-614 Poznan, Poland

adyrdal@amu.edu.pl

The efficient spin-to-charge interconversion is currently one of the most important issues in spin electronics. The two main effects responsible for all-electrical charge-to-spin conversion are current-induced spin polarization and spin Hall effect as well as their inverse counterparts [1]. Many recent experiments performed on graphene-based hybrid structures revealed spin-orbit proximity effects strong enough to measure spin currents or spin polarization up to room temperature [2]. This, in turn, opened a new era of spintronics, i.e., a van-der-Waals spintronics, that couples charge, spin, and valley degrees of freedom.

An important feature of spin-to-charge interconversion effects in graphene-based van-der-Waals systems is their strong tunability by external fields, e.g., by gating in the so-called ex-so-tic structures [3], or by mechanical forces that can induce either a twist of graphene with respect to adjacent vdW layers [4] or strain in vdW layers that can significantly change the spin-orbital and magnetic proximity effects in graphene.

In the first part of our presentation we will discuss our recent results concerning anomalous, spin, valley and spin-valley Hall effects controlled by gate voltage in the ex-so-tic vdW system consisting of bilayer graphene sandwiched between semiconducting monolayer of transition metal dichalcogenide, TMDC, (e.g., WS2) and monolayer of Cr2Ge2Te6 [5]. We have found that in such a case, both A(S)HE and VHE are simultaneously nonzero and strongly picked in a specific range of chemical potential and gate voltage.

In the second part of the talk, we will present a detailed study of spin and valley Hall effects as well as spin polarization in graphene twisted with respect to monolayer of semiconducting TMDCs (we discuss results for twisted graphene on MoS2, WS2, MoSe2, and WSe2) and show that spin-to charge conversion strongly depends on the twist angle [6].

Our theoretical calculations are based on Green function formalism in the linear response limit adapted to effective low-energy Hamiltonians derived from symmetry analysis and DFT calculation [7].

This work has been supported by the Norwegian Financial Mechanism 2014-2021 under the Polish-Norwegian Research Project NCN GRIEG "2Dtronics" no. 2019/34/H/ST3/00515

References

[1] J. Sinova, Rev. Mod. Phys. 87, 1213 (2015)
[2] A. Avsar et al., Nature Commun. 5:4875 (2014); T. S. Ghiasi et al. , Nano Lett. 19, 5959 (2019), B. Zhao et al., Appl. Phys. Lett. 117, 242401 (2020)
[3] Authors, Journal, Issue (Year) page
[4] K. Zollner et al., Phys. Rev. B 108, 235166 (2023)
[5] I. Wojciechowska, A. Dyrdal, to be published
[6] I. Wojciechowska, A. Dyrdal, to be published
[7] A. Dyrdal, J. Barnas, 2D Materials 4, 034003 (2017)

Topological invariants of quantum walks

Jan Wójcik[1]
Andrzej Grudka[2], Marcin Karczewski[3], Paweł Kurzyński[2], Antoni Wójcik[2]

[1] *Faculty of Physics, Adam Mickiewicz University, 61-614 Poznań, Poland*
[2] *Institute of Spintronics and Quantum Information, Faculty of Physics, Adam Mickiewicz University, 61-614 Poznań, Poland*
[3] *International Centre for Theory of Quantum Technologies, University of Gdańsk, 80-309 Gdańsk, Poland*
janwoj2@st.amu.edu.pl

We focus our presentation on discrete-time quantum walks and their topological properties. Quantum walks are periodically driven (Floquet) systems. Their discrete model due to its simplicity may be a very powerful tool while studying complex systems. They've been studied both theoretically and experimentally [1]. As was previously shown even the most basic model of the quantum walk may have some interesting topological properties. Quantum walks can help study topological phenomena as was shown in [2-3]

The dynamic of a quantum walk consists of two parts, the step of the walker and the coin toss. We can distinguish the topological properties of the quantum walk based on the coin toss operator.

We define topological properties for translational invariant walks. Due to this symmetry, we define a unique map from the first Brillouin zone to the Bloch sphere. We want to infer the topological properties of discrete-time quantum walks only by studying this map.

Until now the most popular way to approach the distinction of topological phases in quantum walks is the usage of a winding number.

In a recent paper [5] we show possible issues regarding inferring the topological properties of a quantum walk only from studying the winding number. We propose a new approach. Using relative homotopy we propose a new topological invariant. We show that it agrees with previous models and more generalized ones. Our invariant indicates the number of edge states at the interface between two topological phases. We identify those states for arbitrary coin toss operators. Those states we found to be protected by PHS. We managed to find the exact form of topological edge states in the sharp edge model.

References

[1] J. Wu, W.-W. Zhang, and B. C. Sanders, Frontiers of Physics 14, 61301 (2019).
[2] F. Harper, R. Roy, M. S. Rudner, and S. L. Sondhi, Annual Review of Condensed Matter Physics 11, 345 (2020).
[3] T. Kitagawa, Quantum Information Processing 11, 1107 (2012).
[4] T. Kitagawa, M. S. Rudner, E. Berg, and E. Demler, Physical Review A 82, 033429 (2010).
[5] A. Grudka, M. Karczewski, P. Kurzyński, J. Wójcik and A. Wójcik, Phys. Rev. A 107 (2023) 032201.

Figures

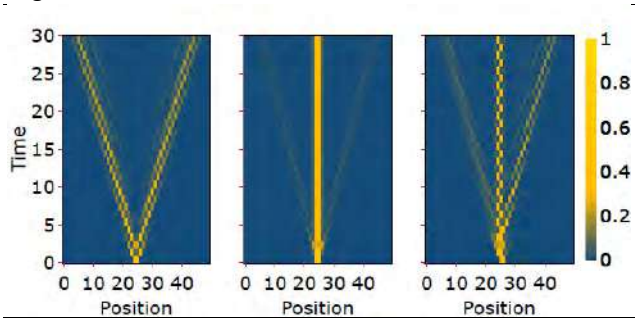


Figure 1: Simulation of basic quantum walk with two distinct topological phases. The color of the legend imposes the probability of finding the walker in position "x" and time "t". Simulations differ because of the initial state of the walker. On the left, the state of the walker is orthogonal to both edge states, in the middle one, the state has non-zero overlap with only one of the edge states whereas the right one has non-zero overlap with both edge states.

Andreev Bound States in Ge-Si Core-shell Nanowires

Zhen Wu
Joost Ridderbos, Ang Li, Erik P. A. M. Bakkers, Alexandre A. Golubov, Chuan Li, Floris A. Zwanenburg, Alexander Brinkman

MESA+ Institute for Nanotechnology, University of Twente, 7500AE, Enschede, The Netherlands

z.wu@utwente.nl

Abstract

Ge-Si core-shell nanowires are semiconductors with large potential for both quantum and topological research. In this work, we employ an original interlayer approach instead of conventional diffusion method [1] to induce superconductivity in these wires (Figure 1). Subsequently, the intact Si shell not only prevents metallization [2] with controllable proximity gap for the advantage of topological studies, but also enables a rich interplay between superconductivity and energy quantization. For the latter, long ballistic channels facilitate the emergence of multiple Andreev bound states beneath the 2 μm long electrodes, forming a diverse subgap spectrum combined with quantization levels (Figure 2). Additionally, we observed a singlet-to-doublet ground state transition under increasing external magnetic field. Finally, we attribute an anomalous critical current enhancement with increasing magnetic field to quasiparticle cooling (Figure 3), supported by both experimental evidence and a theoretical model.

References

[1] Ridderbos, J. et al, Nano Letters, (2020) pp. 122–130.
[2] Reeg, C. et al, *Physical Review B,* (2018) p165425.

Figures

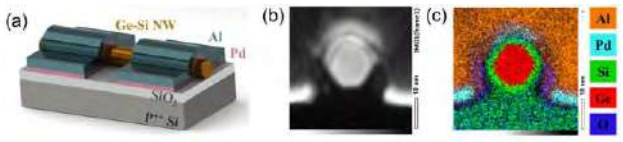


Figure 1: (a) Schematics of an Al/Pd/Ge-Si/Pd/Al device. (b) TEM image and (c) EDX mapping of a lamella cut on the cross section of a device as (a). TEM studies were performed by our collaborators at Eindhoven Technical University.

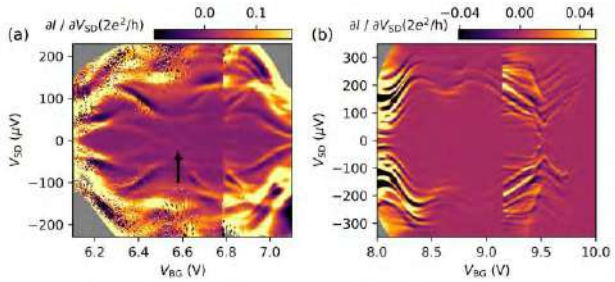


Figure 2: Subgap states in the device. (a) and (b) Differential conductance versus bias voltage and backgate voltage at two different gate ranges. The black arrow highlights an eye-shape subgap state.

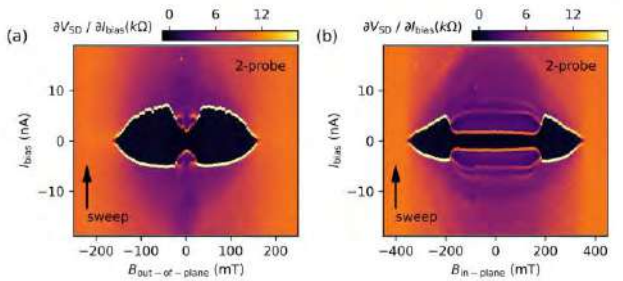


Figure 3: Magnetic field dependence of the device. Differential resistance versus bias current and magnetic field rotated along (a) out-of-plane and (b) in-plane.

Analysis and compensation of the fringe contrast loss in an atomic gravimeter caused by carrier motion

Yishu Yang
Yukun Luo*, Fufang Xu, Wenjun Kuang

National Innovation Institute of Defense Technology, Beijing, 100071, China

*yk.luo@outlook.com

Fringe contrast loss is a prominent problem for atomic gravimetry applications on moving platforms. The non-inertial carrier motion leads to the change in the relative position between the atomic cloud and the Raman laser cross section. Along with the Inhomogeneous distribution of the Raman laser intensity distribution, this results in a modulated laser intensity and effective Rabi frequency felt by the atoms, which causes reduction in Raman pulse fidelity, additional parasitic paths and fringe contrast loss in the atom interferometer.
In this work, the effects on both single Raman pulse fidelity and final fringe contrast due to transverse accelerations and attitude rotations have been investigated. The coupling between different motion components is analysed. Fixed motion rates as well as random motion noises are studied. The quantitative results show a strong correlation with the gravimeter parameters. The compensation method is then proposed. By monitoring the carrier motion in real time, the pulse-to-pulse effective Rabi frequency fluctuation is dynamically estimated, which is thus corrected via quickly adjusting the Raman intensity or pulse duration. Fine compensation strategies considering the integration within the atomic cloud are comparatively discussed.
A significant improvement of 18% in fringe contrast is achieved.

References

[1] A. Louchet-Chauvet, New Journal of Physics, 13 (2011) 065025.
[2] Q.Q. Hu, Optik, 276 (2023) 170637.
[3] C.D. Panda, Applied Physics Letters 123 (2023), 064001.
[4] C. Huang, Applied Sciences, 13 (2023) 8774.

Figures

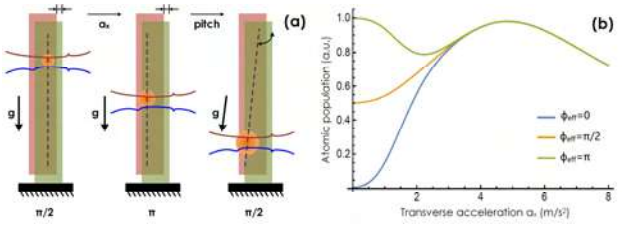


Figure 1: Influence mechanism of carrier motion and its influence on single pulse fidelity

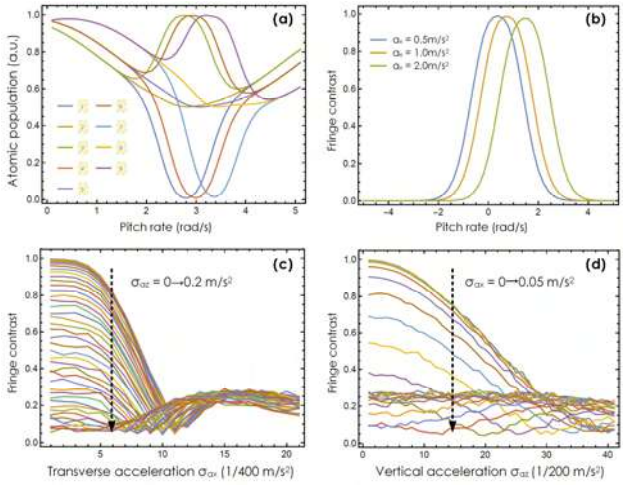


Figure 2: Coupling effect of carrier transverse acceleration and attitude rotation on fringe contrast

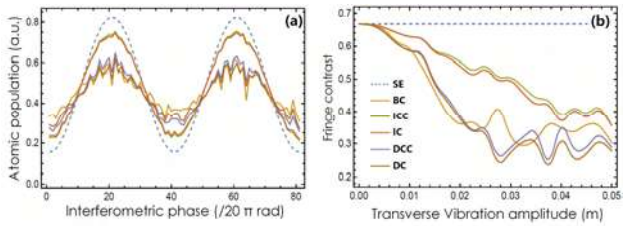


Figure 3: Fringe contrast compensation effect

Simulating Strongly Correlated Phases in One-Dimensional Rydberg Systems

Zeki Zeybek[1,2]
Peter Schmelcher[1,2], Rick Mukherjee[1]

[1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

[2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

zzeybek@physnet.uni-hamburg.de

Platforms based on neutral Rydberg atoms are highly practical quantum simulators as their large dipole moments provide tunable strong interactions with different characters and ranges. In this work, we consider a system of neutral atoms that are modeled as two-level systems with a pair of Rydberg states, leading to both van der Waals and dipolar interactions among the atoms. Focusing on one-dimensional systems, we provide two examples where we leverage the van der Waals and dipolar interactions of the Rydberg atoms to study ground states with rich properties.

The first example considers a dimerized chain of Rydberg atoms where the competition between long/short-range processes is illustrated. We identify bond-ordered-density-wave (BODW) phases that simultaneously exhibit density wave and bond orders [1]. Including on-site density modulation is shown to help stabilize symmetry-protected topological BODW phases at certain fillings [2]. We also find a unique non-topological BODW phase without any analog in the non-interacting model. The second example includes the strong nearest-neighbor interaction limit where a constrained model with non-local fluctuations from interacting Rydberg atoms alongside local fluctuations is considered. The combined effect of such fluctuations drives the system from a disordered phase to an intrinsically quantum-ordered Rydberg crystal, which was not previously reported in one dimension. We provide an intuitive explanation of the underlying physics and a variational ansatz that describes both the ordered and disordered regimes.

Our findings show that Rydberg atoms offer an exceptional platform even in a simple setup such as a one-dimensional lattice for exploring the interplay between short/long-range interactions and fluctuation-driven phenomena that are otherwise only possible to probe in higher-dimensional and complicated systems.

References

[1] Z. Zeybek, R. Mukherjee, and P. Schmelcher, Phys. Rev. Lett. 131, 203003 (2023).
[2] Z. Zeybek, P. Schmelcher, and R. Mukherjee, arXiv:2403.06649 (2024)

Towards realistic modeling of proximitized magnetic topological insulator nanoribbons

Eduárd Zsurka

University of Luxembourg, Luxembourg

eduard.zsurka@gmail.com

Proximitized magnetic topological insulator nanoribbons (PMTINRs) are a potential platform for the practical realization of the Majorana zero-energy mode (MZM) [1]. Here, we present a realistic description of PMTINRs and similar superconductor-topological insulator heterostructures. Both bulk and effective surface-state models are used to capture the low-energy electronic spectrum, with realistic parameters extracted from ab initio calculations. Using numerical simulations, we study in a tight-binding framework the properties of PMTINRs. Particular attention is given to the thin-film limit, where theoretical results have been conflicting on the topology of the hybridization gap. Magnetic and nonmagnetic disorder, as well as device imperfections, can all be detrimental to the formation of MZMs in PMTINRs. We aim to clarify what are the optimal conditions to obtain MZMs in PMTINRs, that are robust against such effects

References

[1] C.-Z. Chen, Y.-M. Xie, J. Liu, P. A. Lee, and K. T. Law, Phys. Rev. B 97, 104504 (2018).

Generalisation of a novel routine for band gap mapping at sub-nanometric resolution

Marc Botifoll[a]
Sara Martí-Sánchez[a], Quentin Ramasse[b], F. Javier García de Abajo[c,e], Ernesto Joselevich[d] Jordi Arbiol[a,e]

a. ICN2, CSIC and BIST, Barcelona, Spain
b. SuperSTEM Laboratory, STFC Daresbury Campus, Daresbury WA4 4AD, UK
c. ICFO, BIST, 08860 Castelldefels, Barcelona, Spain
d. Department of Molecular Chemistry and Materials Science, Weizmann Institute of Science, Rehovot 76100, Israel
e. ICREA, Pg. Lluis Companys 23, 08010 Barcelona, Catalonia, Spain

marc.botifoll@icn2.cat

Germanium and silicon-based devices for quantum computing are experiencing a huge rise in popularity over the last few years. They have proven to be magnificent candidates for efficient qubit generation, and are flexible enough to hold different quantum computing paradigms. Based on the morphology and dimensionality of the devices they may act as either spin qubits or (topological) superconducting qubits. For this purpose, heterostructures contacting combinations of pure Ge, pure Si, and alloyed SiGe with varying Si/Ge ratios are successful candidates towards the obtention of qubits [1].

Interestingly, the low effective mass and the electrically tuneable g factors that are key for the qubit performance closely correlate with the strained interface that rules the energy splitting. This constitutes an interesting materials science problem that is worth tackling at the high spatial resolutions the transmission electron microscope can offer, in search of local effects. Therefore, in the present contribution we present a new methodology that can sub-nanometrically map the band structure of semiconductor devices, and the novelty towards making it accessible, reproducible and fast for any material, specially for quantum materials.

The proposed new methodology is based on the correlation of high-resolution low-loss electron energy loss spectroscopy (EELS) and strain mapping to link the accumulations of strain with bandgap shifts [2]. The novelty lies in being able to address the limitations this kind of spectroscopy implicitly have, and semi-automate the routine to enable generalising the methodology to new materials and systems. This semi-automation is based on spectral unmixing techniques, and the possibility to produce tailored simulations to retrieve the optical response of the materials. Therefore, we present a path from the generation of the model till is extrapolation to make it more general and applicable to any system.

References

[1] Jirovec, D. et al. *Nature Materials*, (2021) doi.org/10.1038/s41563-021-01022-2
[2] Martí-sánchez, S. et al, Nat. Commun. 13, 4089 (2022).

Figures

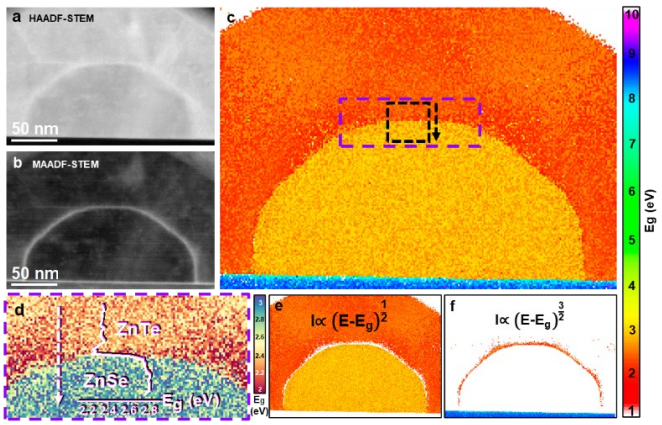


Figure 1: Bandgap maps obtained from applying the proposed methodology to a ZnSe/ZnTe nanowire.