QUANTUM MATTER 2022

International Conference on Science & Technology of Quantum Matter

JUNE 21-23 • Barcelona (Spain)

ORGANISERS

PHANTOMS foundation

CSIC
Consejo Superior de Investigaciones Científicas

DIPC

ICN2
Institut Català de Nanociència i Nanotecnologia

EXCELENCIA SEVERO OCHOA

SCAN ME

ikur estrategy

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

SCIENTIFIC RESEARCH AREAS

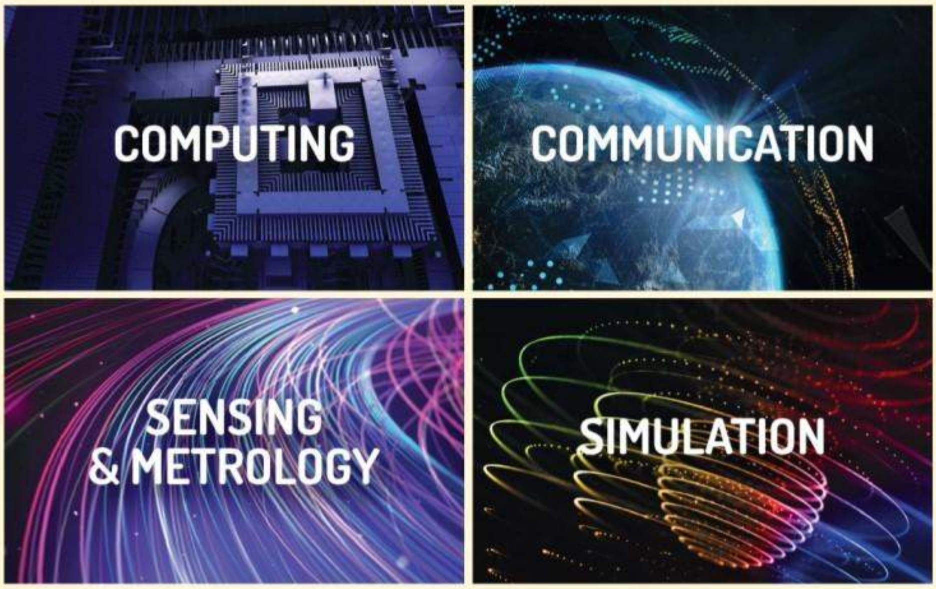
- Neurobiosciences
- Neutrionics
- High Performance Computing & AI
- Quantum Technologies

TOTAL INVESTMENT
+282 M€

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

ikur qt quantum technologies

RESEARCH TOPICS



2021-2023

65 New researcher hires

More than 15 collaborative projects

8 Basque research and technology centers

Over 1.5M investment in equipment

NEW PROJECTS

- 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.

ikerbasque Basque Foundation for Science
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Plan de Recuperación, Transformación y Resiliencia
Financiado por la Unión Europea NextGenerationEU

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FOREWORD

On behalf of the Organising and the International Scientific Committees we take great pleasure in welcoming you to Madrid (Spain) for the 3rd edition of the Quantum Matter International Conference & Exhibition (QUANTUMatter2023).

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.

QUANTUMatter2023 Highlights:

- Nearly 400 participants in-person
- 38 Plenary, Keynote & Invited Speakers
- More than 120 posters
- Nearly 120 oral contributions
- 21 Exhibitors and 18 Sponsors
- 2 Parallel Workshops
- 1 day 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, QTEP/CSIC, Quantum Machines, QBLOX, Multiverse Computing, Zurich Instruments/RHODE & SCHWARZ, QUANDELA, PASQAL, Single Quantum, Qilimanjaro, GMV, IQM, Oxford Instruments NanoScience, UAM/IFIMAC, APS and C12.

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

We truly hope that QUANTUMatter2023 serves as an international platform for communication between science and business.
Hope to see you again in the next edition of QUANTUMatter in San Sebastian.

QUANTUMatter2023 Organising Committee

QBLOX

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GENERAL INFO

FREE WIFI
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Password: eventosfpvi*

EXHIBITION & POSTER AREA
Level -1

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

COCKTAIL LUNCH
Offered by QUANTUMatter 2023 organisers
Tuesday May 23
Wednesday May 24
Location: Exhibition & Poster Area

CONFERENCE DINNER*
Wednesday May 24, 21:00
Restaurant LA MASÍA - JOSÉ LUIS
Avenida de las provincias s/n; Recinto ferial de Casa de Campo de Madrid
Underground line number 6 - Station "Puerta del Angel" - 5 minutes walking
* 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 23 & Wednesday May 24
You need to make sure you remove your poster after the morning coffee break on May 24
Session II Wednesday May 24 & Thursday May 25
You need to make sure you remove your poster after the morning coffee break on May 25

E-CERTIFICATE OF ATTENDANCE
Certificates of attendance will be sent by email to all registered delegates after the congress.

AGENDA & LOCATION

Tuesday – May 23	Room	Time
Plenary Session	Auditorium	08:45 - 19:15
Poster Session 1	Exhibition area	14:00 - 14:30
Exhibition & Posters	Exhibition area	-
Cocktail Lunch	Exhibition area	13:00 - 14:00
Wednesday – May 24	**Room**	**Time**
Industrial Forum	Auditorium	09:00 - 16:50
Parallel Session 1 - Quantum information and techs	Room Maritain	09:00 - 13:20
Parallel Session 2 - Quantum materials	Room Newman	09:00 - 13:20
Poster Session 2	Exhibition area	14:30 - 15:00
Parallel Session 1 PhD Student	Room Maritain	15:00 – 16:50
Parallel Session 2 PhD Student	Room Newman	15:00 – 16:50
Plenary Session	Auditorium	17:30 – 19:10
Exhibition & Posters	Exhibition area	-
Cocktail Lunch	Exhibition area	13:30 - 14:30
Conference dinner	Restaurant LA MASIA de Jose Luis	21:00
Thursday – May 25	**Room**	**Time**
Plenary Session	Auditorium	09:30 - 17:15
B2B Brokerage event	Room Van Thuan	09:30 – 13:30
Parallel Session I Orals Senior	Room Maritain	11:15 - 13:25
Parallel Session II Orals Senior	Room Newman	11:15 - 13:25
Poster Awards Ceremony	Auditorium	13:30 – 13:5
Exhibition & Posters	Exhibition area	-

COMMITTEES

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Pablo Ordejon (ICN2, Spain)

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Singularity

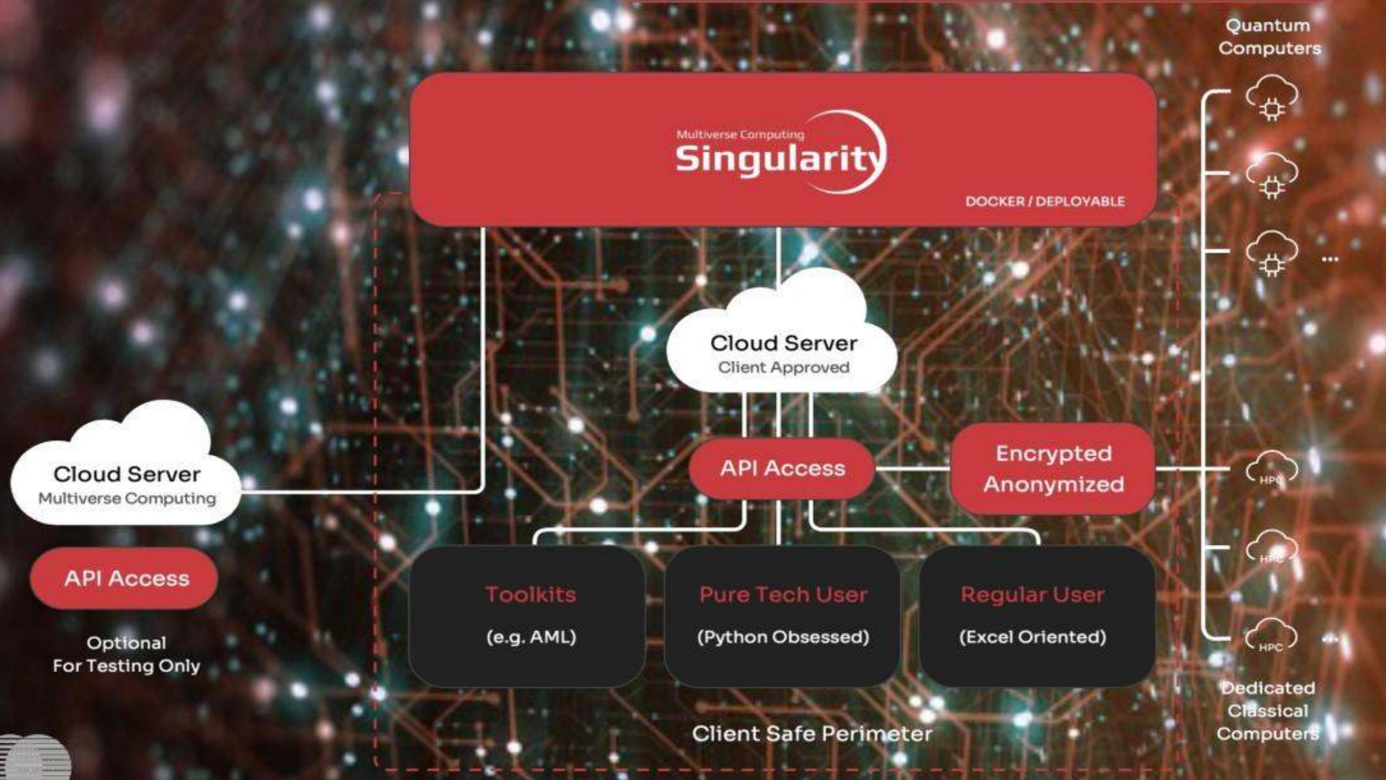
The SaaS platform with quantum and quantum-inspired algorithms developed by the leading European quantum software company based on real-world experiences with clients

"Multiverse has a strong focus and experience in quantum computing for finance"

– Quantum computing specialist in a European Company belonging to EU Fortune 100

APPLICATIONS

- Portfolio optimizer
- Optimizer for forex trading
- Index tracking toolbox
- Algorithmic trading
- Defect detection
- Optimization
- Quantum and quantum-inspired machine learning



MULTIVERSE COMPUTING

SPONSORS

DIAMOND 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.

PLATINUM SPONSORS

QUANTUM MACHINES

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**.

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.

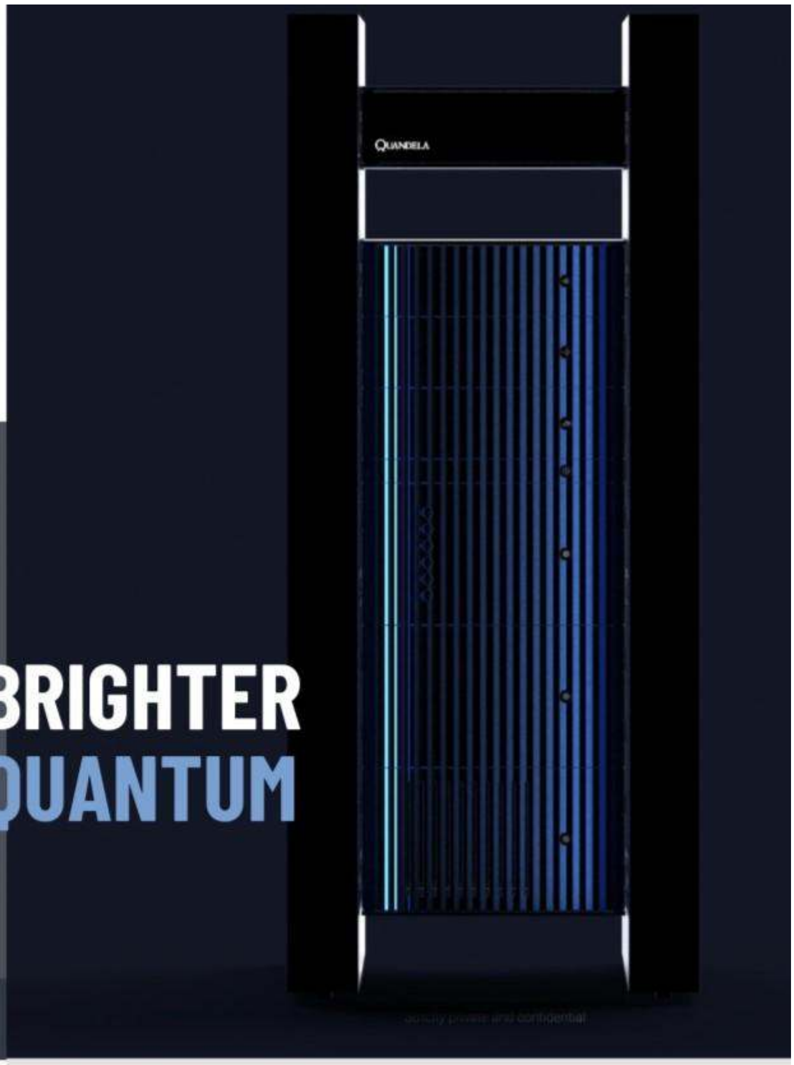
QBLOX With a dedicated team of scientists, engineers and developers we are pushing quantum technology to support scientists worldwide with our scalable qubit control and readout equipment from ultrastable DC to 18.5 GHz for academic and industrial quantum labs. The Qblox (**www.qblox.com**) control stack combines unlevelled noise performance, low-latency arbitrary control flows and can be scaled up to 100s of qubits. Our company is based in the Netherlands as a spinoff of QuTech, which enables us to implement the latest scientific insights and take a position upfront in the worldwide race towards quantum advantage. Using the technology developed at QuTech as a springboard, the Qblox team has fundamentally reimagined the architecture of quantum control to create a single integrated control stack that provides all the functionality needed to manipulate and measure quantum computers. The Qblox architecture speeds up calibration routines by orders of magnitude, saving research teams significant amounts of time and money. The Qblox team is interested in meeting experiment quantum physicists to learn about their applications and how Qblox could support their scaling needs.

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/**

QUANDELA

QUANDELA.COM



WE MAKE FUTURE COMPUTING BRIGHTER THROUGH PHOTONIC QUANTUM COMPUTERS

About Us

Quandela provides photonic quantum computers that are modular, scalable, energy-efficient and accessible both on the cloud and on premise. Our team specialises in the development of both software and hardware solutions for a variety of quantum applications.

We are a dynamic team of international experts who share a common goal: to push the boundaries of computing using photons and quantum computers. To do so, we have developed MosaiQ, the first generation of quantum computers based on the manipulation of photons in the world. In parallel, we have developed a unique software and opened our cloud to public access. Using these unique tools, our teams have demonstrated a quantum advantage based on entanglement for cybersecurity applications. We are now dedicating our efforts on solving the next challenges of our industries—from logistics to chemistry and pharmaceutical or even finance.

Our Solutions

Hardware

MOSAIQ: Single-photon based quantum computer

PROMETHEUS: High performance stand-alone deterministic quantum-light source

Software

PERCEVAL: Open-source software platform for photonic quantum computing

Cloud

QUANDELA CLOUD: The gateway to our photonic Quantum Processing Units (QPUs).

WE DESIGN AND DEVELOP INDUSTRIAL SOLUTIONS FOR WIDE-RANGING **APPLICATIONS**

ENERGY · AEROSPACE · AUTOMOTIVE · CHEMISTRY · PHARMACEUTICALS · FINANCE · CYBERSECURITY · LOGISTICS

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.

Rohde & Schwarz (**www.rohde-schwarz.com**) is a market-leading supplier that produces and markets a wide range of electronic capital goods in the mobile and wireless communications sector, offering a comprehensive portfolio of T&M instruments and systems for the development, production and acceptance testing of components and consumer devices. Other important T&M markets include the automotive industry, the aerospace & defense sector, all industrial electronics segments as well as research and education.

Quandela is a photonic quantum computing company providing hardware, middleware, and software solutions. Thanks to our cutting-edge technology and the dedication and expertise of our team, we develop ground-breaking quantum light solid-state sources of unparalleled performance for applications to quantum computing and quantum optics in the industrial and academic sectors. We create quantum algorithms and software to power the new generation of quantum computers, and we provide access to Quandela's photonic quantum processing units via the cloud. **www.quandela.com**

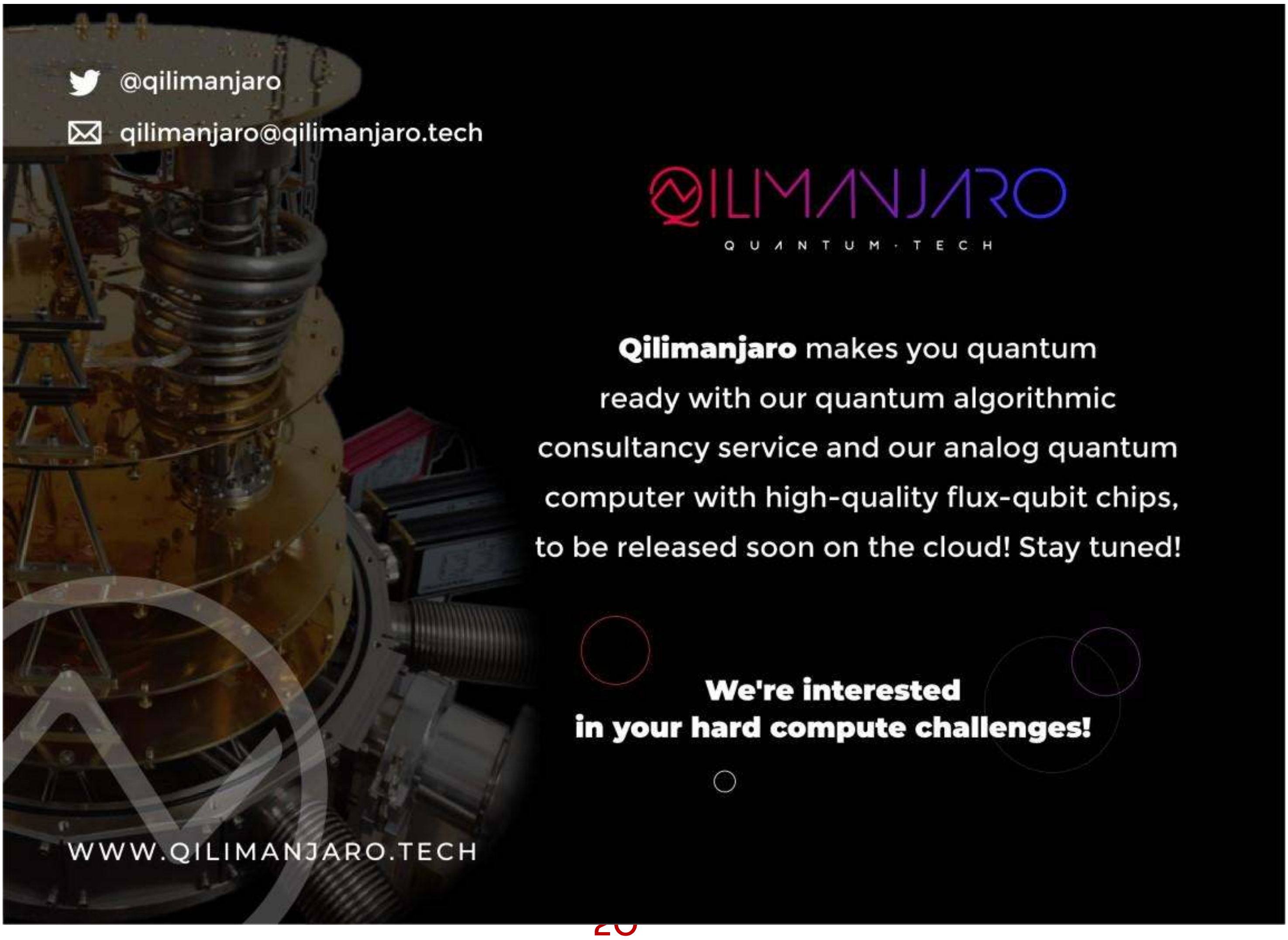
At Pasqal (pasqal.io), we build Programmable Quantum Simulators and Quantum Computers made of 2D and 3D Atomic Arrays. Neutral atoms trapped in optical tweezers and addressed with laser beams are ideal indistinguishable quantum systems to realize superposition and entanglement, at the heart of powerful 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.

GOLD SPONSORS

Single Quantum (**singlequantum.com**) was established as the first European company manufacturing and commercializing superconducting single photon detectors. By sharing this groundbreaking technology, we aim to create a better future!
Our multi-channel detection system has already been chosen by more than 150 academic and industrial labs all over the world to perform complex optical measurements.

The unique combination of unparalleled detection efficiency and time resolution is what makes our superconducting detectors the ideal choice for quantum communication, cryptography, infrared fluorescence spectroscopy, laser ranging and many other applications.

Qilimanjaro Quantum Tech (www.qilimanjaro.tech) is a quantum computing company that began operations in 2020 as a spin-off of the Barcelona Supercomputing Center - Spanish Supercomputing Center (BSC, www.bsc.es), of the Institute High Energy Physics (IFAE, www.ifae.es) and the University of Barcelona (UB, www.ub.edu). It develops algorithmic and cloud access services as well as quantum platforms aimed at optimization, simulation and Machine Learning problems for use cases in sectors such as logistics, chemistry and finance. Qilimanjaro participates in the direction of the European Innovation Council Horizon2020 project on "Coherent Quantum Annealing". It is a member of the European Quantum Industry Consortium (QuIC) since its creation in 2021. It has been awarded as "Exponential Leader 2021" by the Generalitat de Catalunya.



GMV is a privately owned technology business group founded in 1984 and trading on a worldwide scale in the following sectors: Space, Aeronautics, Defense and Security, Cybersecurity, Intelligent Transportation Systems, Automotive, Healthcare, Telecommunications and IT for government authorities and major corporations. Working with a staff of over 3,000, the company now runs subsidiaries in Spain, USA, Germany, France, Poland, Portugal, Romania, UK, The Netherlands, Belgium, Malaysia, and Colombia.

Our aim is to support our clients' processes with technologically advanced solutions, providing integrated systems and specialized products and services that cover the entire life cycle. From consulting and engineering services to the development of software and hardware, turnkey systems integration, and operational support. **www.gmv.com**

IQM creative approach is to bring application-specific problem solving to a multitude of industries. Through combining hardware and software design in the development of quantum processors, IQM can bring application-specific capabilities to our customers. This approach is one of a kind; for example, it is expected to offer entirely new avenues for health care, machine learning, financial modeling, materials science, and chemistry, and in general, it may boost up discoveries and breakthroughs in science and engineering. **www.meetiqm.com**

SILVER SPONSORS

Oxford Instruments NanoScience (OINS), is a leading provider of high-technology products and services to the world's leading industrial companies and scientific research communities. They design, supply and support market-leading research tools that enable quantum technologies, nanotechnology research, advanced materials and nanodevice development in the physical sciences. Building on a 60-year heritage, Oxford Instruments are at the forefront of the development and commercialisation of quantum computing around the world, including working on a number of Innovate UK projects. **www.oxinst.com**

The Condensed Matter Physics Center (IFIMAC) is a "María de Maeztu" Excellence Research Unit, located in the campus of the Universidad Autónoma de Madrid (UAM) pursuing cutting-edge research and scientific excellence. IFIMAC got the first MdM Excellence accreditation on the 2014 call and it was renewed in 2018. The Center comprises researchers from several university departments aiming to advance the limits of knowledge in both theoretical and experimental Condensed Matter Physics. 64 researchers constitute its permanent staff, together with 19 tenure-track positions for young researchers --Ramon y Cajal, Talent Attraction, Junior Leader, IFIMAC Leaders (from MdM funds)--, and up to 150 postdoctoral researchers and PhD students. Research performed in IFIMAC has gained world reputation in the following areas: Advanced Materials, First Principles Simulations and Modelling, Nanophysics, Nano and Quantum Optics and Soft Condensed Matter and Biophysics. **www.ifimac.uam.es**

EXCELENCIA MARÍA DE MAEZTU

Condensed Matter Physics Center (IFIMAC) is a "María de Maeztu" Excellence Research Unit since 2014, located in the campus of the Universidad Autónoma de Madrid (UAM) pursuing cutting-edge research and scientific

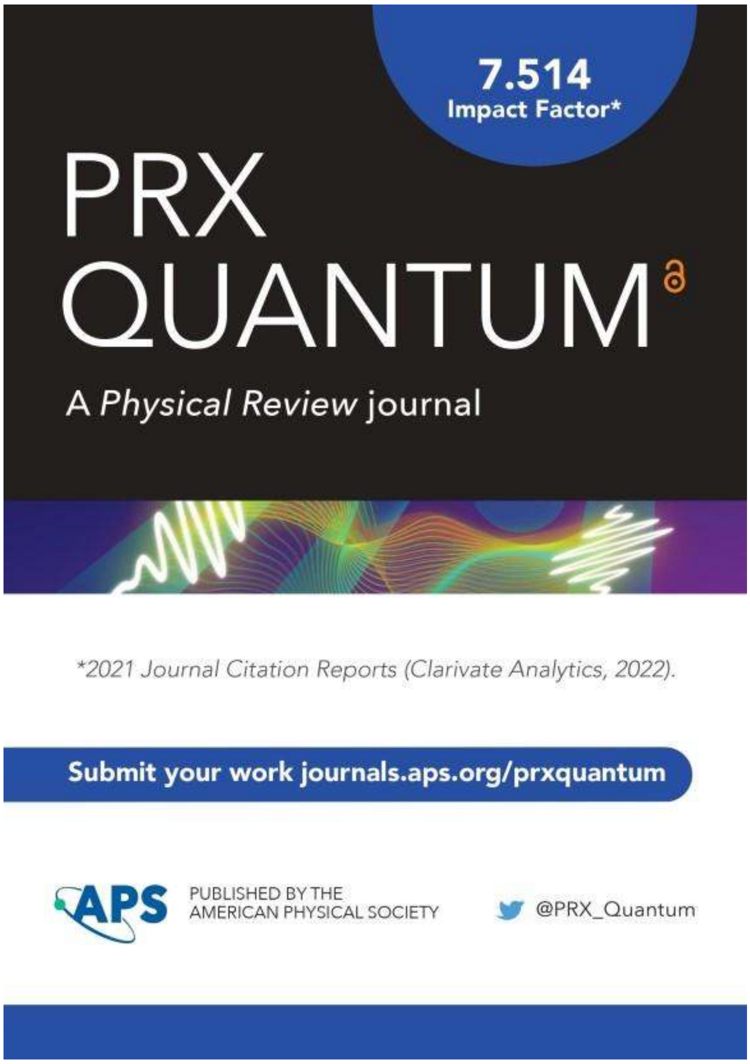
64 staff researchers
19 tenure-track positions
Up to 150 postdoc & PhD students

excellence at the crossroads of Physics, Chemistry, Materials Science and Biology, fostering a truly multidisciplinary approach. Research performed in IFIMAC has gained world reputation in the following areas: **Advanced Materials, First Principles Simulations and Modelling, Nanophysics, Nano and Quantum Optics and Soft Condensed Matter and Biophysics**.

BRONZE SPONSORS

APS physics PHYSICAL REVIEW JOURNALS

The Physical Review Journals, published by the American Physical Society, feature seventeen of the leading peer-reviewed journals in physics, seven of which are open access. The collection includes several high-impact titles including Physical Review Letters, the highest-impact letters journal in physics, Reviews of Modern Physics, the highest-impact review journal in physics, and PRX Quantum, which achieved a debut impact factor of 7.514 in 2021. **journals.aps.org**



C12

C12 (www.c12qe.com) is a French start-up that builds reliable quantum computers. The company is a spin-off from ENS launched in January 2020 by twin brothers Matthieu and Pierre Desjardins to supercharge the development of the lab's promising new quantum technology. Unlike other quantum computers, C12 uses carbon nanotubes as the fundamental building block of their processor. By combining the power of an ultra-pure material with an easy-to-manufacture semiconductor device, C12 is building a scalable platform for quantum computing. C12 is leading the next materials leap in quantum computing.

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LSQUANT Linear Scaling Quantum Transport

SPECSGROUP

SMA SÜSS MicroTec

SPEAKERS

The next wave of computing: quantum-centric supercomputing

Jerry Chow

IBM, USA

chowmj@us.ibm.com

The last few years have witnessed a strong evolution in quantum computing technologies, moving from research labs to an unprecedented access by the general public via the cloud. Recent progress in quantum processor size, speed, and quality, have cleared the picture towards a long-term vision in computing, where quantum processors will play a key role in extending the computational reach of supercomputers. In this talk I will describe how modularity will enable scaling, and how quantum communication will increase computational capacity. All this orchestrated by a hybrid cloud middleware for quantum for seamless integration of classical and quantum workflows in an architectural construct that we call quantum-centric supercomputer.

Spin Qubits in Semiconductors for Scalable Quantum Computers

Daniel Loss

University of Basel, Department of Physics, Basel, Switzerland

daniel.loss@unibas.ch

Abstract: Semiconductor spin qubits offer a unique opportunity for scalable quantum computation by leveraging classical transistor technology. This has triggered a worldwide effort to develop spin qubits, in particular, in Si and Ge based quantum dots, both for electrons and for holes [1-4]. Due to strong spin orbit interaction, hole spin qubits benefit from ultrafast all-electrical qubit control and sweet spots to counteract charge and nuclear spin noise . In this talk I will present an overview of the state-of-the art in the field and focus, in particular, on recent developments on hole spin physics in Ge and Si nanowires, Si FinFETs, and Ge heterostructures [5,6].

References

[1] C. Kloeffel and D. Loss, Annu. Rev. Condens. Matter Phys. 4, 51 (2013)

[2] A. Chatterjee, *et al*., Nat. Rev. Phys. 3, 157 (2021)

[3] G. Burkard, *et al.*, arXiv:2112.08863

[4] P. Stano and D. Loss, Nat. Rev. Phys. (2022)

[5] S. Bosco, B. Hetényi, and D. Loss, PRX Quantum 2, 010348 (2021)

[6] L. C. Camenzind, *et al.*, Nat. Electr. (2022)

The Coming Decades of Quantum Simulators

Maciej Lewenstein
Joana Fraxanet, Tymoteusz Salomon

ICFO, Intitute of Photonic Sciences and ICREA, Av. C.F. Gauss, 3, 08860 Castelldefels, Spain

Maciej.lewenstein@icfo.eu

Abstract Contemporary Quantum Technologies face major difficulties in fault tolerant quantum computing with error correction, and focus instead on various shades of quantum simulation (Noisy Intermediate Scale Quantum, NISQ) devices, analogue and digital Quantum Simulators and quantum annealers. There is a clear need and quest for such systems that, without necessarily simulating quantum dynamics of some physical systems, can generate massive, controllable, robust, entanglement and superposition states. This will in particular allow the control of decoherence, enabling the use of these states for quantum communications [6] (e.g. to achieve efficient transfer of information in a safer and quicker way), quantum metrology, sensing and diagnostics (e.g. to precisely measure phase shifts of light fields, or to diagnose quantum materials). In this Lecture we present a vision of the bright future of Quantum Simulators in the decades to come.

References

[1] Joana Fraxanet, Tymoteusz Salomon, and Maciej Lewenstein, The Coming Decades of Quantum Simulation, in print in Lecture Notes in Physics vol. **1000**, arXiv:2204.08905.
[2] M. Lewenstein, A. Sanpera, and V. Ahufinger, "Ultracold atoms in Optical Lattices: simulating quantum many body physics", 460 pages, Oxford University Press, Oxford, 2017, ISBN 978-0- 19878580-4

Figures

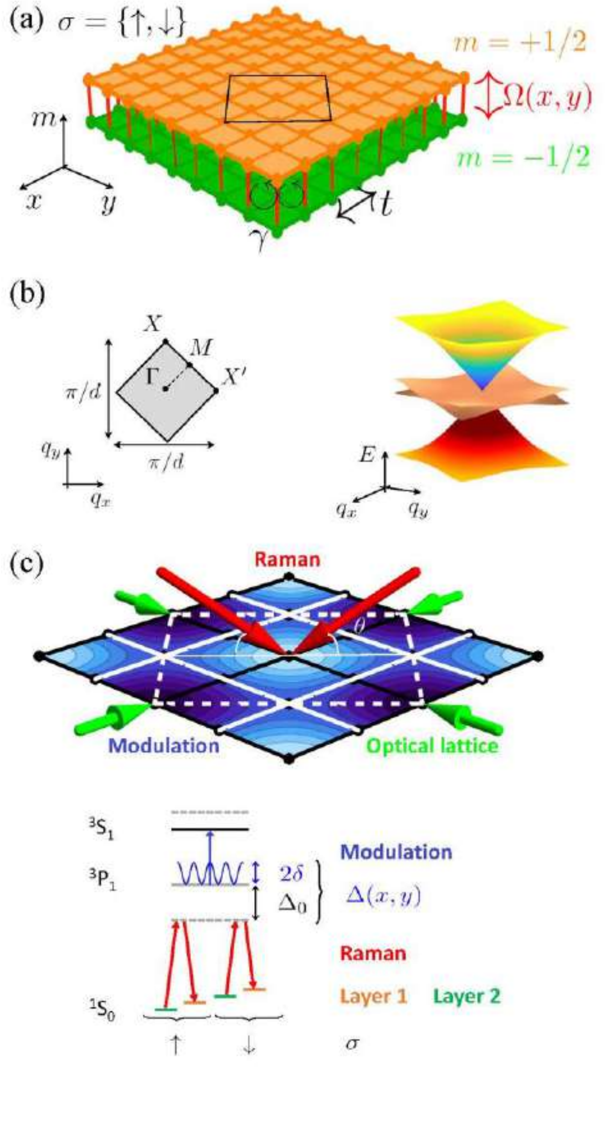

Figure 1: Twistronics without the twist.

Topological Superconductivity in Superconductor-Semiconductor Hybrids

Chetan Nayak
Microsoft Quantum

Microsoft, 5383 Hollister Ave, Goleta, CA 93111

cnayak@microsoft.com

Abstract:

Topological superconducting nanowires are characterized by Majorana zero modes, which can form the basis of topological qubits. In this talk, I will present some recent theoretical and experimental progress on these systems.

References

[1] Microsoft Quantum, "InAs-Al Hybrid Devices Passing the Topological Gap Protocol," arXiv:2207.02472.

Figures

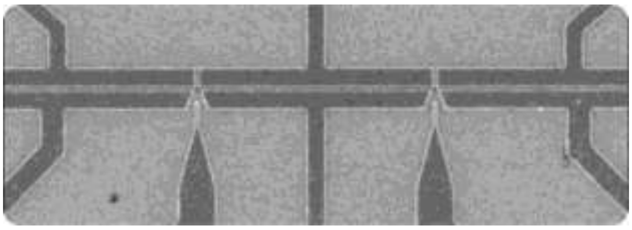

Figure 1: SEM image of a superconductor-semiconductor hybrid device.

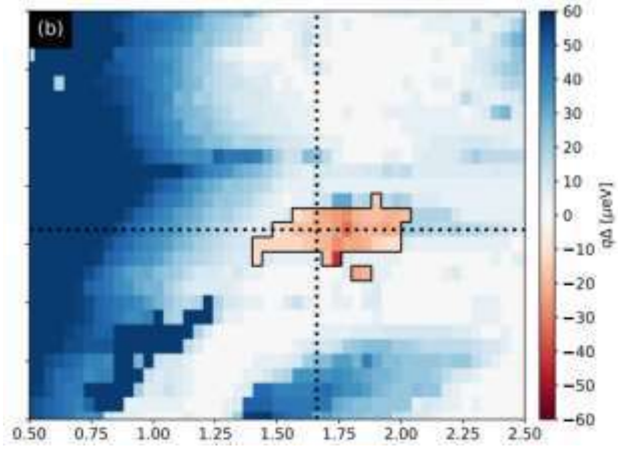

Figure 2: Experimental phase diagram of a superconductor-semiconductor hybrid device.

Giant Artificial Atoms and Waveguide QED

William D. Oliver

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Abstract

We present a demonstration of "giant artificial atoms" realized with superconducting qubits in a waveguide QED architecture. The superconducting qubits couple to the waveguide at multiple, well-separated locations. In this configuration, the dipole approximation no longer holds, and the giant atom may quantum mechanically self-interfere. This system enables tunable qubit-waveguide couplings with large on-off ratios and a coupling spectrum that can be engineered by design. Multiple, interleaved qubits in this architecture can be switched between protected and emissive configurations, while retaining qubit-qubit interactions mediated by the waveguide. Using this architecture, we generate a Bell state with 94% fidelity, despite both qubits being strongly coupled to the waveguide. We furthermore use an artificial molecule comprising two qubits to demonstrate directional photon emission with 97% fidelity (a chiral waveguide). Such waveguide QED technologies are applicable to quantum interconnects and support architectural modularity.

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Figures

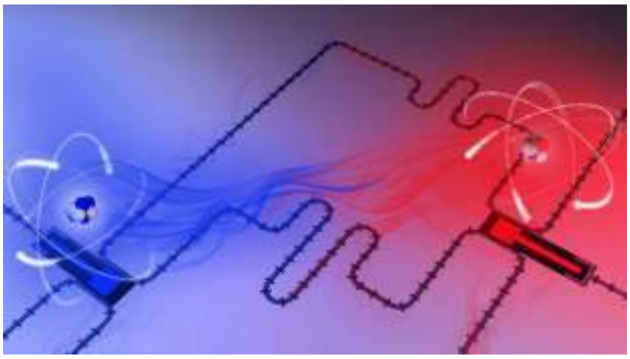

Figure 1: Illustration of two giant atoms interacting with one another via a 50-Ohm waveguide while isolated from the 50-Ohm environment via quantum interference.

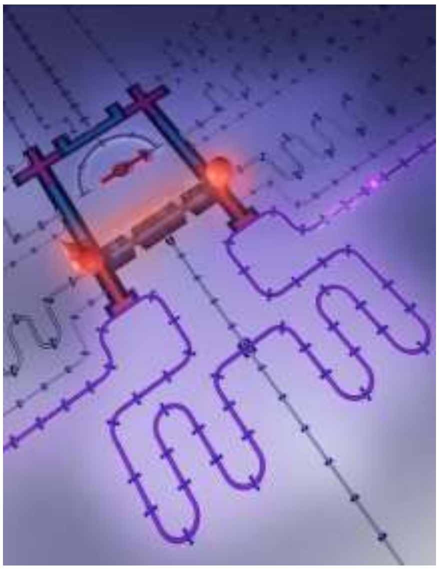

Figure 2: Illustration of direction emission of a directional (chiral) photon to a waveguide from two qubits entangled in a Bell state.

Pair creation, correlations and entanglement dynamics in dipolar multi-layers

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Abstract

Understanding and controlling the growth and propagation of quantum correlations and entanglement is an emerging frontier in non-equilibrium many-body physics, and a crucial key step for unlocking the full advantage of quantum systems. In this talk I will discuss how in multi-layer spin systems, currently accessible in a broad range of quantum platforms, such as arrays of neutral atoms, Rydberg atoms, magnetic atoms and polar molecules, spin interactions can be utilized to realize in a controllable manner a variety of correlated pair-production processes. In particular, I will describe how in bi-layer systems, the capability to select individual layers and prepare targeted initial states, can enable the generation of iconic two-mode squeezing models that feature exponential growth of entanglement and are relevant in many contexts ranging from the foundations of quantum mechanics, to parametric amplification in quantum optics, to the Schwinger effect in high energy physics and Unruh thermal radiation in general relativity. In multi-layers I will show it is possible to engineer a chiral bosonic Kitaev model featuring chiral propagation of correlations. Overall in this talk I will report how current single layer addressing capabilities can allow shaping and controlling the temporal growth and spatial propagation of quantum correlations in a variety of spin systems relevant for quantum simulation[1-3].

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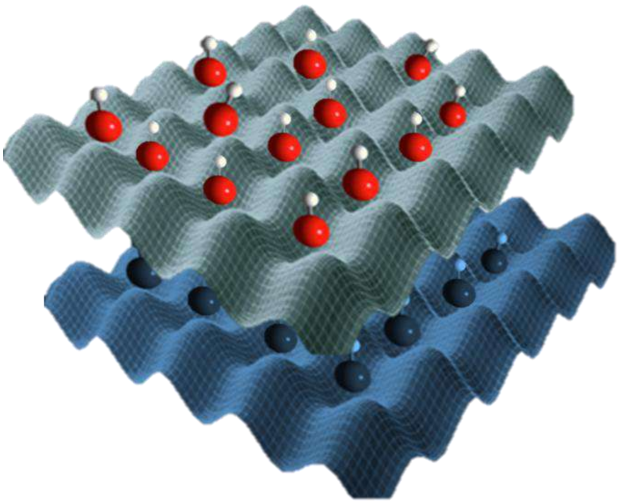

Figure 1: Pair creation in multi-layers

Semiconductor sources of quantum light

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Quantum light is a key ingredient of the emerging second quantum revolution. It is the cornerstone of many applications ranging from quantum computing to quantum networks, offering many degrees of freedom to encode the information. Semiconductor quantum dots are artificial atoms that, over the years, have been shown to be excellent sources of quantum light.
In this talk, I will briefly present the platform and explain how, using the tools of cavity quantum electrodynamics and semi-conductor nano-processing, quantum dots have become close to text-book quantum emitters. They generate single photons at unparalleled efficiency and near perfect quantum purity [1,2] opening the path toward the development of intermediate scale quantum computing [3]. Playing with the spin degree of freedom of a carrier trapped in the quantum dot, we recently unlocked a critical knob for scaling up: the efficient generation of photonic cluster state – chains of entangled photons [4]. Finally, this system also allows us to revisit the fundamentals of light-matter interaction and exploit them to generate entanglement in the photon number basis [5].

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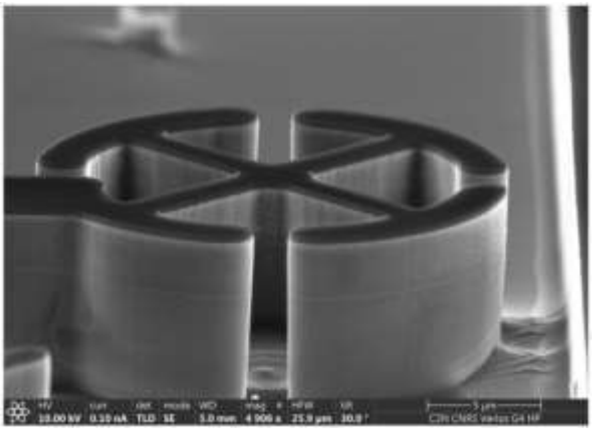

Figure 1: Scanning electron microscope image of a quantum dot-cavity device that we explore as a source of single and entangled photons, as a spin-photon interface as well as a model system to revisit light-matter interaction at the quantum level.

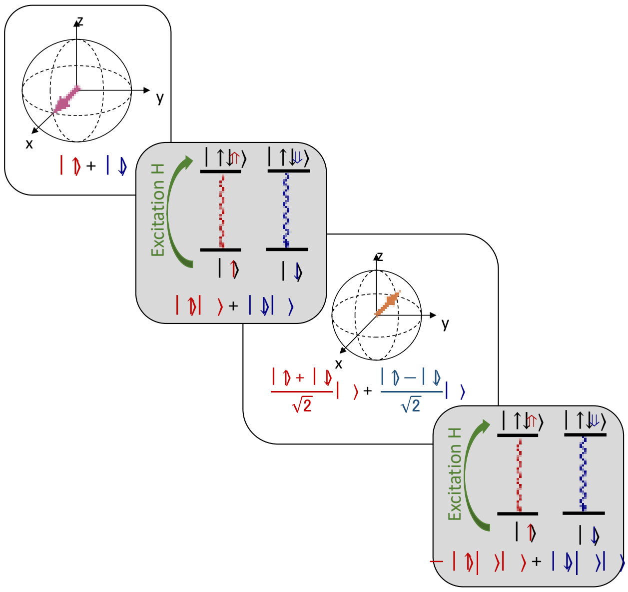

Figure 2: Schematic of the spin-photon-photon entanglement scheme [4].

Quantum simulation with ultracold atoms – from Hubbard models to gauge theories

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Well-controlled synthetic quantum systems, such as ultracold atoms in optical lattices, offer intriguing possibilities to study complex many-body problems in regimes that are beyond reach using state-of-the-art classical computations. The basic idea is to construct and use a well-controlled quantum many-body system in order to study its in- and out-of-equilibrium properties and potentially use it to develop more efficient tailored numerical methods that can then be applied to other systems that are not directly accessible with the simulator.

An important future quest concerns the development of novel experimental techniques that allow us to expand the range of models that can be accessed. I will demonstrate this using the example of topological lattice models, which in general do not naturally appear in cold-atom experiments. I will show how the technique of periodic driving, also known as Floquet engineering, facilitates their realization and show how charge-neutral atoms in lattices can mimic the behavior of charged particles in the presence of an external magnetic field.

A key ingredient for quantum simulation is the degree of control one has over the individual particles and the microscopic parameters of the model. We have recently succeeded to not only use the technique of periodic driving to emulate physical systems that we know exist in nature, but to take this idea one step further and realize completely new topological regimes that do not have any static analog. Moreover, we are currently developing a novel hybrid optical lattice platform, where tightly focused optical tweezers are used to locally control the motion of the atoms in the lattice, paving the way towards quantum simulation of simplified lattice gauge theories, which play a fundamental role in a variety of research areas including high-energy physics and topological quantum computation

Quantum networking with solid-state based quantum repeater nodes

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The distribution of entanglement between the nodes of a quantum network will allow new advances e.g. in long distance quantum communication, distributed quantum computing and quantum sensing [1]. To distribute quantum entanglement over long distances, quantum repeaters have been proposed [2]. The nodes of a quantum repeater are matter systems that should efficiently interact with quantum light, allow entanglement with photons at telecommunication wavelengths and serve as a quantum memory allowing long-lived and faithful storage of (entangled) quantum bits. In addition, for efficient distribution of entanglement, the nodes should allow multiplexed operation and ideally enable quantum processing capabilities between stored qubits.

In this talk, after introducing the context I will describe our recent progress towards the realization of quantum repeater nodes with multiplexed quantum memories, using cryogenically cooled rare-earth ion doped solids. Recent experiments include demonstration of long distance multiplexed quantum teleportation from a photonic telecom qubit to a solid-state collective qubit with active feed-forward [3] as well as the distribution of entanglement between a photon and a quantum memory over a 50 km link in the installed fiber network [4].

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Quantum Information Processing with Bosonic Circuit QED

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A promising path to realize robust universal quantum computing involves the encoding logical qubits in continuous variables (CV) quantum elements. In particular, superconducting microwave cavities coupled to one or more anharmonic elements in the bosonic circuit quantum electrodynamics (cQED) architecture provide a valuable resource for the hardware-efficient encoding of logical qubits.

In this talk, I will introduce our recent results on creating, manipulating, and characteristing highly non-classical states in superconducting cavities. These works provide the important building blocks of a robust universal quantum computer.

Hyperfine interaction in graphene nanostructures

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Graphene is an exceptional material with attractive properties to explore fundamental physics and to use in technological applications. Recent advances in on-surface chemistry pave the way to grow with atomic precision customized graphene nanostructures that can be designed to exhibit desired magnetic and transport properties. We study systems exhibiting π magnetism and their possibility to host spin qubits. In this talk, we'll consider the hyperfine interaction (HFI) of localized spins in graphene nanostructures. We show that a simple fitting procedure allows to predict HFI from π-spin densities. Its relevance for electron and nuclear spin qubits is discussed.

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Figures

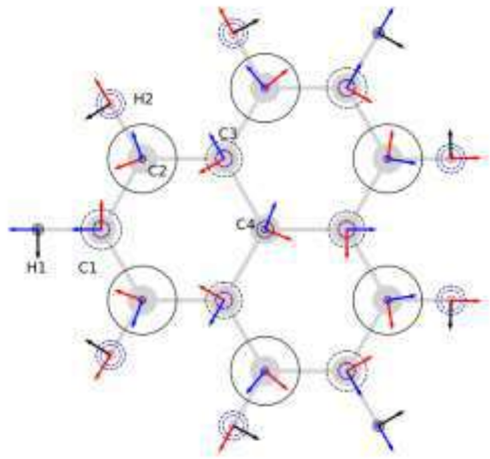

Figure 1: Depiction of the hyperfine tensors for all nuclei of [2]triangulene ($C_{13}H_9$) computed with ORCA. Radii of the circles correspond to the size of the eigenvalues of the hyperfine tensor, the arrows show the direction of the in-plane eigenvectors.

Combining tunnelling and Coulomb blockade spectroscopy on hybrid Al/InAs nanowire devices

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Maksim Borovkov[1]
Elsa Prada[2]
Sara Marti-Sanchez[3]
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Hybrid semiconductor–superconductor devices hold great promise for realizing Majorana zero modes [1-3]. However, multiple claims of Majorana detection, based on either tunnelling or Coulomb blockade (CB) spectroscopy, remain disputed. In this talk I will introduce an experimental protocol that allows to perform both types of measurement on the same hybrid island by adjusting its charging energy via tunable junctions to the normal leads [4,5]. This method reduces ambiguities of Majorana detections by checking the consistency between CB spectroscopy and zero-bias peaks in non-blockaded transport. I will discuss the theoretical interpretation of the experimental observations in terms of low-energy, longitudinally confined island states rather than overlapping Majorana modes. The results highlight the importance of combined measurements on the same device for the identification of topological Majorana zero modes.

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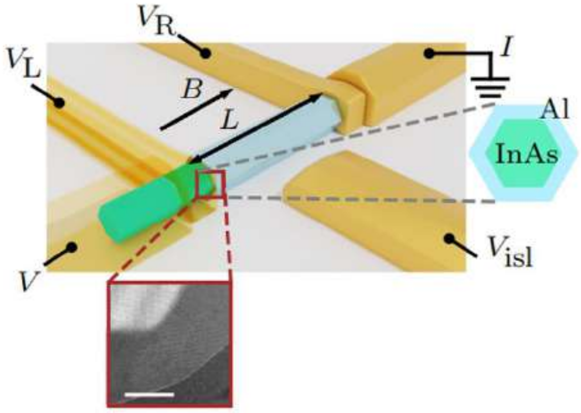

Figure 1: Schematics of a full-shell NW device. Turquoise represents the hexagonal InAs core, light blue the Al full-shell and gold the Ti/Au leads and gates. The insets show the NW cross-section schematic (right) and an atomic-resolution, high-angle annular dark-field scanning transmission electron microscopy image (left). Scale bar, 20 nm.

Realizing non-Abelian statistics using graph gauge theory on a quantum processor

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The indistinguishability of particles is a fundamental principle of quantum mechanics. For all (quasi)particles observed to date - including fermions, bosons, and Abelian anyons this principle guarantees that the double-exchange of identical particles leaves the system unchanged. However, an intriguing possibility exists in two spatial dimensions: double-braiding of non-Abelian anyons transforms the multi-anyon state. Such anyons can non-locally encode quantum information, which can be processed through pair-wise exchanges. Despite numerous theoretical proposals, experimental realization of non-Abelian anyon exchange, i.e., braiding of their space-time trajectories, has remained elusive. We propose a simple and systematic prescription to construct unitary protocols for braiding, manipulation, and readout of non-Abelian anyons and preparation of their entangled states on a digital quantum processor. We define the plaquette surface code as a stabilizer code on a generic planar graph of qubits with vertices of degrees 2, 3, and 4. By mapping each qubit to four Majoranas and recognizing that each degree-3 vertex (D3V) carries a new discrete Z2 flux of "Kasteleyn" field, we prove non-Abelian statistics of D3V's. In our approach, all the experimentally relevant operators are unambiguously fixed by locality, unitarity, and gauge invariance. Our specific prescriptions for experiments on a near-term digital quantum processor have been carried out to create and braid D3Vs on a superconducting quantum processor. Further, we created an entangled state of three logical qubits by braiding D3Vs. I will discuss the prospect of employing these anyons for quantum computation.

Superconducting diode effect due to magnetochiral anisotropy in topological insulator and Rashba nanowires

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The critical current of a superconductor can depend on the direction of current flow due to magnetochiral anisotropy when both inversion and time-reversal symmetry are broken, an effect known as the superconducting (SC) diode effect [1]. In our work, we consider one-dimensional (1D) systems in which superconductivity is induced via the proximity effect [2,3]. In both topological insulator and Rashba nanowires, the SC diode effect due to a magnetic field applied along the spin-polarization axis and perpendicular to the nanowire provides a measure of inversion symmetry breaking in the presence of a superconductor. Furthermore, a strong dependence of the SC diode effect on an additional component of magnetic field applied parallel to the nanowire as well as on the position of the chemical potential can be used to detect that a device is in the region of parameter space where the phase transition to topological superconductivity is expected to arise [3-7].

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Figures

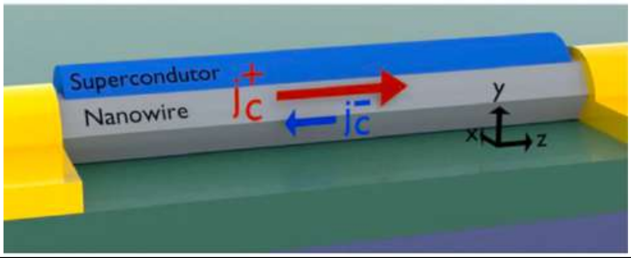

Figure 1: SC diode effect due to magnetochiral anisotropy in nanowire devices. When the subbands of a nanowire possess a finite spin polarization due to broken inversion symmetry, a magnetic field applied along the spin-polarization direction results in a relative Zeeman shift of the subbands. The magnetochiral anisotropy (MCA) of the energy spectrum can lead to MCA rectification in the diffusive normal state . On the other hand, if a nanowire is brought into proximity with a superconductor, the MCA of the energy spectrum results in a critical supercurrent in the proximitized nanowire that is different depending on whether current flows to the left or right of the device, the SC diode effect. The dependence of this diode effect on an additional magnetic field component parallel to the nanowire can be used to detect that the nanowire is in parameter regime where topological superconductivity is expected.

Joule spectroscopy and heating in hybrid superconductor-semiconductor devices

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Hybrid superconductor-semiconductor devices have been intensively studied in the past decade owing to prospects of applications in quantum technologies. Crucially, towards this goal, an impressive improvement in the quality of materials has been achieved in recent years. Nonetheless, fabricated devices arguably still show a great deal of variability, each being effectively unique. Here, we demonstrate that Joule heating can be used as a powerful tool for the characterization of such devices. Concretely, we show that the transition of the superconducting leads to the normal state by the Joule effect can be used as a spectroscopical signature in transport of the superconductivity of each lead separately and in a single measurement, thus readily providing a "fingerprint" of each device. We demonstrate the potential of the technique by obtaining detailed information of devices based on hybrid epitaxial Al-InAs nanowires. In particular, we study full shell wires, also in the Little-Parks, and uncover different sources of inhomogeneities such as disorder in the parent superconductor (differences in the superconducting coherence lengths of the leads and discontinuous covering from the epitaxial shell), and the inverse superconducting proximity effect. Our work also brings to light important bottlenecks for heat dissipation in hybrid superconducting devices, which can lead to substantial temperatures even for moderate currents/voltages. This underscores the importance of heating effects in hybrid devices, a topic which has been so far largely overlooked [1].

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Circuit QED with molecular spin qudits

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Achieving a quantum computational power that can solve practical problems is still very challenging, even for today's most successful platforms, on account of the need of correcting errors and the fact that this requires increasing the number of physical qubits. Artificial magnetic molecules can provide some competitive advantages for progressing towards large-scale quantum computation [1-3]. They are microscopic yet tuneable via chemical methods. Recent examples of molecular designs are able to integrate 2, 3, 4 and 6 qubits or, in general, *d*-dimensional qudits using their multiple electronic and nuclear spin states. Each of these molecules can, in principle, act as a universal quantum processor or even encode error-corrected qubits [3]. However, exploiting these possibilities calls for a solid-state platform to control, read-out and wire them up [3-5]. I'll discuss recent experiments aimed at achieving this goal via the coupling of molecular spin ensembles, mainly diluted in diamagnetic single crystals, to on-chip superconducting resonators. These experiments show that it is possible to achieve a high cooperativity coupling to electronic and even nuclear spin transitions [6]. In addition, we find that spin clock transitions help optimizing both the spin-photon coupling and the isolation from magnetic noise sources. The results provide the basis for reading out the states of electro-nuclear spin qudits and for performing with them proof-of-concept implementations of qudit based algorithms.

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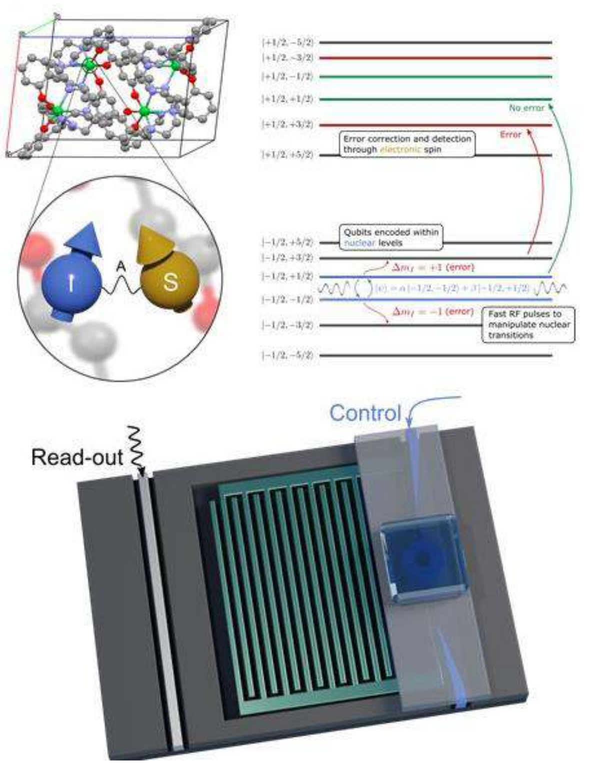

Figure 1: Sketch of a hybrid quantum processor based on molecular spin qudits (here Yb-trensal molecules diluted in a diamagnetic Lu-trensal crystal) coupled to an on-chip superconducting resonator (adapted from [6]).

Addressing the fidelity and scaling challenges of superconducting qubits

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Abstract

We recently discovered a new kind of a superconducting qubit, the unimon [1], that can be fabricated using standard materials and techniques out of a single Josephson junction and a superconducting resonator yet having higher anharmonicity than the transmon and resilience against charge and flux noise. Our first experiments on the unimon demonstrate single-qubit-gate fidelity of 99.9% stable for several hours without recalibration. In addition, we have developed qubit readout, reset, and control electronics that operates at millikelvin temperatures and can be integrated with the unimon in the future [2–6]. Whereas the increased anharmonicity and noise resilience of the unimon seems promising for achieving high-fidelity qubit operations, the integrated millikelvin electronics addresses the scaling challenges of future large-scale superconducting quantum computers.

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Mesoscopic physics challenges (in) superconducting quantum devices

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I will discuss three mesoscopic physics phenomena which significantly complicate the task of engineering coherent superconducting hardware: ionizing radiation interactions with the device substrate [1,2], long lived two level systems which imprint a memory in the qubit's environment [3], and fluctuations in the transparency of aluminum oxide tunnel barriers [4].

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Figures

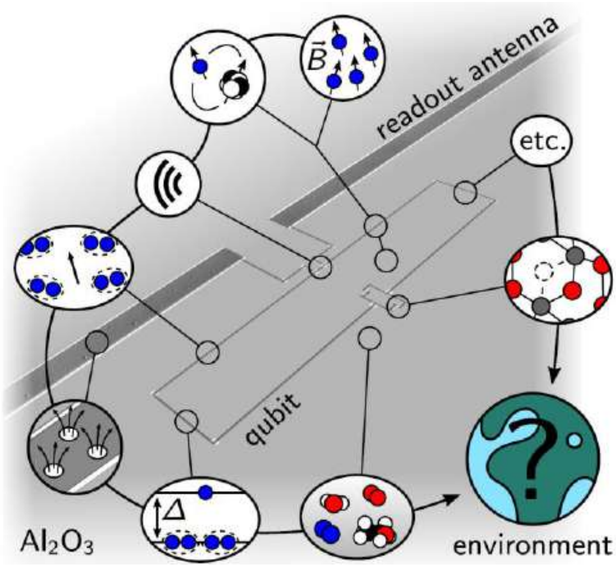

Figure 1: Superconducting qubits live in a complex environment (adapted from Ref. [3])

Materials and Interfaces for spin qubits : On and Off the Beaten Path

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The semiconductor industry knows how to make and integrate billions of excellent transistors. What materials and interfaces do we need to integrate excellent qubits at large scale for the quantum information age of tomorrow? I will examine the materials science progress underpinning silicon and germanium-based planar heterostructures, review our most significant experimental results demonstrating key building blocks for quantum technology, and identify the most promising avenues toward scalable quantum information processing.

Single molecules in photonic quantum technologies

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The generation and manipulation of quantum states of light is required for key applications, such as photonic quantum simulation, linear optical quantum computing, quantum communication, and quantum metrology. In this context, single organic molecules in the family of polycyclic aromatic hydrocarbons (PAH), embedded in suitable host matrices, offer competitive properties and key advantages [1]. Being very small and with well-defined transition dipole moments, they can be used as nanoscopic sensors e.g. of pressure, strain, temperature, electric and magnetic fields, as well as optical fields. Furthermore, PAH molecules can be easily fabricated and exhibit strong zero-phonon lines, which reach their Fourier-limited natural linewidth at liquid helium temperature, thus providing very bright and stable sources of coherent photons in the solid state [2,3,4].
I will present our recent advances on the coupling of single PAH molecules to photonic structures for the enhancement and control of their interaction with quantum light [5,6]. Furthermore, I will discuss two-photon interference (TPI) experiments performed between single-photons emitted by distinct molecules on the same chip [7] (see Fig.1), which stands as a fundamental challenge in the context of solid-state platforms for photonic quantum techs.
In this context, we attain and combine together different milestones: simultaneously addressing on the same sample several molecules operating as on-demand single-photon sources, tuning independently their relative optical frequency [8], measuring in semi-real-time their TPI, and extracting information about joint properties of the photon pairs.
Finally, I will present our recent results on the use of organic molecules as nanoscopic thermal sensors [9], allowing semi-invasive local temperature measurement in a temperature range (3 K to 30 K) where most commercial technologies cannot be used. These results can lead to a deeper understanding of the local phononic environment in complex structures and in an unexplored temperature regime.

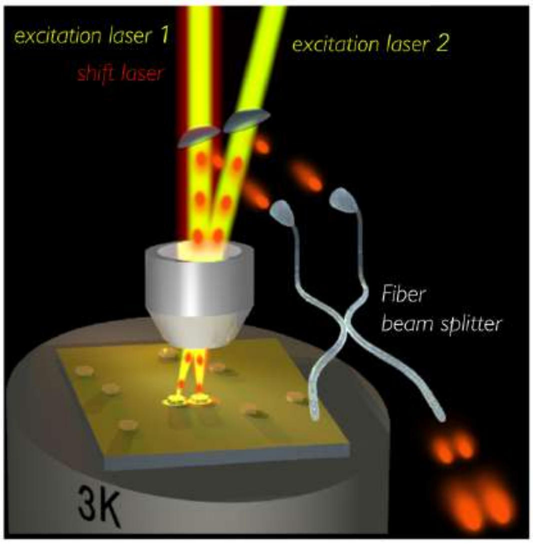

Figure 1: Sketch of the experimental setup employed to measure TPI from distinct molecules, adapted from Ref. [7]

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Chirality and Topology in DNA-type Chiral Materials

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Abstract

In physics, chirality usually refers to the locking of spin and momentum, such as in Weyl fermions and photons. In chemistry and biochemistry, however, it is the geometric asymmetry of non-superposable mirror images that constitutes chirality. While seemingly unrelated characters in different fields, the chiral geometry can lead to topological electronic properties in chiral materials including molecules, polymers, and solids, as we recently discovered. This electronic topology is encoded in the intrinsic orbital nature of the wave function and leads to unexpected consequences, for example, in molecular spin valve devices and light emitting diodes. The chirality information is transferred from the atomic geometry to electronic orbital, and further to the electronic spin and light, which promises broad impacts in fundamental science and technology application.

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Figures

Figure 1: Chirality-driven electronic orbital texture in DNA-type chiral materials

Unlocking the Potential of Quantum-Classical Processing

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Abstract

In recent years, it has become increasingly clear that realizing the potential of Quantum Computers would require tight quantum-classical integration, in particular to overcome the high error rate in various manners. In this talk, we will dive into the considerations for building quantum-classical architectures and present the latest progress and developments in the field. We will present our latest results from Google-Quantum Machine's collaboration to perform long range quantum teleportation, demonstrating the need of and the advantage of tight, real-time quantum-classical integration. We will discuss the importance of defining quantum-classical processing requirements and benchmarks. Finally, we will introduce NVIDIA-Quantum Machine's DGX Quantum, an architecture built to scale up ultra-low latency quantum-classical machines towards practical implementations of quantum error correction.

Scalable qubit control and readout with fast-scalable feedback

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Abstract
NISQ applications require improvements on 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. 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 (integration, averaging, binning and thresholding) [1]. Orders of magnitude speed-up is achieved by avoiding software-controlled loops [2,3]. While the system generates control pulses up to 18.5 GHz with ultra-low noise and drift, on the readout side, it allows both microwave and lockin measurements in the same device with frequency multiplexing, making it suitable for various qubit types and readout schemes. Qblox's fast scalable feedback distributes measurement outcomes with all-to-all connectivity to allow active-reset operations and error mitigation algorithms. Up to 80 control channels are linked to up to 40 input channels for feedback operations in a single device within 364 ns. 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.

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Figures

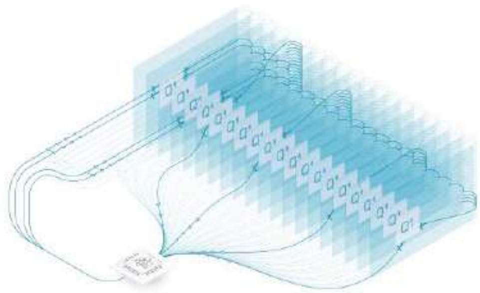

Figure 1: The fast scalable feedback is built on top Cluster's distributed intelligence consisting of 120 cores in a Cluster mainframe, working seamlessly synchronised thanks to proprietary SYNQ and LINQ protocols. The cluster mainframe distributes measurement outcomes with all-to-all connectivity, meaning that up to 80 control channels are linked to up to 40 input channels for feedback operations within 364 ns.

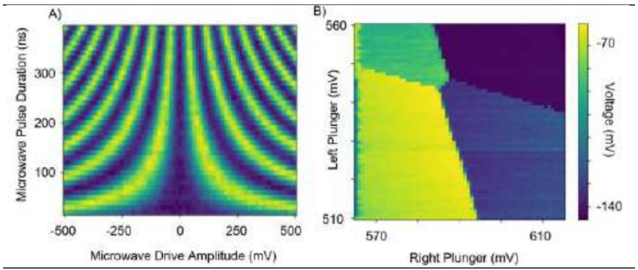

Figure 3: Examples where order-of-magnitude speed-ups are achieved through real-time on-board compiling and on-board data analysis. A) Chevron plot for tuning the pulse amplitudes and duration of a transmon qubit, measured in 23 seconds (IMPAQT consortium) B) Charge stability diagram for tuning a Si double-dot sample, measured in 180 ms (Qutech).

A software framework for scalable quantum computing

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Abstract

Quantum computing architectures have expanded to systems that support many qubits. With an increase in qubit number, both qubit control hardware and software must support quantum engineers and scientists in breaking down experimental complexity. Here, we show the advantage provided by the combination of our open-source software framework with our high-performance control electronics. The software framework supports programming many instruments together as a single machine, allowing users to program experiments at a high level, from which optimized code is generated for the control hardware. We show how the software speeds-up the practical operation of quantum computers and how it performs state-of-the-art experiments on the latest qubit processors.

Quantum Graph Machine Learning on a Neutral Atom Processor

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The manipulation of neutral atoms by light is at the heart of countless scientific discoveries in the field of quantum physics in the last three decades. The level of control that has been achieved at the single particle level within arrays of optical traps, while preserving the fundamental properties of quantum matter (coherence, entanglement, superposition), makes these technologies prime candidates to implement disruptive computation paradigms. For instance, using such a quantum processor to embed and process classical data enables the generation of correlations between variables that are inefficient to represent through classical computation. A fundamental question is whether these correlations could be harnessed to enhance machine learning performances on real life datasets.

To that end, we introduce a quantum feature map to encode the information about graphs in the parameters of a tunable Hamiltonian acting on an array of qubits. Using this tool, we first show that interactions in the quantum system can be used to distinguish non-isomorphic graphs that are locally equivalent. We then realize a toxicity screening experiment, consisting of a binary classification protocol on a biochemistry dataset comprising 286 molecules of sizes ranging from 2 to 32 nodes, and obtain results which are comparable to those using the best classical kernels. Using techniques to compare the geometry of the feature spaces associated with kernel methods, we then show evidence that the quantum feature map perceives data in an original way, which is hard to replicate using classical kernels.

To learn and cancel quantum noise: Probabilistic error cancellation with sparse Pauli-Lindblad models on noisy quantum processors

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Error-mitigation techniques can enable access to accurate estimates of physical observables that are otherwise biased by noise in pre-fault-tolerant quantum computers. One particularly general error-mitigation technique is probabilistic error cancellation (PEC), which effectively inverts a well-characterized noise channel to produce noise-free estimates of observables. Experimental realizations of this technique, however, have been impeded by the challenge of learning correlated noise in large quantum circuits. In this work, we present a practical protocol for learning a sparse noise model that scales to large quantum devices and is efficient to learn and invert. These advances enable us to demonstrate PEC on a superconducting quantum processor with crosstalk errors, thereby revealing a path to error-mitigated quantum computation with noise-free observables at larger circuit volumes.

Useful Quantum Software for Today's Processors

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In this talk I will explain the approach that we are taking at Multiverse Computing in order to bring useful quantum and quantum-inspired software developments for the masses. I will sketch briefly recent results on optimization and machine learning in a variety of problems involving verticals such as energy, manufacturing, finance, and cybersecurity, using real data, and in real industrial environments.

Quantum simulations with superconducting qubits

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In 2019, it was experimentally demonstrated that a quantum processor could perform certain computational tasks exponentially faster than a classical computer [1]. Going beyond this milestone, we seek to utilize these Noisy Intermediate Scale Quantum (NISQ) processors to study computationally intractable physics problems. The class of problems that seems within reach are quench dynamics in interacting spin systems far away from equilibrium. I will provide an overview of our progress by describing some of our recent works [2,3]. The aim of the talk is to provide a sense of what NISQ discoveries to anticipate and a time scale for them.

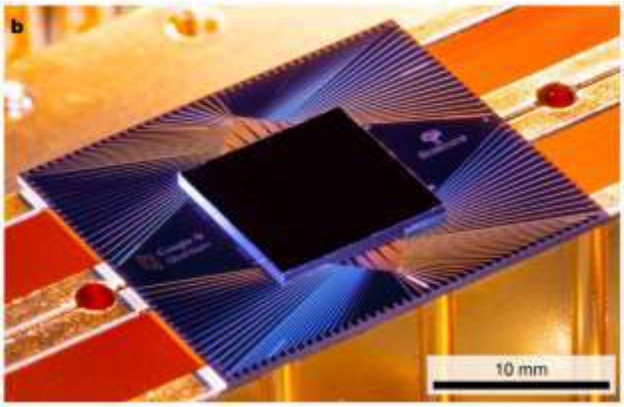

Figure 1: The Sycamore processor can be used to study problems in non-equilibrium spin dynamics.

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Figures

How inhomogeneities enhance the manipulability of Ge spin qubits

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In recent years, there has been a growing interest in utilizing hole spins in silicon and germanium for quantum information processing. One reason for this is the strong spin-orbit interaction present in the valence band of these materials, which allows for versatile interactions with electric fields. As a result, there have been demonstrations of fast electrical manipulation of hole spin qubits [1] and strong spin-photon interactions [2], which are useful for generating long-range entanglement. While these experimental advances are well-established, there is still much to learn on the theoretical side. For example, Ge hole qubits can be operated with in-plane magnetic fields [3], which cannot be easily explained by the expected spin-orbit mechanisms like cubic Rashba or g-tensor modulation resonance.

In this work, we go beyond the usual models for electrical spin manipulation in semiconductor quantum dots. We perform simulations of realistic Ge devices and find that both the electrostatics [4] and the strain [5] display inhomogeneities that heavily affect the performance of hole spin qubits. In particular, we identify overlooked spin-orbit mechanisms that enable manipulation under in-plane magnetic fields and enhance the expected Rabi frequencies. Our simulations show that these mechanisms are dominating the physics of isotropic hole spin qubits.

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Figures

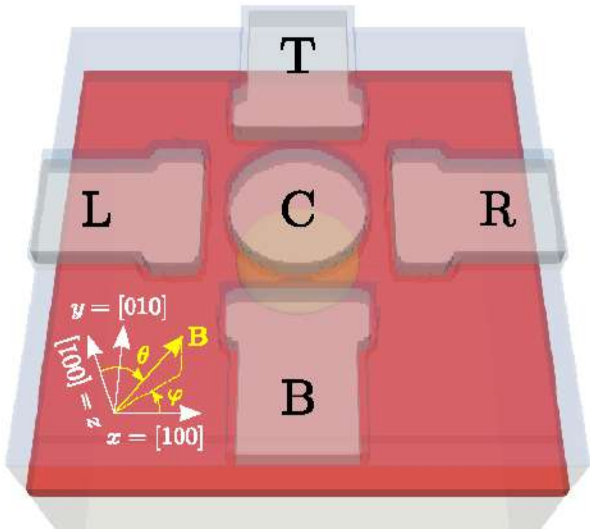

Figure 1: Simulated isotropic Ge quantum dot device.

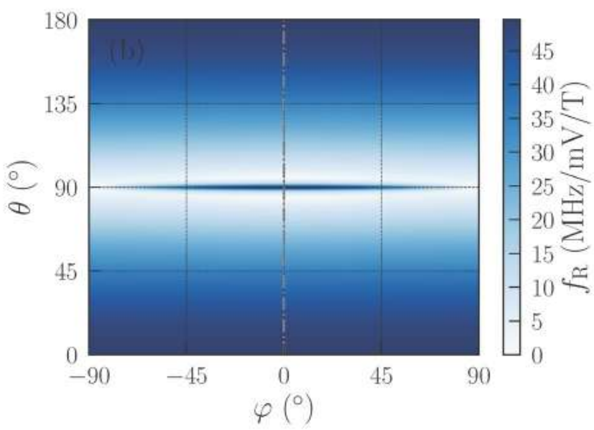

Figure 2: Pattern of Rabi frequencies as a function of magnetic field orientation.

Phase-space inequalities: certification of quantum correlations in the phase space

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The identification and characterization of nonclassical states of light is a central task in quantum optics and photonic quantum information. Nonclassicality as a resource is of major importance for quantum technologies, such as quantum metrology, communication, and entanglement generation. Therefore, it is crucial to develop efficient and experimentally accessible tools for the characterization of nonclassical light. One possibility of identifying genuine nonclassical features is using the framework of quasiprobability distributions. Alternatively, inequality conditions based on moments of observables can be used. We introduce a framework that unifies the certification of quantum correlations through quasiprobability distributions and inequality conditions [1]. In this way, we demonstrate a deep connection between correlation measurements and phase-space distributions and devise nonclassicality conditions which jointly exploit the advantages of both approaches. Our method correlates arbitrary phase-space functions at arbitrary points in phase space, including multimode scenarios and higher-order correlations [2].

In addition, we present experimental implementation of the introduced phase-space inequalities for nonclassicality certification [3]. We demonstrate the practicality and sensitivity of this approach by studying nonclassicality of a family of noisy and lossy quantum states of light.
To this end, we experimentally generate single-photon-added thermal states with various thermal mean photon numbers and detect them at different loss levels. Based on the reconstructed Wigner and Husimi Q functions, the inequality conditions detect nonclassicality despite the fact that the involved distributions are nonnegative, which includes cases of high losses (93%) and cases where other established methods do not reveal nonclassicality. We show the advantages of the implemented approach and discuss possible extensions that assure a wide applicability for quantum science and technologies.

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Implementation of Parallel Arbitrary Single-qubit Gates on High-qubit-count Processors Using a Truly Scalable Control Stack

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Controlling large quantum processors is an engineering challenge for the entire control stack, and simple steps like calibrating simultaneous single-qubit gates may become computationally prohibitive due to crosstalk and interaction between qubits, which requires characterizing and optimizing a number of combinations of gates (i.e., cycles [1]) that grows exponentially with the number of qubits.
In this talk we introduce the necessary hardware and software components of a truly scalable control stack, and we describe a practical methodology to calibrate parallel arbitrary single-qubit gates in large processors. The method uses parallel rabi oscillations experiments and state tomography to obtain high-tolerance X90 gates. The result can be fed into a fully customizable circuit compiler to create arbitrary single-qubit gates in any number of qubits in parallel (i.e., any arbitrary single-qubit gate cycle), using gate decomposition with virtual Z gates. The result can be tested using Cycle Benchmarking (CB) and K-body Noise Reconstruction (KNR), an advanced crosstalk analysis tool.

References

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Figures

Figure 1: A modular and scalable control system hardware

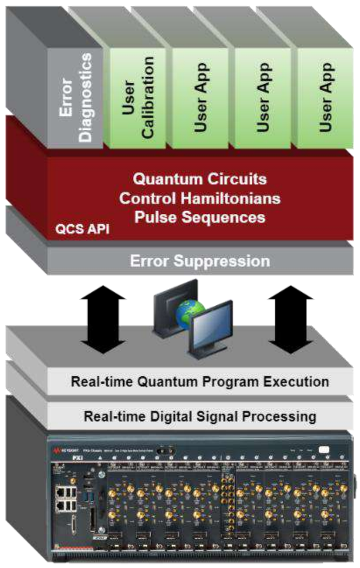

Figure 2: A software stack with custom gate decomposition linkers

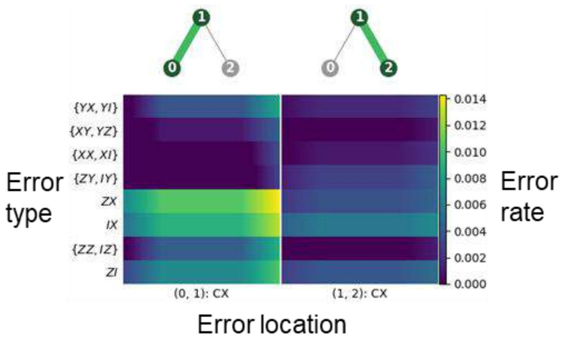

Figure 3: K-body Noise Reconstruction (KNR) example

Atomtronic circuits: From many-body physics to quantum technologies.

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Atomtronics is the emerging quantum technology of ma4er-wave circuits which coherently guide propaga:ng ultra-cold atoms. The field benefits from the remarkable progress in micro op:cs, allowing to control the coherent ma4er with enhanced flexibility on the micron spa:al scale. This way, both fundamental studies in quantum science and technological applica:ons can be carried out. I will sketch recent progress in ma4er-wave circuitry and atomtronics-based quantum technology. I par:cular, I will flash on possible applica:ons to a broad range of quantum technologies, from quantum sensing with atom interferometry to future quantum simula:on and quantum computa:on architectures.

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Enhancing atom-interferometric inertial sensors in dynamic environments using robust control

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We experimentally demonstrate tailored light pulses that improve the sensitivity of a cold-atom interferometric accelerometer. We designed and implemented these error-robust pulses in software using quantum control techniques to mitigate noise sources that can severely inhibit operation in dynamic environments inherent to onboard applications. Our results show that these robust pulse sequences improve the fringe visibility of an order-3 Bragg-pulse atom interferometer by a factor of 3X over conventional Gaussian pulses, using an atomic source with a broad momentum width of nearly two photon recoils. We also verified their scale factor through absolute measurements of Earth's gravity with 2X enhanced precision. Furthermore, when we introduced laser intensity noise that varied up to 20% from pulse-to-pulse to mimic the effect of lateral platform accelerations, our robust control solution preserved phase sensitivity while the utility of the Gaussian pulses collapsed. This improvement delivered a 10X increase in measurement precision of an applied acceleration. These results show for the first time that software-defined quantum sensing can preserve the useful performance in operating regimes where conventional operation is severely degraded, providing a pathway to augment the performance of current and next generation cold-atom inertial sensors in real fielded settings [1].

References

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Figures

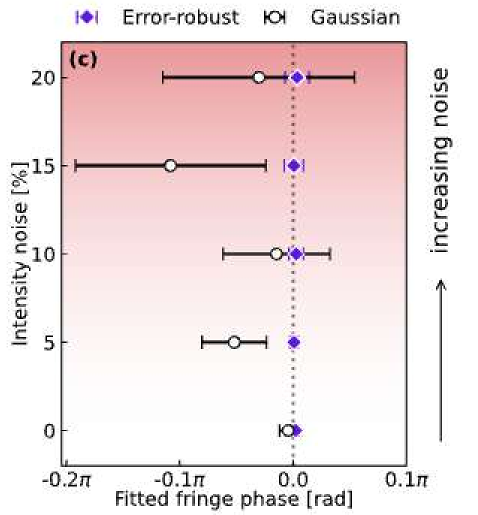

Figure 1: Measured phases of a T = 5 ms order-3 Bragg atom interferometer for different values of applied intensity noise using conventional pulses (black) and error-robust pulses (purple).

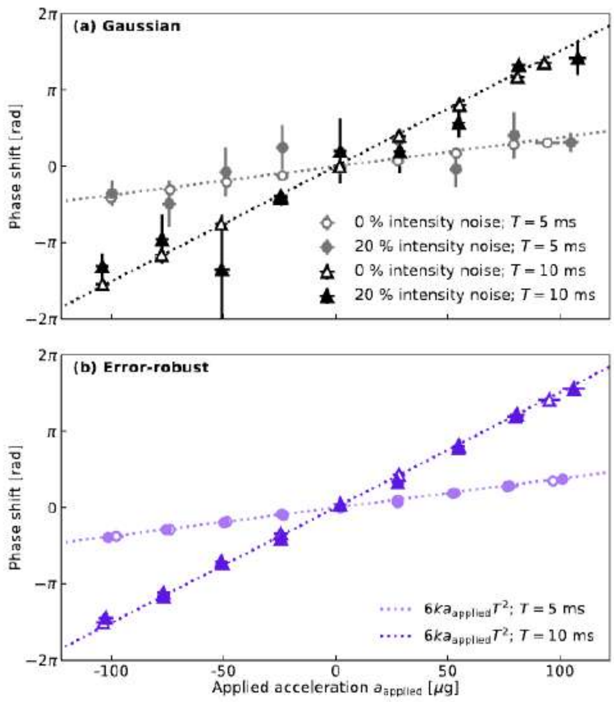

Figure 2: Measured phases of an order-3 Bragg atom interferometer for variable applied acceleration in the presence of 0 and 20% laser intensity noise, using conventional (black) and error-robust (purple) interferometer pulse sequences with T = 5 and 10 ms.

Quantum supremacy with many-body systems: Merging thermalization with complexity theory

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Abstract

Quantum supremacy is the ability for quantum computers/devices to efficiently solve a well-defined computational task that is guaranteed to be inefficient for classical computers. The most common task to realise quantum supremacy in near-term quantum devices is sampling from the output probability distribution, demonstrated with 53 superconducting qubits by Google[1]. Despite being able to outperform classical computers, sampling from a complex quantum system has very few direct useful applications. Early proposals for realizing quantum supremacy include boson sampling, random quantum circuits and 2D Ising models. We have managed to extend this family to include to driven many-body systems in analog quantum simulators settings. The work is based on complexity theory arguments and supports earlier intuitions and heuristic claims, that is indeed computational hard to simulate complex quantum dynamics. Our result opens the path for a multitude of analog platforms to showcase and benchmark quantum supremacy, including cold atoms, ions and superconducting qubits. The connection was made via showing that sampling from the output distribution of thermalizing driven many-body systems is #P hard and the hardness is connected with the quantum phase matter is in. Recently, in collaboration with USTC China, an experiment has been performed where some of our predictions were checked in cold atom setup [3].

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Figures

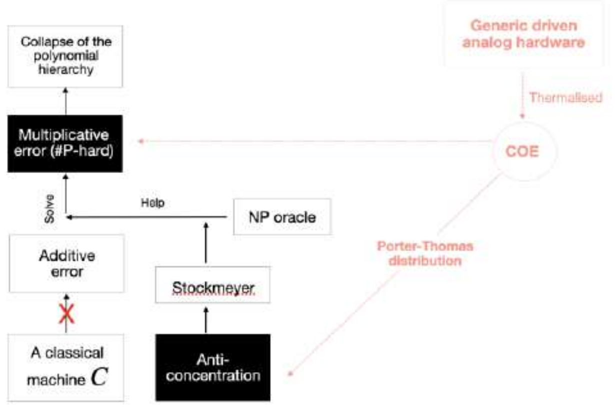

Figure 1: Sketch of the proof that is hard to sample from driven many-body systems

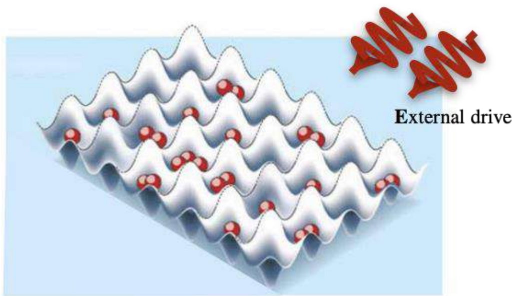

Figure 2: A driven optical lattice such as the one used in [3] to perform the experiment

Time-resolved energetic exchanges during a Ramsey sequence

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Understanding the energetic exchanges between individual quantum systems is an active field of quantum thermodynamics, crucial to analyse the energetic footprint of the developing applications in quantum information processing [1].
In this work, we study the work and heat exchanges between a quantum emitter (an artificial atom constituted by a semiconductor quantum dot) and the electromagnetic field. The quantum emitter is driven resonantly via the Ramsey sequence (two resonant, delayed pulses with $\pi/2$ driving areas), see Fig. 1. Within this excitation sequence, the quantum emitter exchanges work and heat with the vacuum of the electromagnetic field through spontaneous emission. Theoretically, it has been predicted that the work transferred corresponds to the unitary part of the interaction [2].
We propose an experimental protocol to time-resolve emitted work and heat along the spontaneous emission. Our experimental time-resolved approach exploits quantum interference on a beam-splitter in a homodyne configuration [3]. The work emitted by the atom is shown to be independent of the Ramsey phase. Conversely, depending on the Ramsey phase, one can reduce or enhance the heat transferred - a signature of increased emitter-light entanglement during the sequence.

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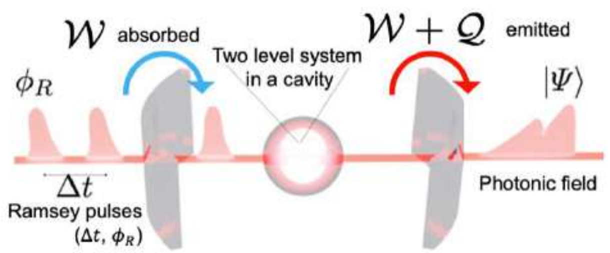

Figure 1: Sketch of the system: the classical drive provides work to the atom via the Ramsey sequence, and it emits heat and work into the photon field.

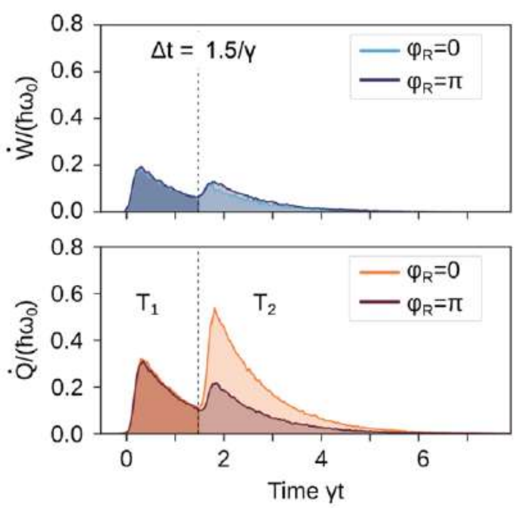

Figure 2: Variation of work (top) and heat (bottom) as a function of time (in units of γ=1/(190 ps)) for a 1.5/γ delay between Ramsey pulses and two different Ramsey phases φ_R=0 (light colors) and π (dark colors). T_1 [T_2] is the time bin between pulses [after the second pulse].

Andreev bound states along quantum Hall edges

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A supercurrent flow in a superconductor-normal metal-superconductor junction is made possible via resonances of normal charge carriers (electrons and holes): Andreev bound states, transmitting Cooper pairs in the superconductors. Engineering superconductivity in the quantum Hall regime is a promising route to create novel electronic states [1,2], but, in this regime different carriers move on opposite device sides which necessitates a tedious coupling between distant edges to achieve small supercurrents [3-5].
Here we present a new geometry where quantum Hall edge states are carried along narrow domain walls (DWs) at the centre of the device allowing localised Andreev bound states insensitive to the magnetic field [6]. At magnetic fields as high as 8 T, we observe Josephson coupling with relatively large critical currents. We find superconducting interferences between domain walls and Fabry-Pérot oscillations in individual DWs, effects attributed unambiguously to a 1D nature.
Such localised Andreev states may host non-trivial excitations and could be a platform for new devices and applications, such as SQUID magnetometers, Andreev qubits, CQUIDs of fluxon devices [7].

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Spin Cross-Correlation Experiments in Semiconducting-Superconducting Heterostructures

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Semiconducting-superconducting hybrid heterostructures provide an ideal system for investigating wide range of fundamental phenomena, for example to study unconventional Andreev bound states (ABSs) in multi-terminal Josephson junctions (JJs) [1] and demonstrate spin correlations in quantum mechanical systems. To this end, we have introduced ferromagnetic split-gates (FSGs) to individually polarize the electron spins in semiconducting InAs nanowire (NW) quantum dots (QDs) [2]. We then implement such spin filters in a Cooper pair splitting (CPS) device [3], an electronic device that emits electrons originating from Cooper pairs, to demonstrate the direct measurement of the spin cross-correlations [4] between the currents emitted from the 'splitting' of spin-singlet Cooper pairs. We find a negative spin correlation of -1/3, which deviates from the ideal value mostly due to the overlap of the Zeeman split quantum dot states. In addition, we show our progress towards implementing epitaxial Al-InAs JJs in a coplanar waveguide resonator for ABS spectroscopy. Our results demonstrate a new route to perform spin correlation experiments in nano-electronic devices, especially suitable for those relying on magnetic field sensitive superconducting elements, like triplet or topologically non-trivial superconductors.

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Advantages of Digital Qubit-Boson Hardware for Quantum Simulation of Lattice Gauge Theories

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Leading the next materials leap in quantum computing

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Majorana bound states in coupled quantum dots

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The creation and detection of Majorana-bound states in semiconductor-superconductor hybrids have been an outstanding challenge facing the condensed matter community for over a decade. This challenge is fueled both by fundamental scientific interest and the promise it holds for quantum computation. Conventional approaches to realizing Majorana-bound states face difficulties due to the demanding requirements for semiconducting quality. We adopt an alternative method for this problem by coupling quantum dots via a superconductor. The formation of this single unit cell of the Kitaev chain allows us to observe the presence of Majorana-bound states at fine-tuned values of the potential landscape. In this talk, I will provide an overview of the formation of the Kitaev chain and the underlying microscopic picture. I will also discuss the observed experimental signatures of the so-called "Poor man's Majorana" states and how to improve them..

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Observation of Universal Hall Response in Strongly Interacting Fermions

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The Hall effect, which originates from the motion of charged particles in a magnetic field, has deep consequences for the description and characterization of materials, extending far beyond the original context of condensed matter physics. Although the Hall effect for non-interacting particles is well explained, understanding it in interacting systems still represents a fundamental challenge even in the small-field case. Here [1] we directly observe the build-up of the Hall response in an interacting quantum system by exploiting controllable quench dynamics in an atomic quantum simulator, see Figure 1. By tracking the motion of ultracold fermions in a two-leg ribbon threaded by an artificial magnetic field, we measure the Hall response as a function of synthetic tunnelling and atomic interactions. We unveil an interaction-independent *universal* behaviour above an interaction threshold, in clear agreement with theoretical analyses [2-3]. Our approach and findings open new directions for the quantum simulation of strongly correlated topological states of matter.

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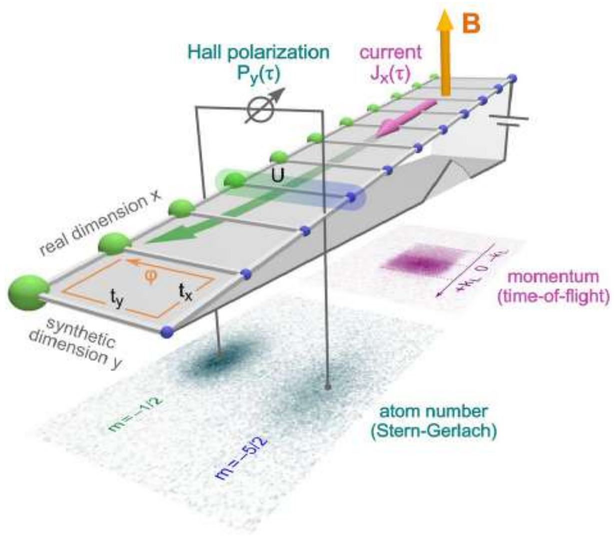

Figure 1: Scheme of the experiments. A synthetic ladder is realized by trapping fermionic ^{173}Yb atoms in a 1D optical lattice with direction $\hat{x}$ and coupling their nuclear spin states $m_{\mathrm{F}} = -1/2$ and $m_{\mathrm{F}} = -5/2$ via a two-photon Raman transition. The position-dependent phase of the Raman coupling simulates an effective magnetic field B described by an Aharonov-Bohm phase φ per unit cell. An atomic current is activated by suddenly tilting the ladder with an optical gradient, equivalent of equivalent to a constant electric field E_x. The growing (diminishing) size of the green (blue) spheres visualizes the leg population imbalance (Hall polarization) induced by the Hall drift. The time-dependent longitudinal current $J_x(\tau)$ and the Hall polarization $P_y(\tau)$ are measured with time-of-flight imaging and optical Stern-Gerlach detection, respectively (typical acquisitions are shown in the two images below the ladder).

Exciton transport in a germanium 4x2 ladder quantum dot array

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Quantum systems with engineered Hamiltonians can be used as quantum simulators of many-body systems to provide insights beyond the capabilities of classical computers [1]. Semiconductor gate-defined quantum dot arrays, owing to their in-situ tunability, are an ideal platform for quantum simulation [2]. Furthermore, the naturally-occurring long-range Coulomb interaction offers unique opportunities for exploring excitonic phenomena such as Wigner crystals [3] and excitonic insulators [4]. In this work, we fabricate a germanium 4x2 ladder quantum dot array and show important ingredients for excitonic simulation such as well-controlled chemical potentials and tunnel couplings as well as strong inter-channel Coulomb interaction. We tune the array into two capacitively-coupled channels and exploit Coulomb drag as a probe for exciton formation. As we decrease the bottom-channel potential while propagating carriers through the top channel using voltage pulses, a transition from single electron transport to exciton transport is observed. Our work paves the way to study excitonic state of matters in quantum dot arrays.

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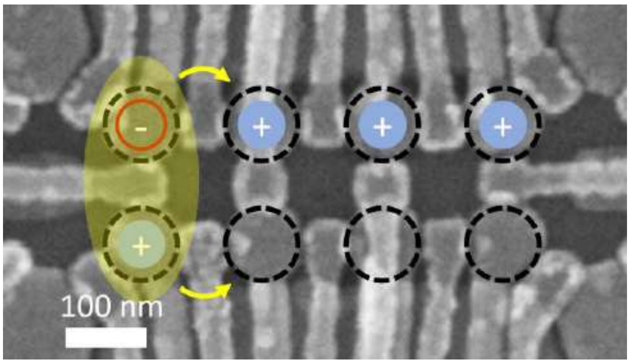

Figure 1: A scanning electron microscope image of a germanium 4x2 quantum dot array with a schematic showing excitonic transport. An electron (missing of a hole) is shuttled through the top channel and a hole in the bottom channel is dragged along because of the inter-channel Coulomb interaction.

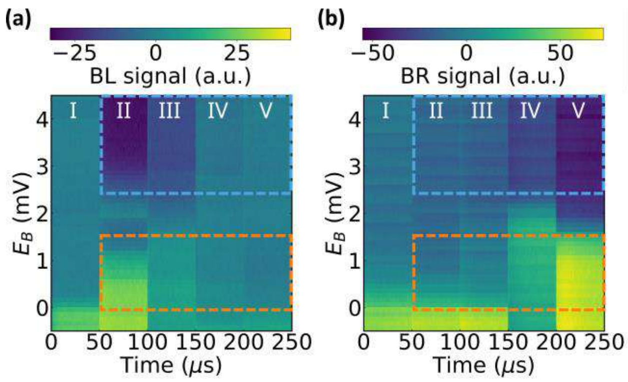

Figure 2: Coulomb drag measurement data. (a) Bottom-left and (b) bottom-right sensor signals as a function of time and energy offset of the bottom channel E_B. In the time domain from II to V an electron is shuttled in the top channel from left to right. As E_B decreases, a transition from single-electron transport (blue dashed region) to correlated electron-hole pair transport, i.e. exciton transport (orange dashed region), is observed.

Atomic-scale tomography of isotopically purified group-IV materials for qubit integration

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Electrostatically defined quantum dots in isotopically purified group IV quantum wells are one of the most promising qubit technologies [1, 2]. Their small size of a few 10nm and straightforward integration with CMOS-technology makes them the most promising candidates for the monolithic integration of qubits and classical bits and hence scalable hybrid classical-quantum computing systems [3, 4].
Mapping the distribution of the isotopes in the nano-structured materials used to fabricate these qubits is unfortunately challenging as the typical interactions utilized in common techniques like electron-, X-ray- or scanning probe microscopy are not sensitive to isotopes and hence cannot image isotopes in standard operation [5-7].
Here we show that Atom Probe Tomography can be used to probe isotopic purity in nanostructures down to the parts-per-million level and hence down to a level were the majority to of electrically defined silicon or germanium quantum dots are expected to contain one or less spin-full nuclei [8, 9].
Furthermore, the three-dimensional maps generated from detecting single atoms during Atom Probe Tomography, as exemplary shown in Figure 1, make it possible to evaluate the quality and topography of interfaces between layers of different material and different isotopic compositions at the sub-nm scale.
Finally, we will show that we can use the information gained from the atomic-scale tomography to seed models for quantum-simulations of the respective qubits [10].

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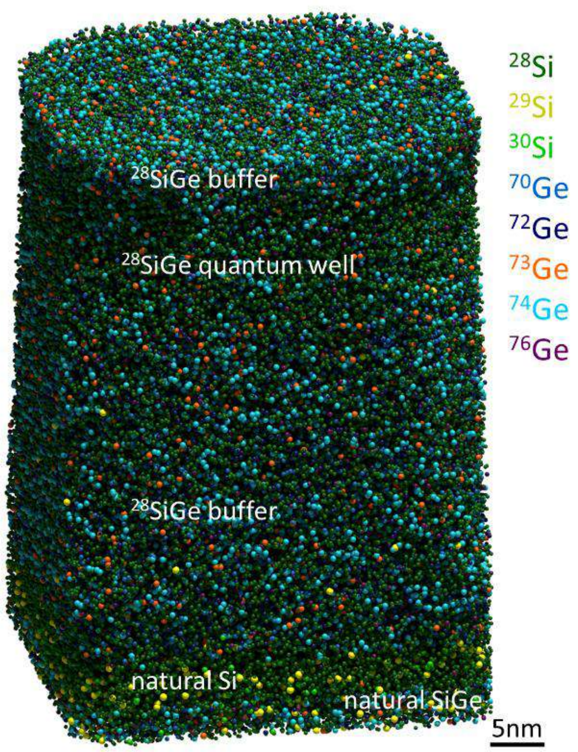

Figure 1: Atom Probe Tomography analysis of a quantum well grown sandwiched between silicon germanium buffers grown with ^{28}Si enriched Silicon.

Coherent coupling of two distant Andreev level qubits

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Andreev qubits are an emerging platform for quantum computation. These qubits utilize the discrete superconducting quasiparticle levels (Andreev levels) that appear in weak links between superconductors. The Andreev qubits combine the scalability of the superconducting circuits and a compact footprint. Until now, the experiments on Andreev qubits [1] and Andreev spin qubits [2] have focused on the manipulation and readout of single qubits. However, realizing universal quantum computation based on Andreev qubits requires connectivity between pairs of Andreev qubits that enables implementation of two-qubit gates.
Here, we experimentally study Andreev qubits in InAs nanowires with epitaxial Al. We demonstrate for the first time a non-local interaction over millimeter distance of two Andreev pair qubits, mediated by a novel microwave cavity architecture. This architecture is based on a molecular state resonator, that minimizes microwave leakage from the antisymmetric coupling mode to the readout circuit, but allows fast readout via the symmetric mode. We have observed parity switching in both qubits and, more importantly, Andreev state entanglement in the even parity case, paving the way for distant two-qubit gates based on Andreev qubits. We additionally demonstrate that the symmetry of the coupling mode is reflected in the symmetry of the entangled two-qubit state.

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Loophole-free Bell Inequality Violation with Superconducting Circuits

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Superposition, entanglement and non-locality constitute fundamental features of quantum physics. Remarkably, the fact that quantum physics does not follow the principle of local causality can be experimentally demonstrated in Bell tests performed on pairs of spatially-separated, entangled quantum systems. While Bell tests, which are widely regarded as a litmus test of quantum physics, were explored using a broad range of quantum systems over the past 50 years, only relatively recently experiments free of so-called loopholes succeeded. Such experiments were performed with spins in nitrogen-vacancy centers, with optical photons and neutral atoms. In this talk, I present a loophole-free violation of Bell's inequality with superconducting circuits[1], which are a prime contender for realizing quantum computing technology. To evaluate a CHSH-type Bell inequality, we deterministically entangle a pair of qubits[2] and perform fast and high-fidelity measurements along randomly chosen bases on the qubits connected through a cryogenic link[3] spanning a distance of 30 meters[4]. Evaluating more than one million experimental trials, we find an average S-value of 2.0747±0.0033, violating Bell's inequality with a p-value smaller than p = 10^{-108}.

Our work demonstrates that non-locality is a viable new resource in quantum information technology realized with superconducting circuits with potential applications in quantum communication, quantum computing and fundamental physics.

Figures

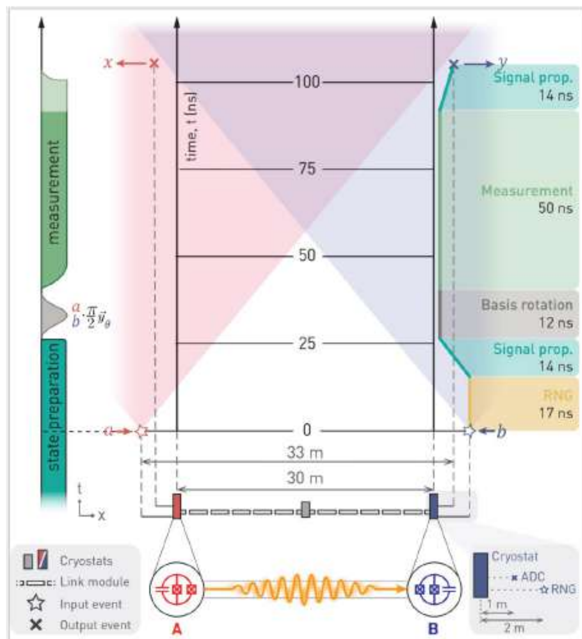

Figure 1: Space-time diagram of the setup. The vertical axis marks time and indicates the duration of the individual Bell test protocol segments (right) and applied MW pulses (left). The horizontal axis marks the spatial locations of the nodes (A and B) and relevant room-temperature devices (bottom right inset). The space-time locations of the start and stop events of a Bell test trial are marked with stars and crosses, respectively.

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Ultrafast Photodetectors for Quantum Circuitry Using Moiré Materials

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Twisted bilayer graphene has emerged as a versatile quantum material. By applying an electric field, conducting, insulating, superconducting and ferromagnetic phases are induced in the material. Electronic devices that exploit these phases include Josephson junctions [1,2] and single electron transistors [3], which are the building blocks for quantum circuitry. However, the optical and optoelectronic properties are not fully understood. In particular, the energy relaxation pathways remain unknown.

Here we study the relaxation of photoexcited carriers in twisted bilayer graphene. We report on a dramatic speed up in carrier relaxation for twist angles close the magic angle, which results in a picosecond response time from ambient to cryogenic (5 K) temperatures. [4] This enhanced response is due to a novel Umklapp-assisted electron-phonon scattering mechanism that is enabled by the moiré superlattice.

This work could give important insights into the role of phonons in superconductivity and lead to the development of ultrafast photodetectors for sensing applications that span the visible, infrared and terahertz spectra.

Figures

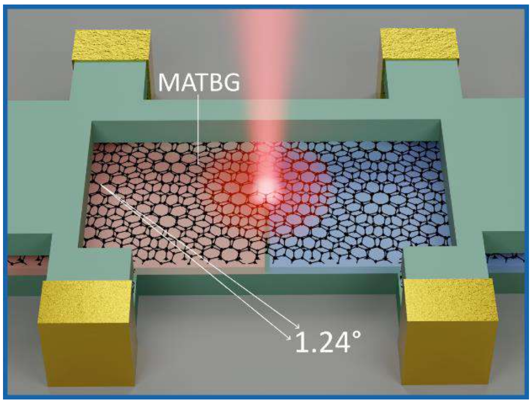

Figure 1: Illustration of the hBN-encapsulated MATBG device with twist angle 1.24°. We generate a photovoltage by illuminating the electrically defined pn-junction (±V, red/blue regions).

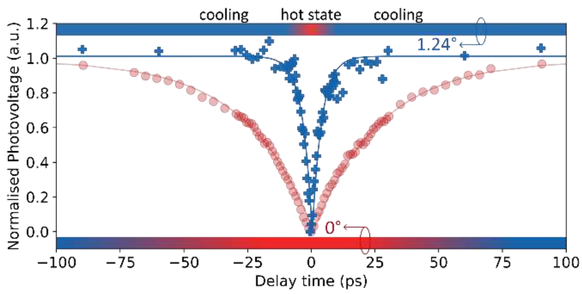

Figure 2: Controlling the time delay between two ultrafast pulses reveals the hot carrier cooling dynamics. At low temperatures, these are significantly faster in the case of MATBG (1.24°) than non-twisted BLG (0°).

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Topological amplification and perfect phase matching in a Josephson junction array with a non-local pump

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We propose a realization of a truly directional and broadband Josephson traveling-wave parametric amplifier (JTWPA) using a homogeneous array of Josephson junctions (JJ) coupled to an auxiliary array of linear superconducting resonators [1]. We send the strong pump on the auxiliary array, which distributes an effective non-local pump on all sites of the JJ array. Tuning the spatial dependence of pump's phase, we can compensate for the momentum mismatch due to the non-linear dispersion of the JJ array and thereby achieve perfect phase matching without dispersion engineering.

Moreover, the phase of the non-local pump breaks time-reserval symmetry, allowing the device to enter a topological amplifying steady-state phase [1,2]. In this regime, microwave signals are unidirectionally amplified along the JJ array with all back-reflections and backward noise exponentially suppressed. Moreover, due to the topological origin of the directional amplification, the gain grows exponentially with system size, and it is robust to large amounts of disorder. We characterize the performance of the topological JTWPA using state-of-the-art superconducting circuit parameters, showing that a device with N~30 sites is enough to surpass 30 dB of near quantum-limited amplification and -30 dB of isolation over a bandwidth of a GHz [1]. Our work opens the door to the scalable integration of the quantum processors with compact, directional, and broadband pre-amplifiers on the same chip.

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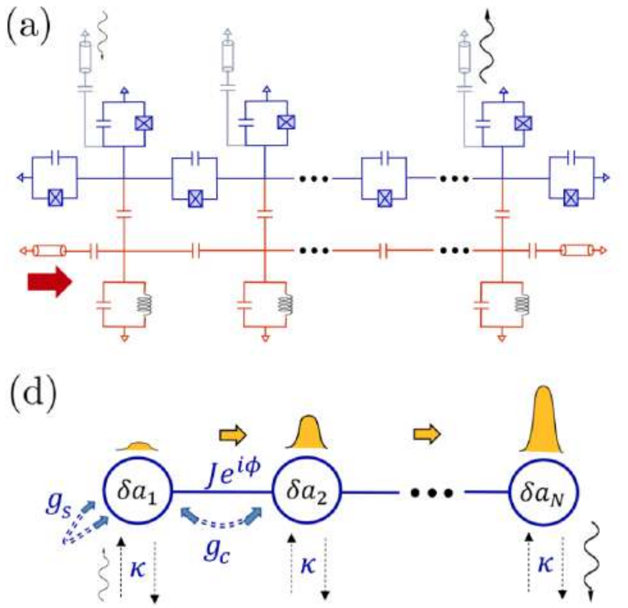

Figure 1: (a) Architecture for the realization of a superconducting topological traveling-wave parametric amplifier. It consists of a Josephson junction array (blue) coupled to a linear array of superconducting resonators (red).
(d) In the topological amplifying phase, the device amplifies unidirectionally and photons accumulate at one extreme of the chain.

Experiments on an entanglement-based quantum network in the lab

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Quantum networks promise the ability to distribute quantum-entangled states over large distances for the purposes of quantum communication, distributed and blind quantum computation, or quantum sensing. Recently, we have realized the first multi-node quantum network in the lab, combining remote quantum photonic links with small quantum processors containing a diamond NV centre communication qubit and a carbon-13 memory qubit[1]. This network can serve as a testbed for control stack development and for exploring quantum network protocols. As an example, quantum teleportation between two non-neighbouring stationary nodes was recently demonstrated[2].

In this talk, we will report on the exploration of more network protocols using NV centres in diamond that are important for scaling quantum networks. We will discuss some of the underlying physical layer and control layer challenges, and our approach to solving these. This work will build up on the detailed study on factors that affect both the rate and fidelity of the quantum-entangled state between two distant qubits[3].

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Short-range interactions generating massive multipartite entanglement for metrology

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Multipartite entanglement is the key resource to push quantum metrology beyond the standard quantum limit imposed on systems of uncorrelated particles; and to explore the ultimate limits of measurement precision. Multipartite entanglement can be very effectively generated by infinite-range interactions among particles — yet the latter are literally realized only by coupling atoms (real or artificial) to a cavity mode; otherwise they can be effectively realized with contact interactions, but only in small atomic ensembles trapped in one or few spatial modes. Identifying entangling mechanisms beyond the infinite-range interactions is therefore of greatest interest, in order to use the native interactions in any quantum device as a resource

Here we focus on time-independent many-body Hamiltonians for qubits and qudits; and we theoretically show that massively entangled states possessing scalable spin squeezing, can be generated by power-law interactions, as well as by genuinely short-range ones. This is achieved either via quantum quenches [1-3], or by driving the system with an external field [4]. Scalable squeezing rests upon an effective dynamical decoupling between collective spin degrees of freedom and spin-wave ones [3], giving rise to a dynamics analog to that of the infinite-range models; or it can rely on spontaneous breaking of a continuous symmetry, which allows a driving field to achieve scalable squeezing even when pushed to very small values [4]. These protocols open the route to achieve scalable squeezing in a vast range of quantum devices, including Rydberg-atom and trapped-ion arrays, superconducting-qubit arrays, or optical-attice atomic clocks.

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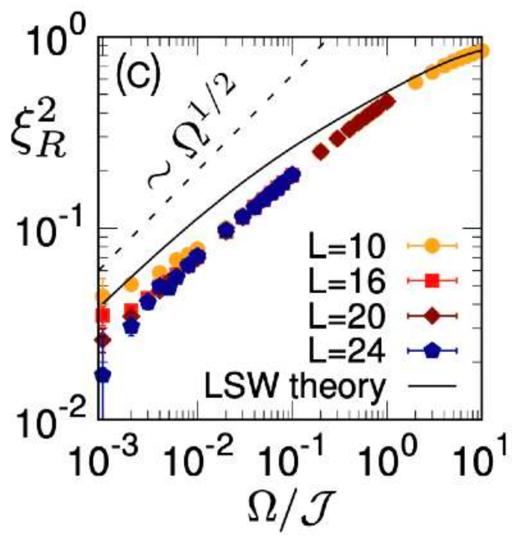

Figure 1: Scalable squeezing (y axis) obtained from driving adiabatically with a Rabi field (x axis) a system of neutral atoms in an optical lattice, realizing the two-dimensional Heisenberg model. Figure taken from Ref. [4].

Bulk current flow in a quantum anomalous Hall insulator

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Theoretical and experimental studies suggest that the quantum anomalous Hall (QAH) system hosts a chiral edge mode (CEM) [1, 2, 3]. The general understanding in the field has been that non-equilibrium current—current flowing in response to applied source-drain bias—flows through the CEM. Here, we measure the potential at multiple locations in a QAH device while elevated temperature is used to induce nonzero but small longitudinal resistance. We show that the potential is well-described by solution of Laplace's equation. Our measurements imply that non-equilibrium current flows primarily through the two-dimensional bulk, not along the edge. Extrapolation suggests that this picture holds at even lower temperatures current where the resistance is vanishing [4].

While non-equilibrium current may not flow around the edges of a device, the CEM is expected to carry circulating persistent current. Yet persistent current is difficult to observe in transport measurements. We argue that persistent currents can be studied using emulations of Chern insulators created in Bosonic quantum simulators. Using numerical techniques, we show that chiral edge states can be created in Bosonic quantum simulators, and we study how edge states form persistent current.

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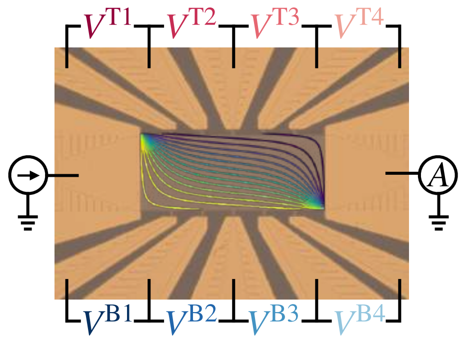

Figure 1: An optical micrograph of the QAH Hall bar studied in this work. Eight longitudinal resistance measurements are indicated. A solution of Laplace's equation is superimposed on the Hall bar, matching resistance measurements.

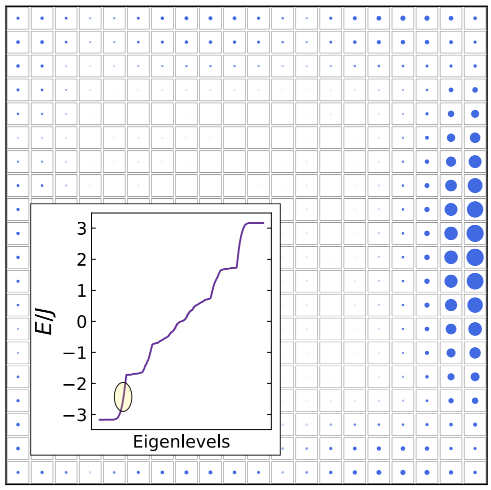

Figure 2: A single-photon chiral edge wavepacket in a simulation of a 20-by-20 qubit Chern lattice, constructed as a superposition of 8 edge states. The size of the blue dots represents the population on each site. *Inset*: The eigenspectrum of the qubit lattice. The states from which the wavepacket is constructed are highlighted in yellow.

Fine-tuned Majorana states in quantum dot systems

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Majorana bound states are quasi-particles with non-abelian statistics that are highly desirable for fundamental research and potential applications in quantum computing [1]. The Kitaev model predicts that these states can appear at the ends of quantum dot-superconductor chains [2]. Recently, a two-site version of such a chain has been reported [sketch in Fig. 1(a)], where non-topological Majorana bound states may appear at a "sweet spot" in the system's tuning [3]. We analyse the problem from the theory side, including many-body interactions, absent in the early studies [4]. We show that high and poor quality Majorana states can appear in the system for different configurations. We developed ways to distinguish between these two states using transport measurements. We also propose experiments to show their non-abelian exchange properties [5], a main challenge in the field.

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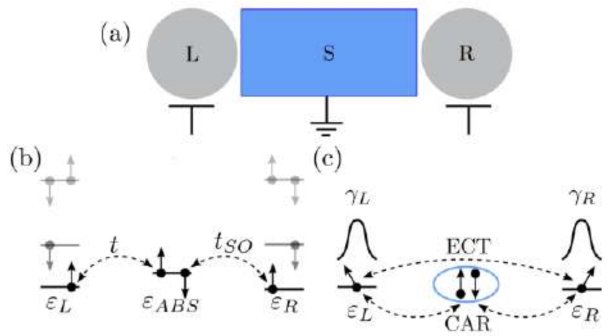

Figure 1: (a) Minimal setup to obtain Majorana states, formed by two quantum dots coupled via a superconductor. (b) Energy sketch of the system, where the middle region hosts an Andreev state. (c) Sketches for cross Andreev (CAR) and elastic cotunneling (ECT) processes, whose amplitudes are equal at the Majorana sweet spot.

Multiplexed continuous-variable quantum communication in the presence of inter-mode cross talk

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Multiplexing of quantum signals can be a feasible and efficient way for improving performance of quantum communication. However, the method can be limited by the presence of inter-mode cross talk, leading to noise from adjacent quantum modes. We consider the effect of linear cross talk in continuous-variable quantum entanglement and key distribution and show that it imposes restrictions on the initial entangled resource to be shared or, equivalently, on the modulation depth of quantum key distribution. Furthermore, the protocols become more sensitive to channel noise if the cross talk between the signals is present. The necessity in optimization of the initial resource is clearly seen in Fig. 1, where distributed entanglement and tolerable channel noise are given with respect to the state variance at different levels of cross talk.
We also propose the method of cross talk compensation by optimized coupling of the multiplexed modes prior to their detection or use of entanglement, as shown in Fig. 2. Such method allows full or partial reconstruction of the entangled resource or efficiency of quantum communication. We show that it is no less efficient than the optimal feed-back control, while preserving the mode structure [1]. Importantly, the method can be equivalently realized on data in the post-processing stage [2], enabling drastic improvement to performance of multiplexed quantum communication.

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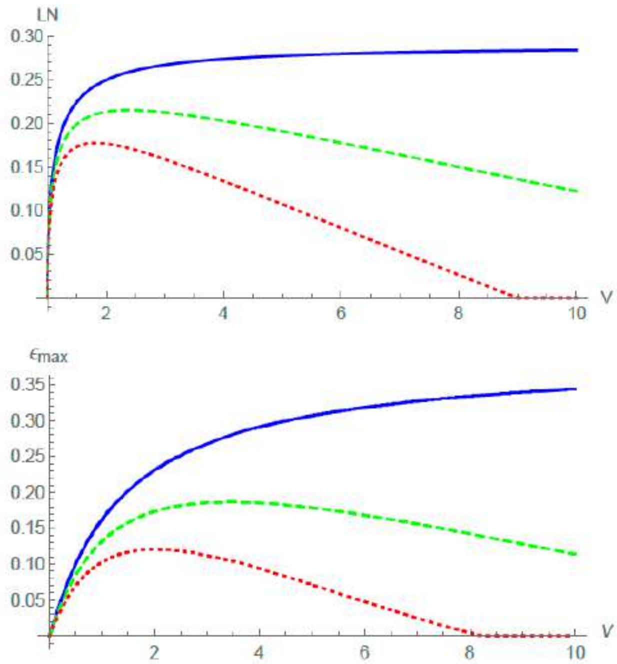

Figure 1: Logarithmic negativity (upper plot) and maximum tolerable channel noise (lower plot) in multimode quantum communication with respect to the variance of the initial entangled state (in case of entanglement distribution) or modulated signal (in quantum key distribution) in the presence of linear cross-talk coupling of 0.9 (green dashed lines), 0.8 (red dotted lines), compared to the absence of cross talk (blue solid lines).

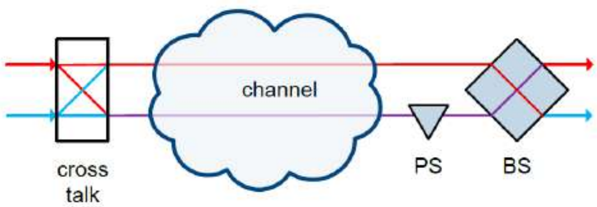

Figure 2: Compensation scheme for linear cross talk between two modes, based on a variable phase-shift (PS) and a beamsplitter (BS). Decoupled modes are then available for use in the entanglement-based schemes or for measurement in the prepare-and-measure quantum communication.

A Qubit Platform Assembled Atom-by-Atom on a Surface

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In recent years the combination of electron-spin resonance (ESR) and scanning tunnelling microscopy (STM) resulted in a breakthrough in the manipulation and detection of the quantum state of individual electrons localized in atoms or molecules. [1,2] Using an ESR-STM, functional structures of a few (~3 to 10) atoms can be built on ultraclean surfaces with atomic precision, leading to systems with well-define interactions (Figure 1).

In this work, we demonstrate for the first time how to utilize atoms hosting single electron spins (S=1/2) to build a structure with quantum functionality. [3] We first characterize the quantum states of the system using continuous-wave ESR. As a result, we are able to determine the coherence time (T_2-time) and demonstrate efficient driving on the quantum states, resulting in Autler-Townes doublets or dressed states. We further demonstrate pulsed operation by visualizing Rabi oscillations in the system. Finally, using pulsed ESR, we demonstrate a universal two-qubit gate set in this architecture with a fast (~20 ns) control-NOT gate (Figure 2).

Our results serve as proof-of-concept that functional quantum coherent structures can be built at the atomic scale – true to Feynman's 1959 vision that there is *"plenty of room at the bottom"*.

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Figures

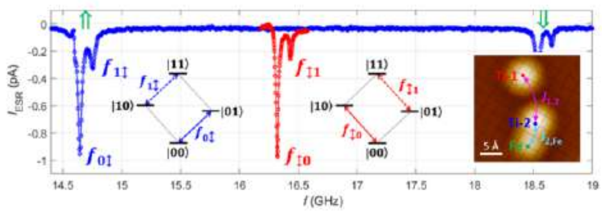

Figure 1: Characterization of the system using CW-ESR spectroscopy. The system is constructed atom-by-atom as shown in the inset.

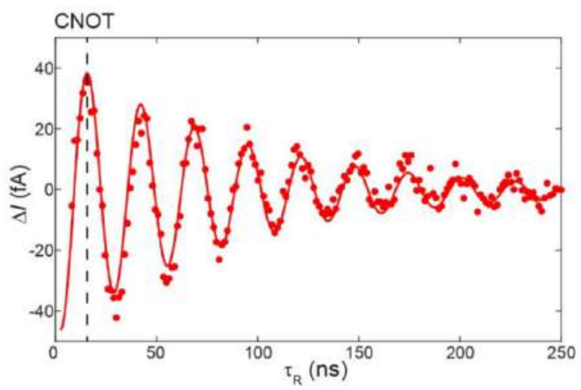

Figure 2: Rabi oscillations demonstrating coherent manipulation of two quantum states. The dashed vertical line indicates the typical time to perform a CNOT gate in our system

Quantum advantage by filtering in optical metrology

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Quantum metrology is the field of using quantum states to accurately estimate unknown quantities, such as magnetic and gravitational fields, distances or time. Often, one cannot measure probes as fast as one can create them. This can lead to detector saturation and information loss. To mitigate this issue, we design a filter to distil all information from many probes into few.

The ability to, via measurements, estimate an unknown parameter θ encoded in N probes, $\rho_\theta{}^{\otimes N}$, is quantified by the quantum Fisher information $\mathcal{I}(\theta|\rho_\theta{}^{\otimes N})$. The quantum Fisher information lower-bounds the variance of every unbiased estimator θ_e of θ via the Cramer-Rao bound: $\mathrm{Var}(\theta_e) \geq 1/\mathcal{I}(\theta|\rho_\theta{}^{\otimes N})$. We show that the quantum Fisher information about θ encoded in $\rho_\theta{}^{\otimes N}$ can be compressed into $\rho_\theta^\star{}^{\otimes M}$, where $M \ll N$ [1]. Moreover, M/N can be made *arbitrarily* small, and the compression can happen *without loss* of information [2].

We experimentally deploy our theory to improve quantum-metrology methods for polarimetry, a common task in optics. We use single photons to probe the strength, θ, of an unknown polarisation rotation. (See Fig. 1.) Direct measurements of the probes yield 1 unit of Fisher information per detected photon. By designing a distillation filter we increased this to >200 units per detection [3]. Thus, our input source could operate at 200 times the detector's saturation intensity, dramatically reducing our θ-estimate's variance. (See Fig. 2.)

The ability to perform this information distillation, we show, stems from nonclassical negativity in a quasiprobability representation of quantum metrology. We demonstrate, theoretically and experimentally, that the more negativity a filter introduces in the quasiprobability representation, the larger the distilled quantum Fisher information can be. Our methods can be used in diverse quantum metrology settings. Even if multiple parameters of $\rho_{(\theta_1,\ldots,\theta_N)}$ are unknown, a filter can be designed to harness negativity and boost the Fisher information per detection.

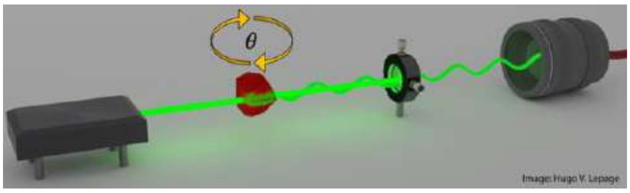

Figure 1: Artistic depiction of our filtered metrology protocol.

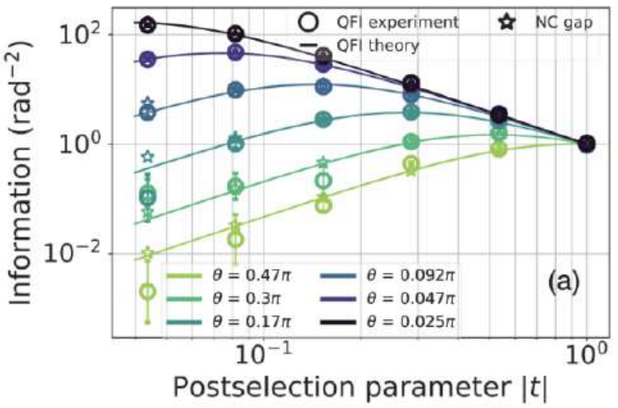

Figure 2: The Fisher information per detected photon vs. the filter's transmission amplitude $|t|$. When no filtering takes place ($|t| = 1$), the detected photon carries 1 unit of information. Using negativity-boosted filtering, we increase this to >200 units of information per detected photon. The success of the compression is sensitive to the filter settings; this figure shows the data obtained with a filter optimised for $\theta \approx 0$. When $\theta \geq 0.17\pi$, the filter can be detrimental.

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Certified randomness in tight space

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Reliable randomness is a core ingredient in algorithms, simulation and cryptography. The outcomes of measurements on entangled quantum states can violate Bell inequalities [1], thus guaranteeing their intrinsic randomness, which constitutes the basis for certified randomness generation [2]. However, this certification requires several spacelike separated devices, making it unfit for a compact apparatus [3]. Here we provide a general method for certified randomness generation on a small-scale application-ready device and perform an integrated photonic demonstration combining a solid-state emitter and a reconfigurable glass chip. In contrast to most existing certification protocols, which in the absence of spacelike separation are vulnerable to loopholes inherent to realistic devices [4], the protocol we implement accounts for information leakage and is thus compatible with emerging compact scalable devices. We achieve the highest standard in randomness with a 2-qubit photonic device cut out for real-world applications. We demonstrate a 94.5-hour-long stabilized process harnessing a bright and stable single-photon quantum-dot based source, feeding into a reconfigurable photonic chip. Using the contextuality framework [5], we robustly certify the highest standard of private randomness generation, i.e. cryptographic security even in the presence of quantum side information. This is a prototype for the controlled alliance of quantum hardware and protocols to reconcile practical limitations and device-independent certification.

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Figures

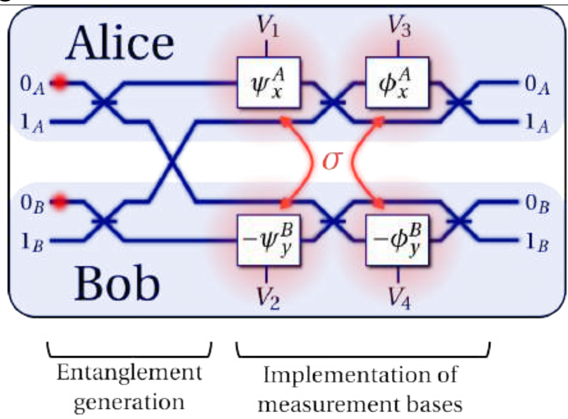

Figure 1: On-chip Bell inequality violation: two dual-rail encoded qubits are entangled via beamsplitters and a swap, and measured in different bases, selected via thermo-optic phase shifters. σ represents the information leakage e.g. crosstalk between the two parties.

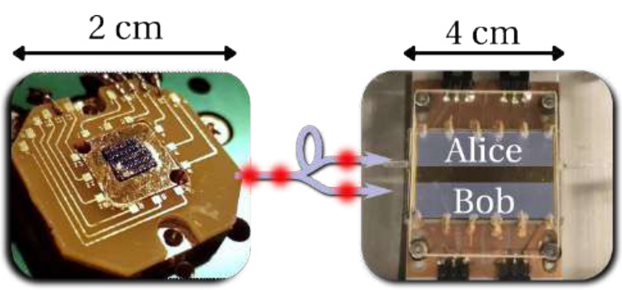

Figure 2: The quantum-dot device generates single photons sent to the photonic glass chip.

State-of-the-Art Measurement Capability for the Characterisation of Materials for Quantum Technologies

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Abstract

The talk will showcase our measurement capability associated with the 4-probe scanning tunnelling microscope (STM) for the research and applications of materials for quantum technologies, at scales ranging from several micrometres down to individual atoms. In particular, STM work carried out to verify the positional accuracy of individual ions implanted in target substrates for quantum technology applications, electrical transport measurements on monolayer quantum materials, and spatially resolved mapping of electronic properties at the atomic scale will be presented. These studies highlight the multi-probe STM method as a suitable means to investigate a range of material properties, fundamental to the development of quantum devices of the required complexity for quantum technology applications.

Figures

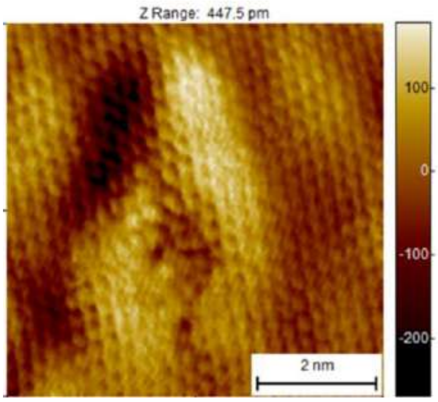

Figure 1: Atomically resolved ion implantation site on graphene on silicon carbide

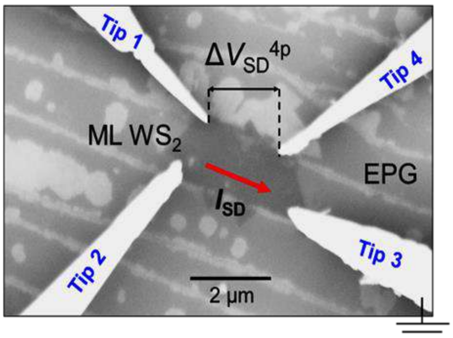

Figure 2: Scanning electron microscope image depicting 4 STM tips on a monolayer tungsten diselenide to measure its resistance

Noise Robust Error Mitigation

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ADR based sub-Kelvin cryostats for applied quantum technologies

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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 adiabatic demagnetization refrigeration (ADR) based sub-Kelvin cryostats[1] specifically developed for the characterization and operation of quantum devices. We address how known challenges of ADR systems such as limited hold time and magnetic stray fields can be overcome. Specifically, 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 taking advantage of the solid-state nature of ADR to cool samples from room temperature to 100 mK in less than 3 hours, as shown in Figure 2. Finally, we show how these novel tools can be used to study low-temperature characteristics of, e.g., superconducting films and resonators.

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Figures

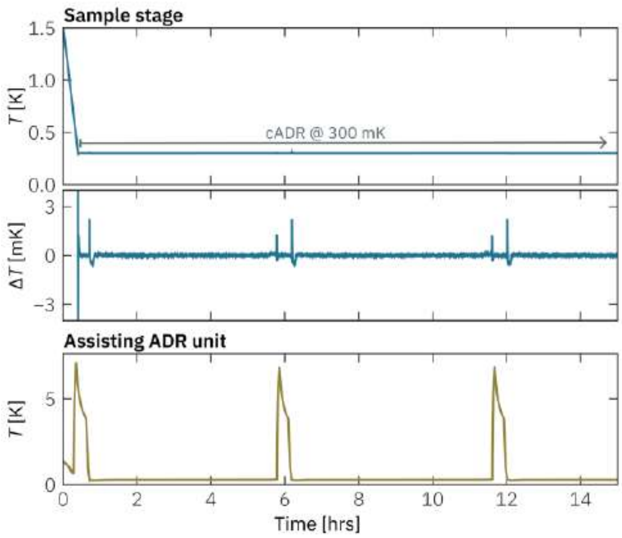

Figure 1: Accurate temperature control of the sample stage during continuous ADR (cADR) cooling. The temperature T of the sample stage and its stability ΔT are shown. The assisting ADR unit recharges automatically during operation.

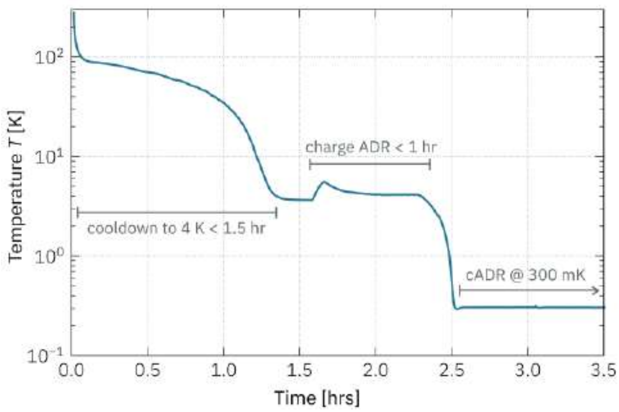

Figure 2: Cooldown curve of a sample from room temperature to continuous operation at 300 mK.

A control system for driving dynamic circuits on atom and ion based quantum processors using camera and photodiode-based readout

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Abstract

Atom- and ion-based quantum computing platforms enjoy many advantages, such as high scalability and state-of-the-art fidelities, but suffer from slow readout compared to qubit driving timescales. This limits the possibility of performing mid-circuit measurements, quantum error correction schemes, and lowers the number of achievable circuit layer operations per second (CLOPS). Feedback based on cameras typically suffers from high latency, limited by atom/ion exposure times, camera frame transfer rates, as well as the control system's latency, which limits current systems to readout rates below 100Hz.

Here we show a user-programmable FPGA-based control system designed for executing dynamic circuits on ensembles of trapped atoms and ions, and present an optimistic path toward kHz readout rates for atom- and ion-based processing units. We demonstrate camera and photodiode readout and real-time processing while maintaining the controller's residual latency below 100us, negligible compared to common atom/ion exposure times and camera frame transfer rates.

The users can program complex sequences of gates interlaced with mid-circuit camera/photodiode readout, image processing and arbitrary calculation. Sequences allow for branching, and sub-μs waveform synthesis latencies for atom/ion transport, and qubit driving. Users can preserve defect-free sorted arrays by replacing lost atoms from a reservoir, rather than re-instantiate the whole array for each shot, allowing for higher CLOPS and increased overall system bandwidth. The system supports multiple regions of operation, allowing to separately configure qubit arrays, atom reservoirs, and detection and excitation regions complete with atom shuttling between them.

The proposed control system allows to quickly elevate disordered arrays of atoms and ions into managed QPUs capable of executing dynamic circuits, meshing gates, measurements, atom transport, and real-time processing for next-generation atom- and ion-based devices.

Deterministic Storage and Retrieval of Telecom Quantum Dot Photons Interfaced with an Atomic Quantum Memory

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A hybrid interface of solid-state single-photon sources and atomic quantum memories is a long sought-after goal in photonic quantum technologies [1]. The storage and retrieval of single photons on demand is a key requirement for merging disparate quantum systems into large-scale hybrid quantum networks capable of supporting the future quantum internet [2]. Here we demonstrate deterministic storage and retrieval of photons from a semiconductor quantum dot in an atomic ensemble quantum memory at telecommunications wavelengths. We store single photons from a InAs quantum dot [3] in a high-bandwidth rubidium vapour based quantum memory [4], with a total internal memory efficiency of (12.9 ± 0.4)%. The signal-to-noise ratio of the retrieved photons is 18.2 ± 0.6, limited only by detector dark counts. This represents a significant step towards the goal of an efficient hybrid quantum light-matter interface, pivotal for developing future quantum technologies.

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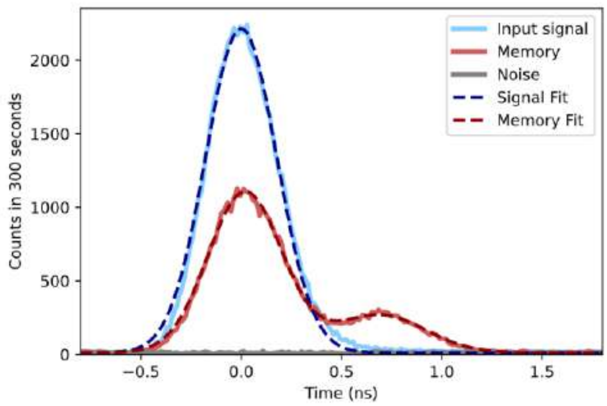

Figure 1: Histogram showing the arrival time of quantum dot photons through the quantum memory when the memory is turned off (blue) and with the memory on (red), indicating storage and retrieval 800ps later.

Photonic indistinguishability of the tin-vacancy centre in diamond

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Indistinguishable photons from quantum emitters provide a fundamental resource for scalable quantum communication. The tin-vacancy centre in diamond provides a promimsing platform for their generation due to its intrinsic insensitivity to electric fields, enabling integration into nanostructures, such as photonic crystal cavities [1-2]. Recent work has shown control of the tin-vacancy qubit [3] as well as transform-limited linewidths [4].

We present measurements of the indistinguishability of photons emitted from a tin-vacancy centre [5]. In particular, we report the generation of single photons with 99.7% purity and 63(9)% indistinguishability from a resonantly excited tin-vacancy center in a single-mode waveguide. We further showcase quantum control of the optical transition with 1.71(1)-ns-long π pulses of 77.1(8)% fidelity and show that it is spectrally stable over 100 ms..

A high-purity high-efficiency source of indistinguishable photons opens the door to measurement-based quantum computation and information through multi-photon entanglement resources [6, 7].

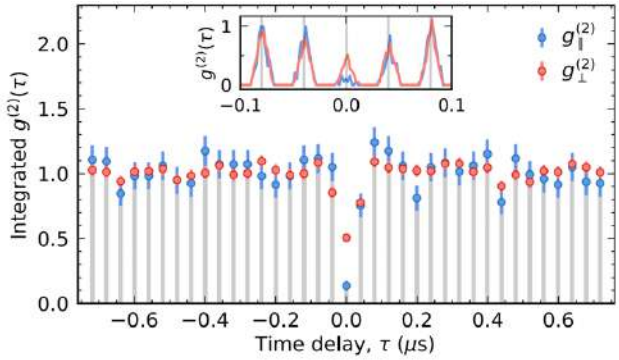

Figure 1: Pulsed two-photon interference measurement for photons with parallel (blue) and perpendicular (red) polarisations (a). Inset: time-resolved distribution of coincidences around τ = 0.

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Investigation of optimal operating point for hole spin qubit

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In the scope of building quantum processors, enhancing quantum bit operation speed and coherence time is of crucial interest.
Hole spin qubits in semiconductors have emerged as a promising candidate thanks to the possibility to perform electrically-driven spin control via their intrinsic spin-orbit interaction. [1] When a spin qubit is coupled to an electrical field, however, it is inherently sensitive to charge noise. A recent experimental study demonstrated the evidence of operational sweet spots minimizing the impact of charge noise and leading to an enhanced hole-spin coherence time [2]. Based on theoretical calculations, it should be possible to find sweet spots where qubit coherence and qubit driving speed are simultaneously maximized, resulting in a regime of so-called reciprocal sweetness [3].
Here we present a first experimental study addressing this possibility in a Si-MOS device made in a foundry-compatible fabrication platform. For a single hole spin, we first measure the angular dependence of the longitudinal spin-electric susceptibility (LSES), which measures the sensitivity to charge noise. We find the existence of sweet line of zero LSES as theoretically predicted [3]. We then investigate the correlation between this angular dependence and that of the qubit Rabi frequency.

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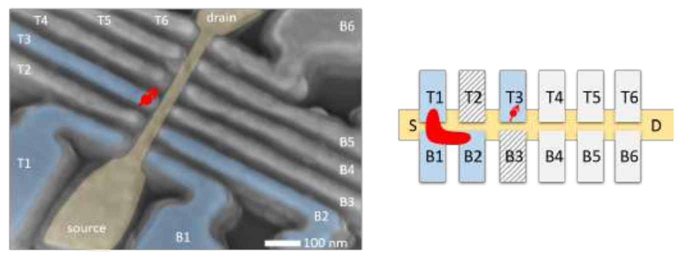

Figure 1: Left panel: false-coloured SEM picture of Si-MOS device showing the silicon nanowire (yellow), and the 6 split-gates on top. Light-blue gates indicate that there are accumulated with charges. The hole spin qubit lies below gate T3. Right panel is a simplified cartoon of the device with corresponding colours. Additionally, red shape illustrates the charge reservoir used for single-shot spin readout.

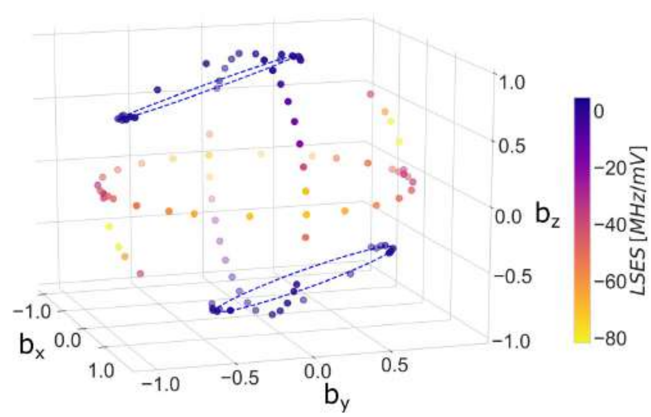

Figure 2: Longitudinal Spin Electric Susceptibility (LSES) as a function of magnetic-field orientation. Purple points correspond to LSES~0 MHz/mV, highlighting insensitivity to charge noise.

Detection of single ions in a nanoparticle coupled to a fiber cavity

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Rare earth ion-doped crystals constitute a promising platform for quantum information processing and networking. They feature exceptional spin coherence times to store information, narrow optical transitions to act as an interface to optical photons, and possibilities to realize quantum gates between single ion qubits through electric dipole interactions. As with other quantum emitters, by coupling them to optical cavities we can channel their emission into the cavity mode while also decreasing their emission lifetime, which allows for efficient and high-rate spin-photon interfaces to be realized.

In order to detect single ions, the total number of ions interacting with the cavity mode must be kept small enough to guarantee spectral distinguishability. At the same time, high ion densities are desired to increase interaction strengths between ions for the implementation of gates. These two requirements motivate us to confine all the ions in a volume as small as possible, which in previous demonstrations has been limited by the optical mode to an order λ^3.

In this work we demonstrate the first detection of single rare earth ions in nanoparticles—a novel material in which the ions are concentrated in a volume over two orders of magnitude smaller than in previous realizations. We couple these nanoparticles into a high-finesse open fiber microcavity which allows for complete tunability both in space and frequency, and as a result observe a 120-fold shortening of the emission lifetime. We report the detection of individual spectral features presenting saturation of the emission count rate and linewidth, as expected by two-level systems, and confirm their single-ion nature by showing that the second-order autocorrelation function of the emitted light is consistent with our expectation for a perfect single photon emitter (Fig. 1). These results pave the way towards photonically networkable quantum information processing nodes based on single rare earth ions.

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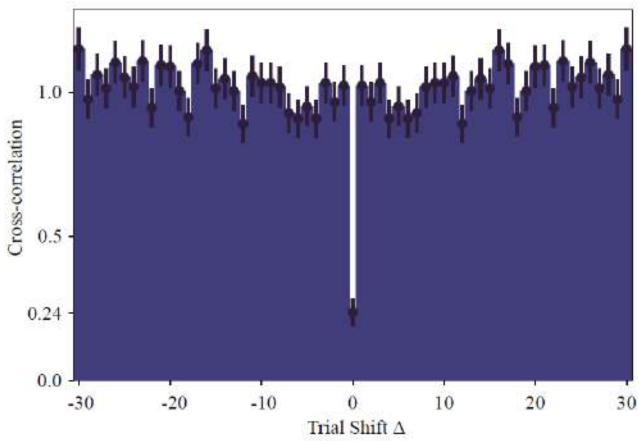

Figure 1: Autocorrelation function of the light collected from the cavity, showing a clear antibunching dip at zero delay. The value at zero delay is compatible with the observed signal-to-noise arising from the dark counts of the detectors.

Magnetically mediated hole pairing in fermionic ladders of ultracold atoms

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The Fermi-Hubbard model is of great interest in the study of strongly correlated electronic materials, such as high-temperature superconductors, where electron-electron (or hole-hole) interactions play a vital role in determining the material properties. In our experiment, we perform quantum simulation of the Fermi-Hubbard model using ultracold ^{6}Li atoms in optical lattices. Quantum gas microscopy enables us to directly study high order, spatially resolved spin and charge correlations of the resulting many-body states.

Here I will present our recent experiment in which we observed hole-hole pairing that is mediated by magnetic correlations [1]. To achieve this, we engineer antiferromagnetic mixed dimensional ladders where an additional potential offset between neighboring legs suppresses the interchain tunneling, while simultaneously enhancing the spin exchange and singlet formation [2]. Our observations reveal that the holes in this system prefer to occupy sites on the same rung of the ladder, resulting in a decrease in pair size and an increase in binding energy, which we extracted to be on the order of the superexchange energy. Furthermore, we detect the formation of spatial structures consisting of pairs of hole-pairs, indicating repulsion between bound hole pairs. Our work provides insights into the pairing mechanism that is conjectured to occur in many unconventional superconductors [3]. I will also discuss the recent technical upgrade of our optical lattices, that allows us to now realize larger and colder systems and possibly explore strongly correlated phases in low-temperature region of the Fermi-Hubbard model.

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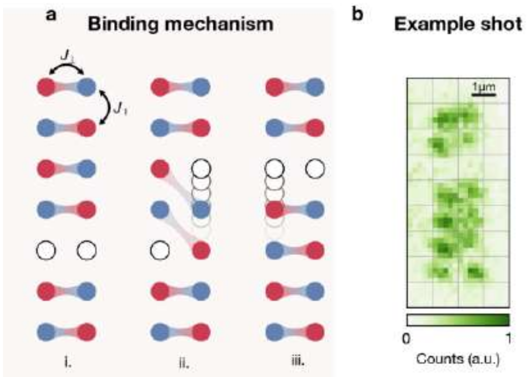

Figure 1: Hole pairing in mixD ladders. a, When a single hole from (i) moves through the system (ii), it breaks the spin order. (iii) The magnetic energy cost can be avoided if the second hole restores the spin order by moving together with the first hole. **b**, Single experimental shot with two holes on the same rung

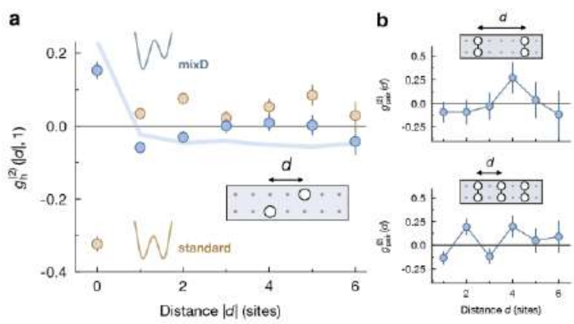

Figure 2: a, Hole–hole correlator between sites on opposite legs for mixD (blue) and standard (brown) ladders. Correlations at this distance are strongly enhanced in the mixD system. **b**, Measured pair–pair correlation of rung hole pairs in the experimental system.

The battle of clean and dirty qubits in the era of partial error correction

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Error correction is becoming an experimental reality [1], but it comes at the cost of dedicating many physical qubits to generate one 'logical' qubit. So what happens if you decide to create a machine with both error-corrected and physical qubits to be used together? This work [1] begins to answer this question by considering the capabilities of a simplified model of noisy and noiseless qubits, which is further developed to include realistic error correction. We find that we do indeed get an exponential suppression of errors by mixing the two types of qubits, as well as the exponential increase in computational space given by the additional qubits. This could extend the computational reach of smaller fault-tolerant machines.

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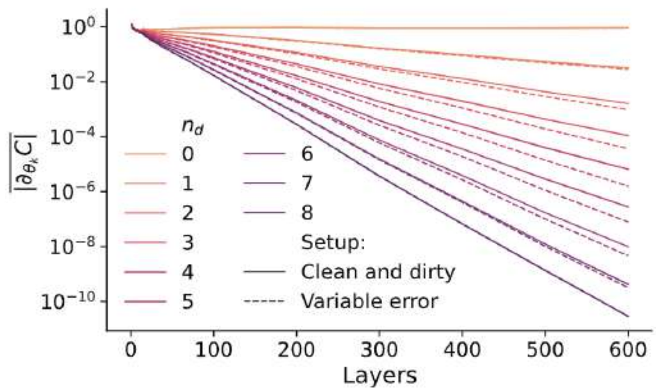

Figure 1: Plot showing the decay of the mean magnitude of gradients over the depth of the circuit (layers) as you increase the number of 'dirty' or physical qubits n_d. This is compared to lowering the overall error rate of the machine.

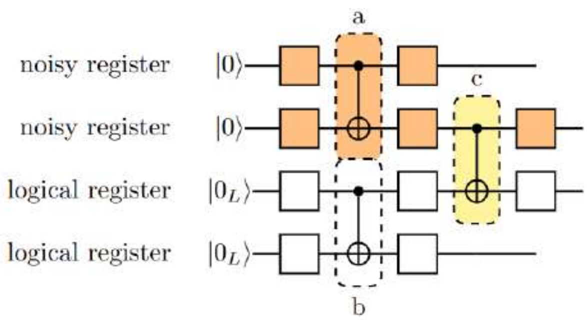

Figure 2: Circuit diagram showing the clean and dirty setup with gate types "a" (orange) which are standard noisy gates on our 'dirty' qubits, gate types "b" (white) which are encoded logical gates acting on the 'clean' qubits, and gate types "c" (yellow) which couple the clean and dirty qubits.

Light-Hole Spin-Orbit Qubit in Germanium

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Holes in Germanium (Ge) attract a great deal of attention due to their numerous attractive properties for the realization of quantum processors. Notably, they have proven to be extremely effective for encoding and manipulating quantum information. [1] In contrast to electrons, hyperfine interactions are weaker for holes, which enables longer relaxation and dephasing times. Moreover, spin-orbit coupling effects are larger for holes, which leads to fast all-electrical spin-manipulation schemes such as electric-dipole spin resonance (EDSR).
EDSR has been demonstrated in Ge quantum wells, nanowires, and hut wires, and is especially convenient in gate-defined quantum dots because the driving field can be applied through the same gates that define the dots. Heavy-holes have been the center of attention regarding studies of EDSR in gated quantum dots due to material limitations and their large out-of-plane effective mass which favors them to the ground state. However, a novel type of two-dimensional hole gas consisting of light-holes can be achieved by applying a significant amount of tensile train (>1%) to the quantum well. [2] A light-hole based quantum device benefits of an effective transfer of quantum information from a photon to a spin.
This work proposes a new qubit design leveraging the properties of light-hole spins in highly tensile strained Ge quantum wells grown epitaxially on silicon wafers using GeSn as barriers [2]. A perturbative framework describing Rabi-flopping and relaxation time of a light-hole spin in a parabolic isotropic gate-defined quantum dot is derived from 8-band k·p theory. An analysis of the Rabi frequency shows that light-holes can be manipulated 2 to 3 orders of magnitude faster than heavy-holes, thanks to a constructive interference between two kinds of Rashba spin-orbit effects exclusive to light-hole systems. The relaxation time is also found to scale as B^7 in most cases. The framework is suitable for any out-of-plane confining potential. Ongoing work focuses on describing rabi-flopping in different magnetic field configurations as well as different LH qubit-optical photon coupling mechanisms.

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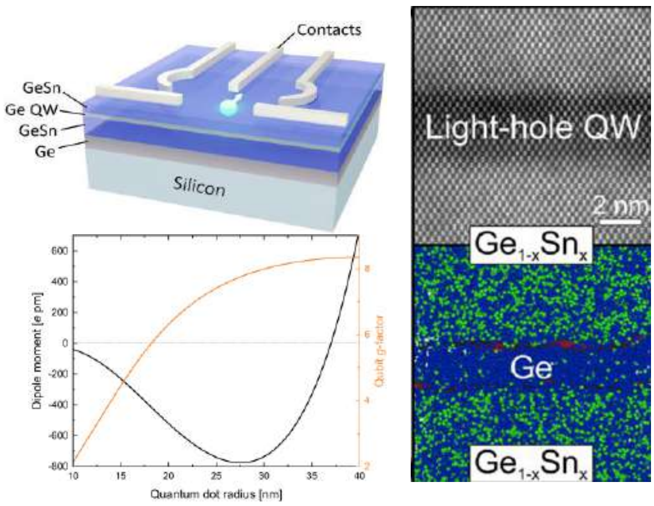

Figure 1: Top: schematic of a gated LH quantum dot in Ge. Bottom: dipole moment and g-factor of a light hole qubit. Right: TEM+APT

Two-qubit logic between distant spin qubits in silicon

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Coupling spin qubits to microwave photons provides an elegant approach for mediating long-range spin-spin interactions. The circuit quantum electrodynamics (QED) framework enables two-qubit gates which can be used for on-chip quantum links. In previous work, resonant spin-spin-resonator coupling in a silicon quantum device was demonstrated [1]. Most two-qubit gate schemes require a spin-spin coupling in the dispersive regime that is larger than the spin dephasing rates, as was recently observed in spectroscopic measurements [2]. In this work, we probe such a dispersive spin-spin interaction in the time-domain and demonstrate a two-qubit gate between spin qubits in silicon separated by 250 μm.

We form a double quantum dot (DQD) in a 28Si/SiGe heterostructure at each end of a 250 μm long high-impedance superconducting resonator (Figure 1) [3]. We trap a single spin in each DQD, and we enable tunable spin-charge hybridization with micromagnets. Due to mitigation of microwave losses [4], we can tune the spin-charge hybridization to reach the strong-coupling regime with spin-photon couplings up to around $g_s/2\pi$ = 40 MHz. The readout is implemented by direct dispersive spin sensing using the same resonator, with the signal-to-noise ratio largely improved by a Josephson traveling-wave parametric amplifier [5].

We first show universal single-qubit control over two flopping-mode qubits [6] and characterize their coherence times. Next, we bring the two spins into resonance with each other, but detuned from the resonator photons, and observe exchange (iSWAP) oscillations between the two remote spins up to 17 MHz. This frequency is consistent with the spectroscopic measurements [2]. Furthermore, we demonstrate that the coupling strength (2J) as well as the coherence times of the qubits can be tuned by two knobs: the inter-dot tunnel coupling and the spin-cavity detuning. In future work we intend to implement single-shot readout and improve the spin lifetimes while dispersively coupled to the resonator. These results pave the way for scalable networks of spin qubits on a chip.

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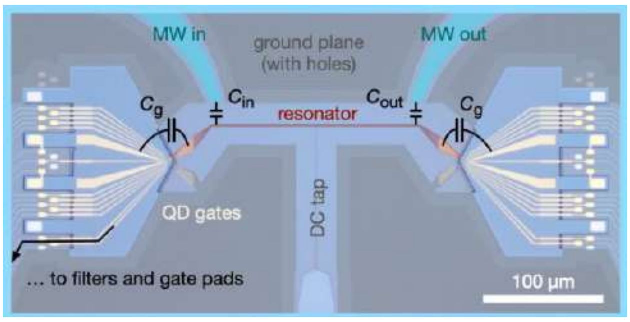

Figure 1: Spin-spin coupling device.

Polariton Bose-Einstein condensate from a Bound State in the Continuum

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Abstract

Optical bound states in the continuum (BIC) [1] are peculiar topological states that, when realized in a planar photonic crystal lattice, are symmetry-protected from radiating in the far field despite lying within the light cone. These BICs possess an invariant topological charge given by the winding number of the polarization vectors, similarly to vortices in quantum fluids, such as superfluid helium and atomic Bose-Einstein condensates. Here we show Bose-Einstein condensation of polaritons, hybrid light-matter excitations, occurring in a BIC thanks to its peculiar non-radiative nature. Because of the high-quality factor of the polariton BIC, condensation takes place even without an absolute energy minimum in the dispersion: by directly accessing the system dispersion through angle and energy resolved PL measurements, we have observed that the BIC in a simple waveguide-grating system is part of a more complex, saddle-like dispersion. Our work opens a promising route for controlling the polariton condensate properties in a new way, i.e., by transferring topological properties from a photonic structure [2] to a macroscopic quantum fluid of light, with potential applications to metasurfaces exciton-polaritons in alternative material platforms [3] using simple shallow patterning of planar waveguides. Such an observation may open a route towards energy-efficient polariton condensation in cost-effective integrated devices, ultimately suited for the development of hybrid light-matter optical circuits.

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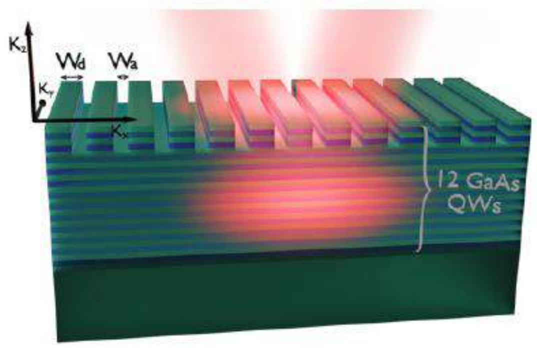

Figure 1: representation of the polariton waveguide with partially etched 1D lattice

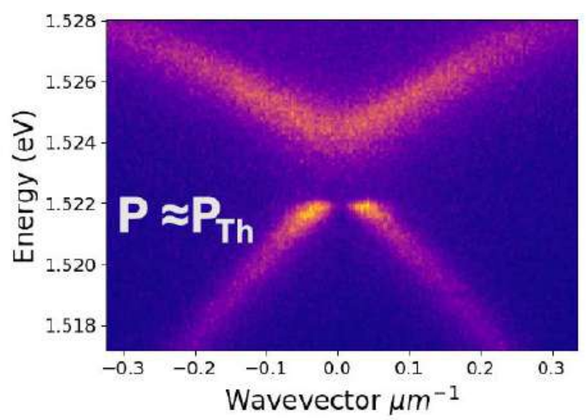

Figure 2: Angular resolved PL emission under non-resonant ps (pulsed) excitation (snapshot from a time-resolved streak camera). Around threshold a double peaked emission occurs around k~ 0. When the pumping power is increased this emission becomes dominant.

Global optimization of MPS and applications to quantum-inspired numerical analysis

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The expressivity and efficiency of tensor networks (TNs) make them ideal tools to develop quantum-inspired algorithms. We revise the problem of operator diagonalization with TNs for quantum-inspired methods for numerical analysis [1,2]. We use matrix product operators (MPO) to represent partial differential equations (PDEs), while matrix product states (MPS) for their solution, based on the encoding of functions in a quantum register [3]. We focus on: (i) imaginary-time evolution, (ii) gradient-descent, (iii) linear algebra approximate diagonalization, and (iv) DMRG-like optimization. We implement methods (i)-(iii) in a framework of approximate linear algebra, concluding that time-evolution is costlier than simple gradient descent. We upgrade gradient descent to work in a Krylov basis of n_v arbitrary vectors, formulating a variant of the Arnoldi method that outperforms (i) and (ii). We benchmark it to DMRG and vector-based Arnoldi using the 2D squeezed harmonic oscillator. We find that, while DMRG performs exponentially better in single-shot experiments (Fig.1(a)), Arnoldi matches it in accuracy and execution time when using a renormalization strategy (Fig. 2) and can be generalized to MPOs of greater depth. This shows its power to address large scale optimization problems, not only in quantum-inspired numerical analysis, but also in other many-body and quantum chemistry applications. MPS-based methods present an exponential advantage in memory when compared to vectors (Fig. 1(b)), evidencing the benefits of quantum-inspired methods for large dimensional problems.

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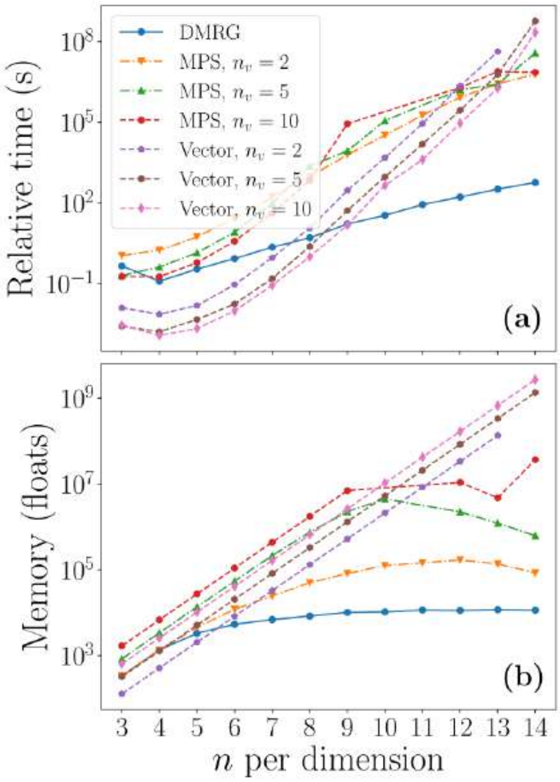

Figure 1: Single-shot results for DMRG and Arnoldi (MPS and vectors) for 2^n points per dimension. (a) Relative execution time with respect to n = 3. (b) Memory.

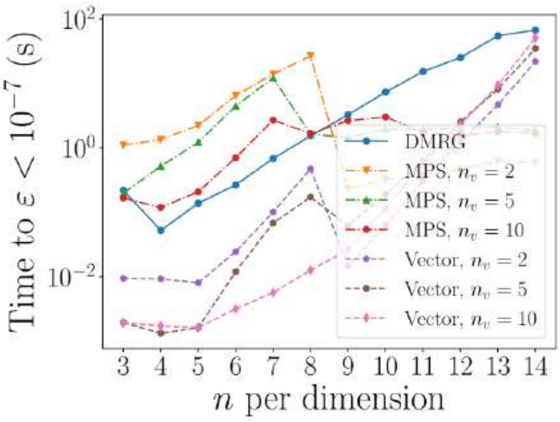

Figure 2: Time to energy error ε < 1e-7 for DMRG and Arnoldi (MPS and vectors) with renormalization for 2^n points per dimension.

Quantum interference with photon-number superposition states from a coherently driven quantum emitter

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Quantum emitters (e.g., atoms and quantum dots) are excellent single-photon sources for quantum technologies. A common method to generate single-photons of high quantum purity is the use of coherent excitation techniques. It was shown in 2019 that such excitation techniques result in the transfer of coherence imprinted on the emitter onto the photon-number basis through spontaneous emission, generating a photon-number superposition state of the form $|\psi\rangle = \sqrt{p_0}|0\rangle + e^{i\varphi}\sqrt{p_1}|1\rangle$ with optical phase φ [1].

In this study, we experimentally show that the often overlooked presence of photon-number coherence impacts core building blocks of quantum optics protocols. We exemplify this by performing phase-resolved correlation measurements using a Hong-Ou-Mandel interferometer with photon-number superposition input states (Fig. 1). We demonstrate that photon-number coherence leads to phase φ-dependent coincidence measurements as shown in Fig. 2 where we plot the coincidences for a single-photon (grey) and a superposition input state (purple) as a function of interferometer delay τ_p, revealing the suppression of coincidences at long delays as a result of coherence.

We show that the presence of photon-number coherence forces us to not only re-examine common normalization procedures used to extract photon indistinguishabilities, but also leads to new quantum interference phenomena, which in turn can seriously impact quantum computing schemes relying on partial qubit measurements as we demonstrate using the Perceval framework [2].

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Figures

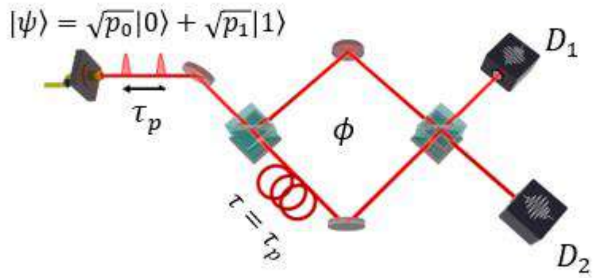

Figure 1: A Mach-Zehnder-based Hong-Ou-Mandel interferometer with photon-number superposition input states separated by excitation repetition rate τ_p and two detectors registering coincidences.

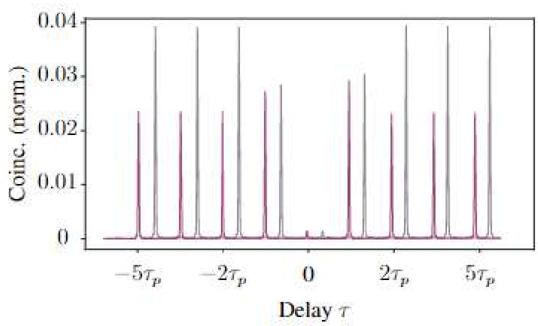

Figure 2: Normalized coincidence histograms for a single-photon input state (grey and shifted along x-axis) and a photon-number superposition state (purple).

Mott physics with Rydberg atoms: using spin quantum simulators to simulate strong fermionic correlations

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In this work, we present a hybrid quantum classical strategy to solve a prototypical many-body fermionic problem, the Hubbard model, with an analog quantum processor with up to a few hundred Rydberg atoms[1]. By using an advanced self-consistent mapping between the fermionic problem and a "slave-spin"[2,3] model, we circumvent the usual non locality issues related to fermion-to-spin transformations. We show that the method allows to compute key properties of the Hubbard model, like the quasiparticle weight renormalization, in the presence of realistic hardware constraints like decoherence, shot noise, readout error, atom position fluctuations, etc. We focus our work on a single-orbital toy model at half-filling for this proof of concept. However, a crucial aspect of the method is that it is readily extendable to doped, and multiorbital problems, which are out of reach of other state-of-the-art classical methods.

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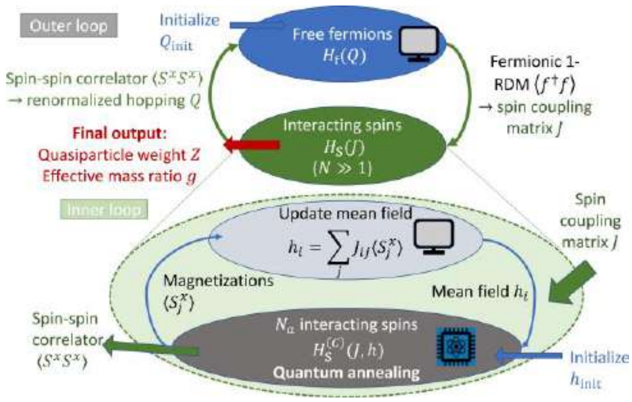

Figure 1: Numerical implementation of the method. A loop between a free fermions Hamiltonian (solved classically) and a Ising-like Hamiltonian (solved with a QPU) is performed to find final parameters. The quasiparticle weight is then extracted from the spin Hamiltonian.

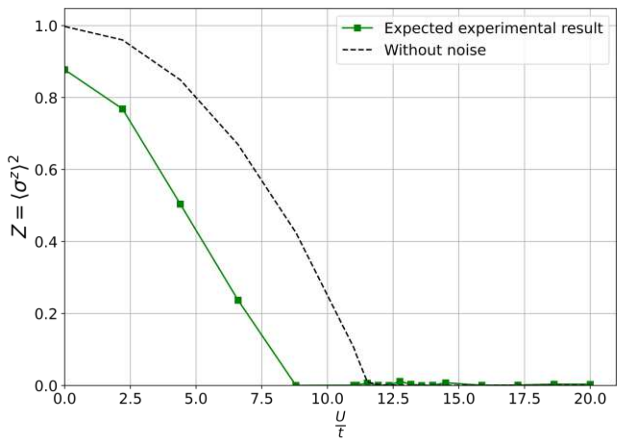

Figure 2: Quasiparticle weight renormalization vs. coulomb interaction renormalized. The black dashed line shows the result for a simulation without noise. The squared green line depicts the experimental result one can expect on a real device. The phase transition occurs when Z=0

Towards coherent control of a spin ladder in germanium quantum dots

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Semiconductor quantum dot lattices are a promising platform for analog quantum simulations of Fermi-Hubbard physics, giving rise to a wealth of physical phenomena. Resent demonstrations include collective Coulomb blockade [1], Nagaoka ferromagnetism [2], Heisenberg spin chains [3] and resonance-valence-bond physics [4]. A particularly interesting configuration is a spin ladder as it is predicted to exhibit the key ingredients behind high-Tc superconducting behaviour [5].
Here we investigate a 2x4 array of Ge/SiGe quantum dots to simulate the physics of a spin ladder. We show the basic characterization of a 2x4 germanium quantum dot array (Fig. 1), and demonstrate single charge occupation in each quantum dot, tunable tunnel couplings and Pauli spin blockade.
Motivated by the need for calibrating the spin exchange interactions across the ladder, we study the coherent two-axis control of all four spin pairs along the rungs of the ladder, which effectively form singlet-triplet qubits. Specifically, we show ST^- oscillations around the x-axis of the Bloch sphere and demonstrate rotations around the z-axis that are driven by the exchange coupling. We are able to control the couplings either via detuning of the double dot or via the barrier voltage between two dots (Fig 2).
Experiments demonstrating sequential readout of two or more qubits are underway, as are measurements geared at two-qubit gates between the ST- qubits.
Next we will probe the expected quantum phase transition between a spin-liquid-like phase and a dimer phase as a function of exchange couplings.

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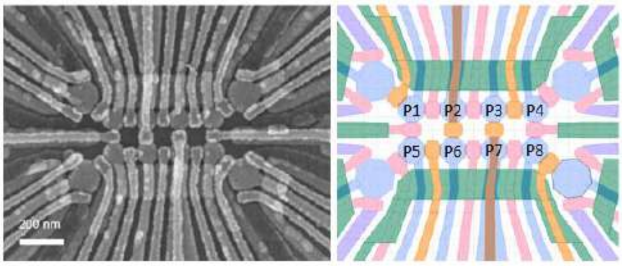

Figure 1: AFM image of the device (on the left). Device design (on the right): plunger/sensor gates are in blue, barrier gates are in pink (first fabrication layer) and orange (top fabrication layer), screening gates are in green, ohmic contacts are in purple.

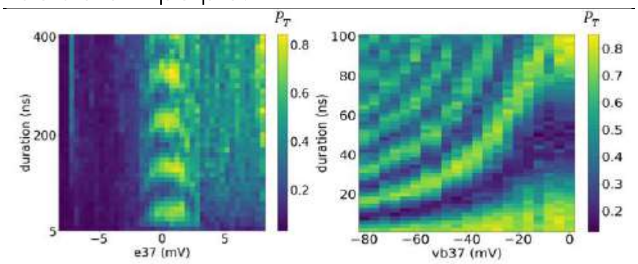

Figure 2: Two axis control of the P3-P7 pair of the device: x-axis control resembling ST^- oscillations (on the left), z-axis control resembling exchange oscillations tuned via the barrier voltage (on the right).

Towards resonant coupling between a RF superconducting qubit and a mechanical resonator

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Nowadays, the state-of-the-art chip-scale mechanical resonators can achieve lifetimes over 100 s and coherence times in the order of seconds in a thermal environment at 10 mK. [1]. The strong coupling between these outstanding mechanical resonators and the superconducting qubits, the most promising platform for scalable quantum computers, has been a long-pursued goal since it could open the door to novel quantum technology applications, like record-beating quantum memories or microwave-optical quantum transducers [2]. The main challenge to overcome is reducing the wide frequency difference between both quantum devices, typically 10^3. Inspired by recent works [3], our group had proposed a novel coupling scheme to finally turning the dream into a reality, nevertheless, for it to work out, we need a qubit that is resonant with the mechanical mode, in the MHz range, that is sufficiently insensitive to charge noise and that has strong capacitive matrix elements at the right frequency, all three at the same time. Is it possible? The answer is the so-called heavy fluxonium [4], which is a highly non-linear circuit made of a Josephson junction shunted by a large inductance and a large capacitance in the high-impedance regime. Recently, we had managed to design it and fabricate it in our lab achieving frequencies as low as 2 MHz with state-of-the-art coherence times for this qubit architecture [5].

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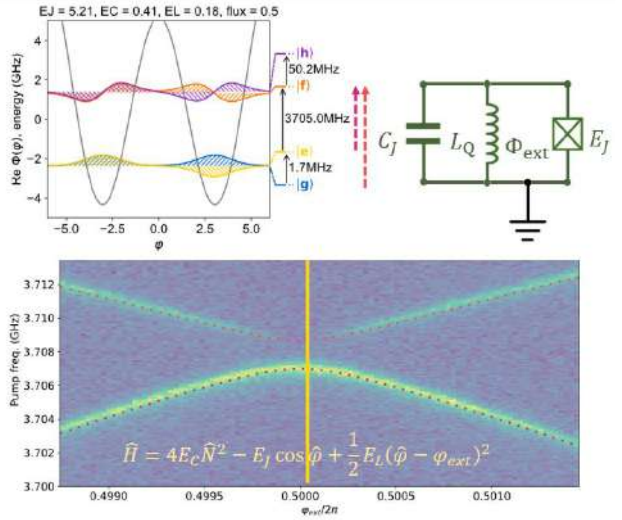

Figure 1: Grounded heavy fluxonium: potential energy and wave functions (top left), lumped-element simplified circuit (top right), and two-tone spectrum (bottom).

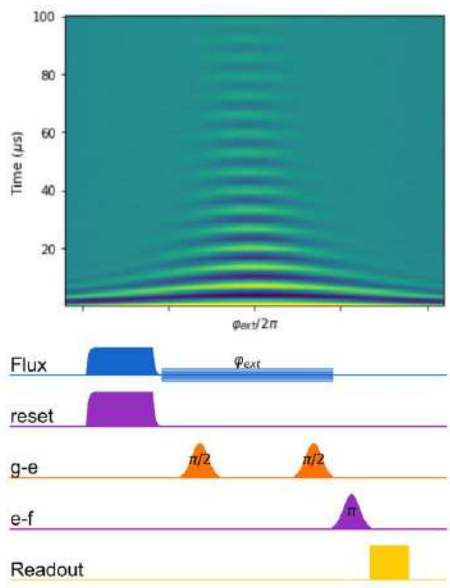

Figure 2: T2 Ramsey as function of bias flux (top) and protocol pulse sequence (bottom)

Exploring dispersive qubit readout in the strong driving limit.

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Dispersive readout in superconducting circuits is a limiting factor in the performance of current quantum processors. Experimentally, it has been observed that increasing the intensity of the readout pulses improves the signal-to-noise ratio of the measurement up to some threshold [1,2], where non-dispersive effects and leakage to higher levels enter into play. In this work, we perform a numerical study of the dispersive measurement of superconducting qubits beyond dispersive approximation to find the optimal calibration point in the strong driving limit according to different metrics. The simulations were done by solving the stochastic Schrödinger equation. Our results match with theoretical predictions [3] for long measurements with weak driving at the deep dispersive limit but disagree for detunings of order Δ~10g, strong driving, and short integration times. This behavior defines an optimal calibration point regarding the driving and the detuning. Finally, using quantum tomography [3,4], we identify the physical processes and error sources that affect the non-demolition nature of the measurement.

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Figures

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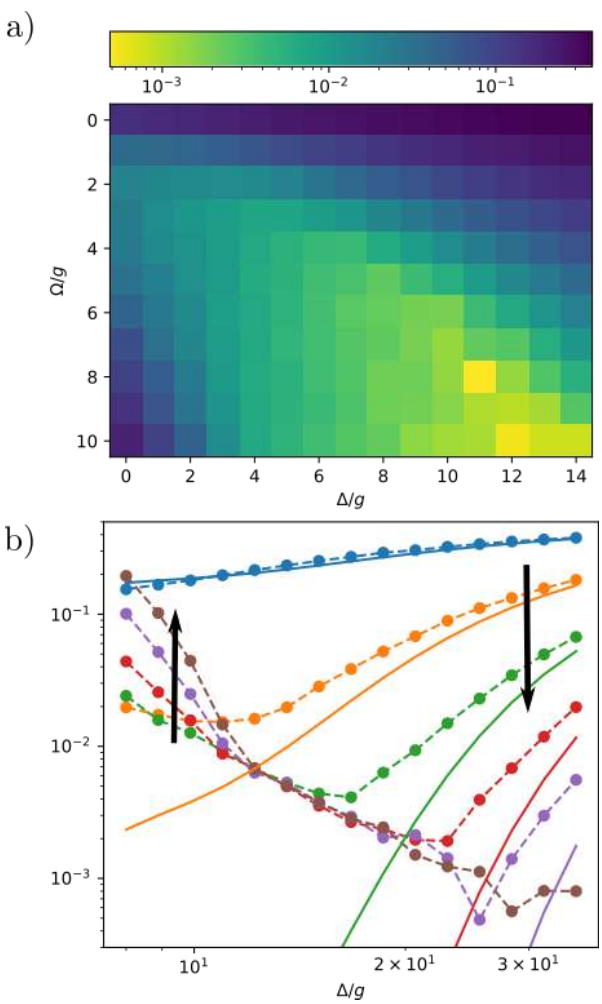

Figure 1: a) Color map of Infidelities obtained from simulations of dispersive readout in terms of detuning and driving. b) Infidelities from simulations of dispersive readout (dots) for fixed driving (colors) in terms of detuning. The driving increases in the directions shown by the arrows. The solid lines are the theoretical prediction of infidelity [3].

Light-matter correlations in Quantum Floquet Engineering

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Since the earliest studies to understand the nature of light, harnessing light-matter interactions has been a persistent goal in condensed matter physics and, more recently, in quantum technologies. A well-known example is the use of classical driving fields as external knobs to alter and control the properties of materials, in what is now widely known as Floquet engineering [1].

An avenue currently being explored known as Quantum Floquet engineering [2,] involves the use of quantum fields rather than classical ones. Theoretically, this regime entails some difficulties. It was recently revealed that a gauge-invariant description of this interaction requires including the photonic field operators to arbitrary order in the Hamiltonian [3]. Unfortunately, such Hamiltonians are extremely non-linear and complex to simulate. This makes it important to develop effective models which can describe the system over a wide range of coupling regimes, being also simple enough to capture the main mechanisms governing the physics.

In this work [4], we present a framework to obtain simple effective Hamiltonians by means of a disentangling technique. It allows us to find a non-perturbative, polynomial expansion of the full, gauge-invariant Hamiltonian, which can be truncated to low order and provides accurate results for arbitrary coupling strength.

Within this framework, we study the paradigmatic case of a Su-Schrieffer-Heeger (SSH) chain [5] coupled to a single mode cavity, and show that their interaction can produce topological phase transitions. Interestingly, each photonic band exhibits its own topological phase transitions, which allows the control of the topological properties of the fermionic system through the number of cavity photons.

Furthermore, we find that light-matter correlations are crucial as they can spontaneously break chiral symmetry, severely affecting the topology even when the cavity frequency is far detuned from the electronic system. With these results in mind, we address the important differences between classical and quantum Floquet engineering in the high frequency regime. Finally, we discuss how the spectroscopy of the photons can be used to detect all our findings and the possibility to use the cavity to externally control the state transfer between topological edge states.

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Supercurrent-mediated coupling between two Andreev spin qubits: theory and device

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Semiconducting spin qubits are currently one of the most promising architectures for quantum computing. However, they face challenges in realizing high-fidelity quantum non-demolition readout and multi-qubit interactions over extended distances. A recent alternative, the Andreev spin qubit (ASQ), has emerged with realizations in InAs/Al hybrid nanowire Josephson junctions [1,2]. In these qubits, the spin degree of freedom is intrinsically coupled to supercurrent via the spin-orbit coupling. The spin-dependent supercurrent of ASQs facilitates qubit readout using circuit quantum electrodynamics (cQED) techniques, as recently demonstrated and can facilitate inductive multi-qubit coupling via a shared inductance [3].

Here, we investigate the supercurrent-mediated coupling between two ASQs in separate SQUID loops that share a third gate-tunable Josephson junction. We investigate the character of the coupling using numerical simulations and find it to be either longitudinal or transverse depending on the direction of the applied magnetic field. Moreover, we calculate the expected dependence of the coupling strength on different model parameters: spin-dependent Josephson energies, superconducting phase offset across each ASQ and shared inductance. These simulations are all done with realistic parameters and set the stage for experimental realizations of supercurrent mediated spin-spin coupling.

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Figures

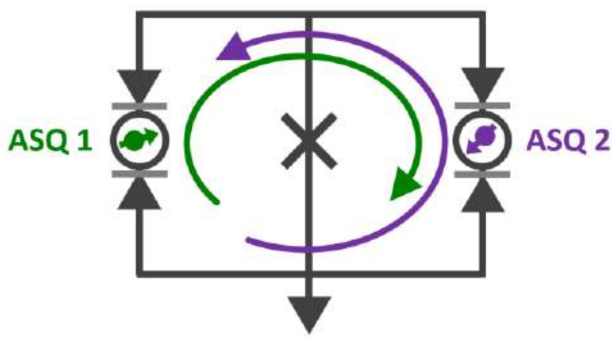

Figure 1: Circuit model of the device showing two Andreev spin qubits and a coupling Josephson junction in parallel.

Machine learning-based device-independent certification of quantum networks

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Abstract

Detecting non-classical behaviors is a pivotal ingredient in several quantum technology tasks. The most widely employed techniques to verify the quantum features of a given physical device involve semi-definite programming [1]. However, such tools can only be applied to linear objective functions and constraints and become computationally unfeasible when the complexity and size of the system grow. Building on previous works [2], we introduce a strategy based on artificial neural networks, that allows to carry out numerical optimizations over supersets of the quantum set arising in arbitrary quantum networks. This method has two main advantages: firstly, it can be applied to nonlinear optimization constraints and objective functions, thus being suitable for scenarios featuring independent sources and nonlinear entanglement witnesses. Secondly, it requires less resources than other approaches, thus allowing to explore previously inaccessible regimes. We tested it on experimental data, obtaining estimates on Bell-like violations arising in scenarios involving independent sources of entangled photon states. This work may open new possibilities in the field of the certification of quantum resources in networks of arbitrary size and complexity.

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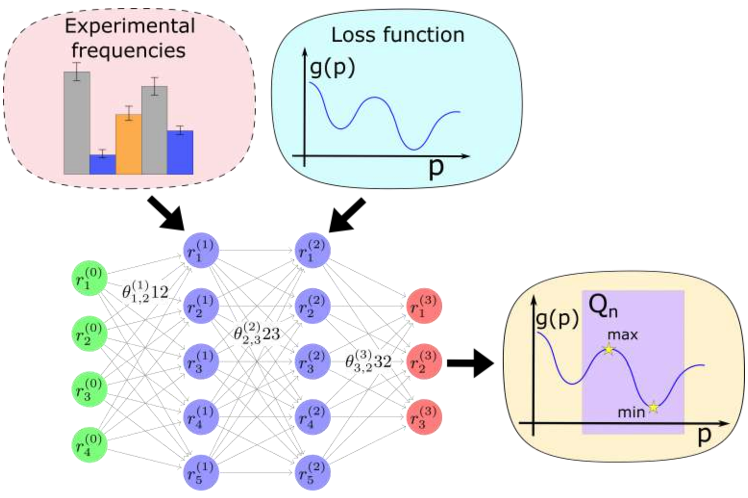

Figure 1: In the most general case, our optimizer takes as input a generic nonlinear function g(p) to be optimized over a given superset of quantum correlations Q_n and additional arbitrary constraints, eventually compatibly with experimental observations.

High-fidelity on chip four-photon GHZ states

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Mutually entangled multi-photon states are at the heart of all-optical quantum technologies. Over the past two decades, major advances in their generation have been achieved by exploiting spontaneous parametric down-conversion, and free space apparatuses [1]. However, bulk optics and probabilistic sources limit scalability and thus real-world applications. We propose to generate multi-photon states making use of cavity embedded quantum-dot (QD) emitters that operate as an on-demand source of pure and indistinguishable single-photons [2] that we synchronize at the input of a reconfigurable chip.

In this work [3], we generate and characterize on-chip high-fidelity quadri-partite GHZ states and perform an integrated quantum secret sharing protocol as a proof-of-principle that our platform is application ready. We first demonstrate the on-chip high-fidelity high-rate generation and characterisation of 4-photon GHZ states using a bright single-photon source. The 4-photon GHZ generation rate of 0.5 Hz is remarkable. It allows to perform a complete characterisation of the 4-partite state through the reconstruction of its density matrix ρ_{exp} via full quantum state tomography (Fig. 1.b). The fidelity of the generated state to the target is F=(86.0±0.4)%, and the purity of the state is P=(76.3±0.6)%, setting a new state-of-the-art for integrated implementations of 4-partite GHZ states. In addition, we test non-classical correlations and certify entanglement, non-separability, and robustness of the generated state to noise using a semi device-independent approach. The violation of a Bell-like inequality characterizing 4-partite GHZ states exceeds the classical bound by more than 39 standard deviations. Finally, as a proof-of concept protocol harnessing the produced state, we implement with our reconfigurable device a quantum secret sharing protocol between four parties with sifted keys up to 1978 bits long and a qubit error rate of 10.87%, below the threshold of 11% required to guarantee a secure communication. These achievements demonstrate that our experimental platform consisting of QD solid state emitter and reconfigurable photonic chip is mature for the high-fidelity integrated generation and manipulation of entangled multi-photon states, setting a milestone in the implementation of photonic technologies protocols.

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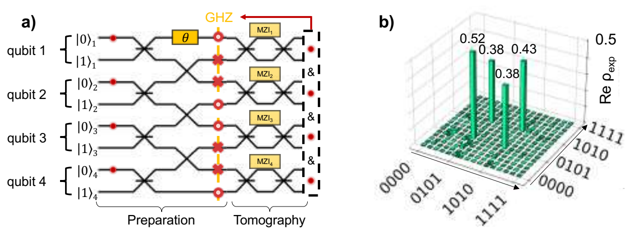

Figure 1: (a) Integrated path-encoded 4-GHZ generator injected by synchronised photons from QD source (red dots). (b) Experimental tomography of 4-GHZ states. The real part of the reconstructed density matrix ρ_{exp} from the experimental 4-photon tomography using maximum likelihood estimation.

Optomechanical Systems as Quantum Heat Engines

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While new quantum technologies [1] are being developed at an accelerating pace, the field of quantum thermodynamics (QTD) [2] is attracting a lot of attention, as researches find themselves wondering, how do these new quantum devices interact with heat. QTD attempts to answer that question by investigating the relationship between two fundamental theories: quantum mechanics and thermodynamics. From such considerations, a completely new type of device can be envisioned. A quantum heat engine [2][3] is a device operating at the quantum level, specifically designed to interact with heat reservoirs and extract coherent work from heat flow. Here we propose to utilize a well-know quantum device in a novel manner in order to realize such a quantum heat engine.

An optomechanical cavity is an interesting type of quantum system where various quantum phenomena are regularly investigated [4]. In an optomechanical system, two oscillator modes are coupled with a non-linear coupling, described by the following Hamiltonian:

$$H_I = -\hbar g_0 \hat{a}\hat{a}^T(\hat{b}+\hat{b}^T)$$

The mode related to the operator $\hat{a}$ is the optical cavity mode and the mode related to $\hat{b}$ is the mechanical mode.

The optical mode in an optomechanical system is typically driven by a coherent laser. Here, we present a new scheme of utilizing an optomechanical system by coupling the optical mode to two heat baths separated in temperature. The heat baths are given Lorentzian line shapes centred at different frequencies, so that the hot bath has a higher characteristic frequency. As heat flows from the hot to the cold bath through the optical cavity, some of that energy is transferred to the mechanical mode due to the difference in average photon energies between the baths.

The rather intricate dynamics of this system can be relatively well captured (in a certain parameter regime) by a Heisenberg-Langevin (HL) stochastic equation. Here, we derive and numerically solve the HL equations for a system described above. In figure 1. we present an example of the time evolution of expected photon occupations in the optical and mechanical modes.

There are numerous ways of realizing the system described here physically. One viable candidate is circuit quantum electrodynamics (cQED) [5], where heat conduction studies are already being performed, and optomechanical coupling can be achieved [6].

Figures

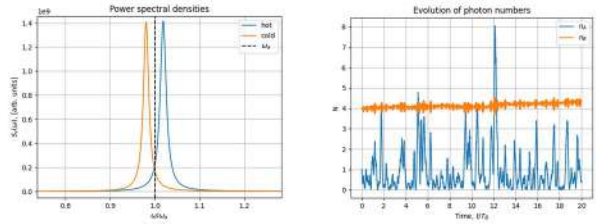

Figure 1: Left: Spectral densities of the heat baths. Right: Example evolution of the optical (blue) and mechanical (orange) modes.

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Charge sensing readout of Ge quantum dots

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Abstract

Germanium arises as a promising material for complex spin qubits architectures [1], by combining high mobilities, low hyperfine interactions and a small effective mass. An efficient readout of Ge quantum dots devices can be achieved by implementing a RF-reflectometry setup on a local charge sensor [2]. Here, we discuss the matching of the resonant circuit used for the reflectometry and its sensitivity to the variation of the charge sensor resistance [3]. We characterize the charge sensitivity and the charge noise of the sensor [4], and evaluate its performances when sensing a double quantum dot. We take advantage of the numerous gates of the device to tune the coupling between the sensor and the double quantum dot in order to increase the signal-to-noise ratio. Our optimization enables us to probe the few-hole regime and to perform spin-to-charge conversion by means of Pauli spin blockade.

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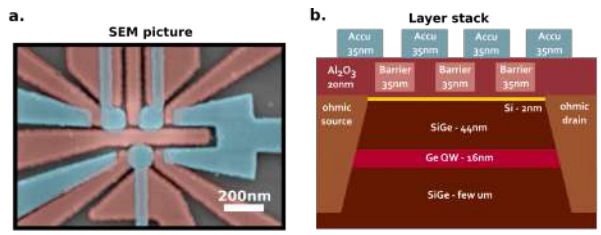

Figure 1: Coloured SEM picture and layer stack of the of the measured device.

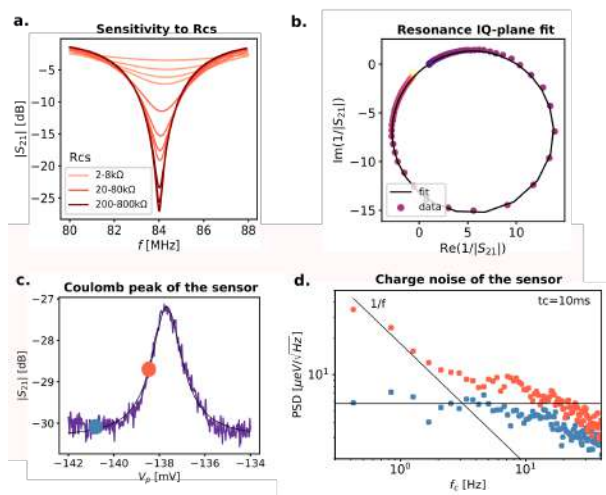

Figure 2: Simulated and measured properties of the resonant circuit and the charge sensor.

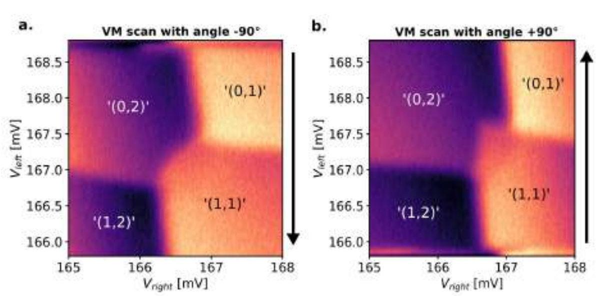

Figure 3: Pauli spin blockade signature for two different scan angles in video mode.

Purcell-enhancement and resonance fluorescence from a low-noise emitter in diamond

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The nitrogen-vacancy center (NV) in diamond exhibits attractive spin properties but lacks the optical characteristics required for fast quantum communication. Only a marginal fraction (2.5-3%) of all the emitted photons are emitted into the zero-phonon-line (ZPL), the radiative lifetime is long, and extraction of photons out of diamond is inefficient [1]. We demonstrate efficient selective coupling of a coherent NV transition to the optical mode of a microcavity [2-4], mitigating these problems. We use a 1.6 μm thick diamond with NVs created via carbon implantation post-fabrication [5]. The ZPL count rates are as high as 140 kcts/s under off-resonant excitation, exceeding the state-of-the-art achieved for photonic interfaces based on solid-immersion lenses (SILs) [6] (Fig. 1). The high photonic flux is achieved through a net Purcell enhancement of 1.9, increasing the fraction of ZPL photons from 3% to 47%. By efficient suppression of the resonant excitation, we measure resonance fluorescence from an NV for the first time without relying on time-bin filtering and extract an NV linewidth of 170 MHz (Fig. 2). In two-photon protocols for spin-spin entanglement, our platform would increase the entanglement success probability by more than an order of magnitude, and by more than two orders of magnitude with feasible system improvements. The ability to generate coherent single photons resonantly and with high probability establish our system as an attractive spin-photon interface and is an important step towards quantum networks based on defects in diamond.

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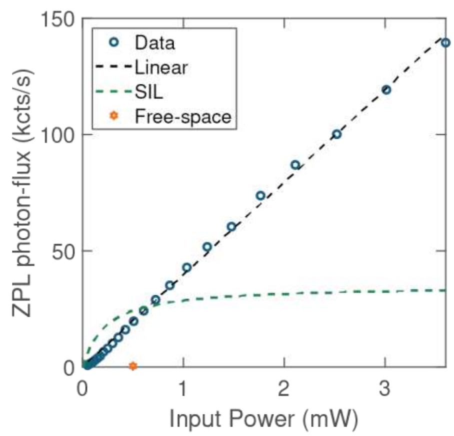

Figure 1: ZPL counts under off-resonant excitation as a function of power, compared to the state-of-the-art count rates with a SIL [6] and typical count rates in free-space.

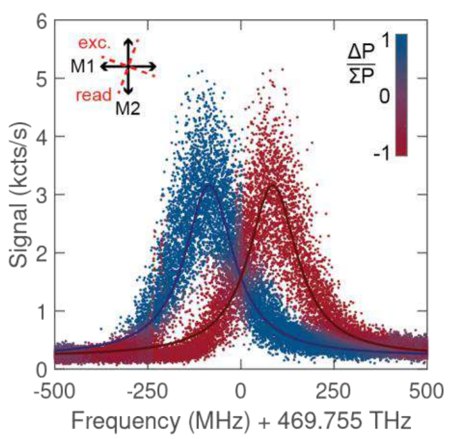

Figure 2: NV resonance fluorescence. The center emission frequency depends on the occupation of a nearby charge trap.

On-chip distribution of quantum information using traveling phonons

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Distributing quantum entanglement on a chip is a crucial step towards realizing scalable quantum processors. Using traveling phonons as a medium to transmit quantum states is currently gaining significant attention, due to their small size and low propagation speed compared to other carriers, such as electrons or photons. Moreover, phonons are highly promising candidates to connect heterogeneous quantum systems on a chip, such as microwave and optical photons for long-distance transmission of quantum states via optical fibers. Here, we experimentally demonstrate the feasibility of distributing quantum information using phonons, by realizing quantum entanglement between two traveling phonons and creating a time-bin encoded traveling phononic qubit. The mechanical quantum state is generated in an optomechanical cavity and then launched into a phononic waveguide in which it propagates for around two hundred micrometers. We further show how the phononic, together with a photonic qubit, can be used to violate a Bell-type inequality [1].

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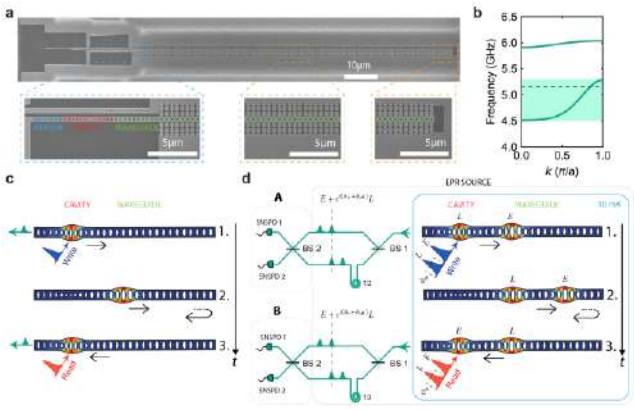

Figure 1: a) SEM of the device, showing different parts. B) band structure of the phononic waveguide. C) Sketch of various stages of the protocol for writing and retrieving a mechanical excitation from the structure. D) Simplified schematics of the time-bin entangling protocol, where we highlight the three main steps. 1. The creation of the entangled state between the photonic excitation (Stokes scattered photons) and the traveling phononic excitation in the waveguide. 2. The propagation of the mechanical qubit in the waveguide, with the reflection at the end. 3. The mapping of the phononic state onto a photonic state in order to verify the entanglement. The boxes conceptually divide Einstein–Podolsky–Rosen (EPR) source, and parts A and B, which are used to create and detect the entangled state.

Experimental superposition of time directions

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Quantum systems do not experience time as an asymmetric quantity, i.e. flowing in a fixed direction, from past to future. This is reflected in the laws of Nature, which remain valid also when flipping the sign of the time coordinate.

This implies that, if it was possible to interact with physical systems both in the forward and backward time direction, we could implement a coherent superpositions of time directions. This would be of great interest, first, due to the generality of such a process, which could not be described even through process matrices, the formalism of indefinite causal order (e.g. quantum switch [1]). Secondly, time direction superposition has been demonstrated to bring an informational-theoretic advantage in specific computational tasks.

However, to experimentally investigate the possibility of realizing a process with indefinite time direction, it is first necessary to clarify the operational meaning of a time direction change. This topic was recently addressed in [2], by introducing an "input/output" inversion supermap, sending a general quantum channel C into its backward version $C_{bwd} = C^*$. At this point, valid operations (i.e. completely positive trace preserving) that remain valid under such transformation are defined bidirectional, i.e. accessible in both time directions. An example is constituted by unitaries, where $U_{bwd} = U^T$.

In this work [3], we experimentally implement an instance of an indefinite time direction process, the so-called "quantum time flip", defined as $C \rightarrow\ C\,|\psi\rangle_T|0\rangle_C + C^*|\psi\rangle_T|1\rangle_C$ where the subscript C(T) indicates a control (target) system.

In our experiment, we exploit the polarization of a single photon state as our target qubit and its path as the control. Then, we adopt an interferometric structure (see Fig. 1), such that, when the control is in the state $|0\rangle$ ($|1\rangle$) the operation applied to the target will be UV^T (U^TV), with U and V being arbitrary unitary operations. Then, when the control is in the state $|+\rangle$ or $|-\rangle$ we have a coherent superposition.

We then witness the indefinitess in the time direction of our implemented process through a game, in which the use of the quantum time flip beats any other strategy. This game amounts to guessing if two unitaries U and V belong to the set S_- or S_+, having access to them only for one shot, with $S_- = \{U, V\colon UV^T = -U^TV\}$ and $S_+ = \{U, V\colon UV^T = U^TV\}$. For this game, the highest winning probability for fixed-time direction strategies amounts to 0.92. In our case, the experimental success rate was 0.9945, which certifies that our apparatus is implementing a process indefinite in the time direction.

Figures

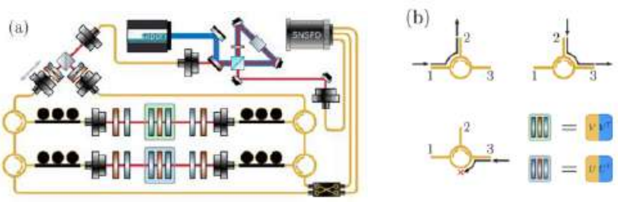

Figure 1: Experimental apparatus for the coherent superposition of two time directions on a photonic platform (a). The green and blue optical apparatuses implement any arbitrary unitary U when photons travel in one direction and its transpose U^T in the opposite one (b).

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Photon bound state dynamics from a single artificial atom

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The interaction between photons and a single two-level atom constitutes a fundamental paradigm in quantum physics. The nonlinearity provided by the atom means that the light-matter interaction depends strongly on the number of photons interacting with the two-level system within its emission lifetime. This nonlinearity gives rise to the formation of strongly correlated quasi-particles known as photon bound states [1]. While signatures consistent with the existence of photon bound states have been measured in strongly interacting Rydberg gasses, their hallmark excitation-number-dependent dispersion and propagation velocity have not yet been observed on a single emitter.

Here we report on the direct observation of a photon-number-dependent time delay of photons scattering off a single semiconductor quantum dot coupled to a one-sided optical cavity (Fig. 1a) [2, 3]. By scattering a weak coherent pulse off the cavity-QED system and measuring the time-dependent output power and correlation functions, we show that single photons, two- and three-photon bound states incur different time delays of 144.0 ps, 66.5 ps and 45.5 ps respectively (Fig. 1b) [4]. The reduced time delay of the two-photon bound state is a fingerprint of the celebrated example of stimulated emission, where the arrival of two photons within the lifetime of an emitter causes one photon to stimulate the emission of the other from the atom. Furthermore, we show that at the optimal pulse width the two-photon scattering results in the efficient creation of two-photon bound states with a temporal wave function that matches theoretical predictions very precisely.

Figures

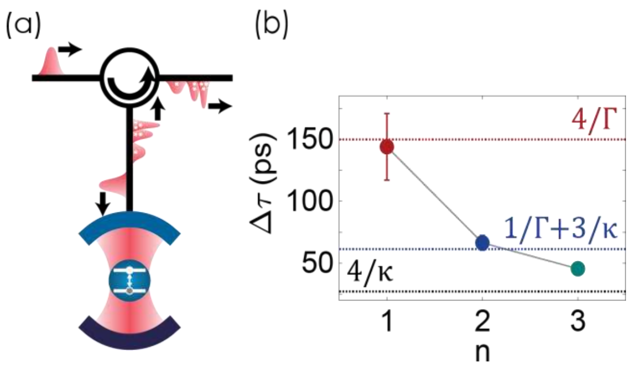

Figure 1: (a) Schematic of experimental setup for photon-number-dependent pulse scattering measurement: a Gaussian-shaped pulse of light is launched into a circulator, which guides the pulse towards a semiconductor quantum dot coupled to a one-sided cavity. States of light with different photon-number emerge at the output with different time delays; (b) Delay $\Delta\tau$ of scattered single-, two- and three-photon components.

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Coherent superconducting thermoelectrical nanodevices

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Abstract

Superconducting nanodevices have been recently identified as strong thermoelectrical engine.
We will explore different examples where the thermoelectricity in linear and nonlinear regimes is generated even in a particle-hole symmetric systems. We discuss how phase-dependent Andreev reflections[1] or even non-equilibrium spontaneous symmetry breaking[2,3] would generate strong and phase controlled thermoelectrical effects. We successfully report also different applications such as current-controlled superconducting thermoelectric memories[4], broadband single-photon detectors, microwave assisted generator[6]

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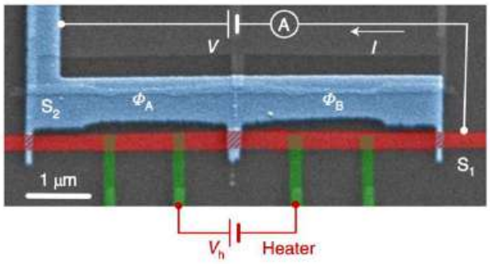

Figure 1: Bipolar thermoelectric Josephson engine. Pseudo-colour scanning electron micrograph of the engine. In red Al istand tunnel coupled to Cu/Al bilayer to realize a double-loop SQUID.

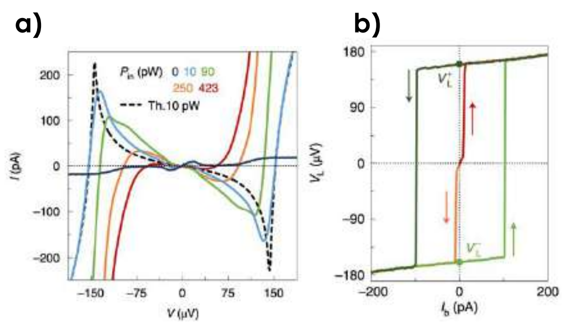

Figure 2: a) Reciprocal IV characteristic of the superconducting thermoelectrical engine. b) Hysteresis cycle spontaneous symmetry-breaking of the particle-hole symmetry at the base of the effect.

Quantum speed steering

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Abstract

The energy/time uncertainty relation has a very different interpretation than the standard Heisenberg uncertainty principle, which is stated in terms of the variance of observables. In quantum theory, time does not have an associated observable and its relation with the energy variance implies a bound on the rate of change of a quantum state given the fluctuations of its Hamiltonian. This quantum speed limit (QSL) has been theoretically explored in different contexts for several quantum states and dynamics [1].

On the other hand, steering is a non-classical correlation, stronger than entanglement but weaker than non-locality, stated by Schrödinger in response to the EPR paradox [2]. In the standard formulation we have two parties, Alice and Bob, who share a quantum state and are allowed to perform local operations and classical communications. Bob's setting is trusted and they know what their state is and which measurements their device carried out, whereas Alice's operations are untrusted. If the correlations observed in the shared state do not admit a classical description, e.g. a Local Hidden State (LHS), then the uncertainty principle can be violated [3].

In this work we present new steering witnesses, in the form of the violation of a conditional QSL. Furthermore, we provide a new interpretation of quantum correlations, namely the possibility to influence the speed of evolution of an entangled quantum state using local measurements and classical communications. We provide applications of our steering witnesses on different physical scenarios and states (e.g. two modes squeezed state and GHZ state), finding the most suitable QSL bound to be violated according to the degrees of freedom of the system. These new bounds might find applications in different fields of quantum physics, such as quantum computation, quantum thermodynamics and quantum control theory. Moreover, quantum speed limits can be probed on different physical platforms, such as cavity QED and ultracold atomic gases, allowing to experimentally test the violation of the bounds.

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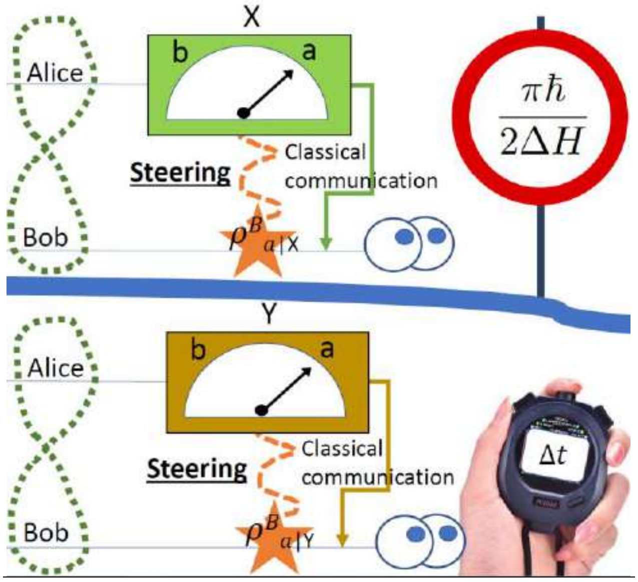

Figure 1: Conditioned on Alice's measurement outcome and setting, Bob decides to either measure the QSL or the effective time of the evolution. The violation of the speed limit is a witness of quantum steering from Alice to Bob.

Shortcuts to Adiabaticity for Fast Qubit Readout and Quantum Gate in Circuit Quantum Electrodynamics

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Superconducting quantum circuits (SC) and circuit quantum electrodynamics (cQED) have become promising quantum platforms for quantum information processing to implement quantum algorithms. It also has been suitable for quantum simulation and, lately, provided strong evidence of computational advantages over its classical counterpart.
Based on the renewed interest in the shortcut-to-adiabaticity techniques [1] in quantum control, we propose how to engineer longitudinal coupling to accelerate the measurement of a qubit longitudinally coupled to a cavity. We compare different modulations, designed from inverse engineering, counter-diabatic driving, and genetic algorithm, for achieving optimally large values of the signal-to-noise ratio (SNR) at a nanosecond scale. We demonstrate that our protocols outperform the usual periodic modulations on pointer state separation and SNR as well [2].
In addition, this allows us to suppress the unwanted transitions in the time-evolution operator such that the system dynamics resemble a controlled-phase gate acting in the qubit subspace at the nanosecond scale [3]. The reduced gating time mitigates the detrimental effect produced by the loss mechanisms in all the parties.
Finally, we show a possible implementation considering state-of-the-art circuit quantum electrodynamics architecture, see Figs. 1 and 2.

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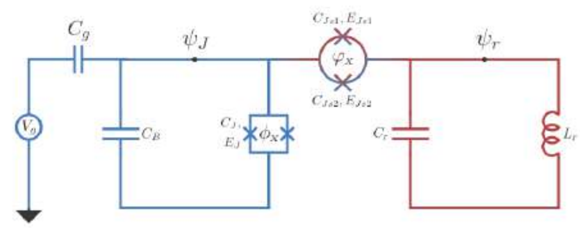

Figure 1: Schematic illustration of the experimental proposal for qubit readout: a transmon qubit formed by a capacitor C_B parallel-connected to a tunable inductor is biased by a gate voltage V_g through a gate capacitor Cg. The two-level system is coupled to an LC resonator of capacitance C_r and inductance L_r via an asymmetric SQUID threaded by an external magnetic flux φ_x. Furthermore, we describe the circuit in terms of their flux nodes ψ_J and ψ_r.

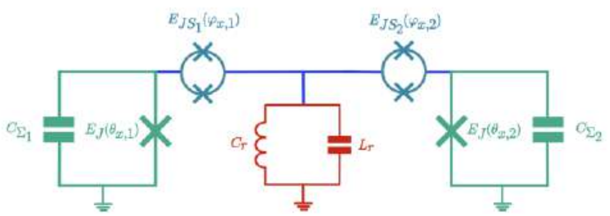

Figure 2: Schematic illustration of the experimental proposal for a controlled-phase gate: two transmon circuits formed by a capacitor $C_{\Sigma l}$ parallel connected to a tunable Josephson junction E_J $(\theta_{x,l})$ coupled to a LC resonator of capacitance C_r and inductance L_r via a SQUID threaded by an external magnetic flux $\varphi_{x,l}$.

Robust optimal control for a systematic error in the control amplitude

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In the NISQ era, physical qubits coherence time and high fidelity gates are essential to the functioning of quantum computers. In this work we demonstrate, theoretically and experimentally, that pulses (a trajectory can be found in Figure) designed by optimisation can be used to counteract the loss of fidelity due to a characterisation error of the coupling of the control to the qubit. We analyse the control landscape obtained by optimal control and find it to be dependent on the error and that the optimisation is less likely to converge at a slow gate-time. Robust controls are found for different error rates and are compared to incoherent loss of fidelity mechanism due to a finite relaxation rate. The controls are tested on the IBMQ's qubit and found to demonstrate resilience against significant ~ 10% errors.

Figures

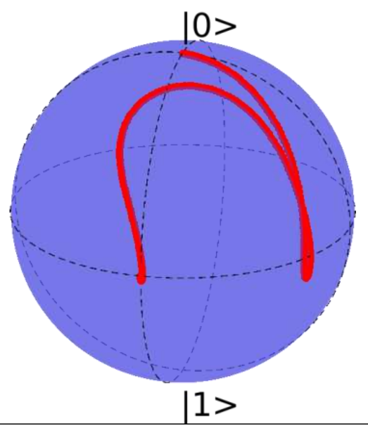

Figure: Robust trajectory of an optimised robust $X_{\pi/2}$ plotted on the Bloch sphere.

Implementing an erasure check for dual-rail qubits in 3D superconducting cavities

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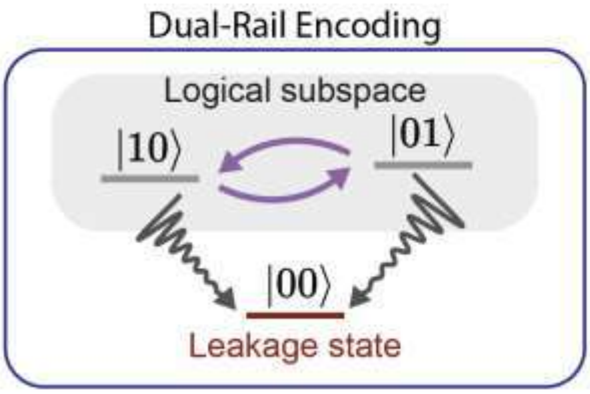
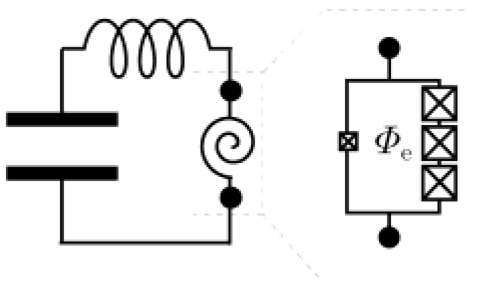
Erasure qubits, designed to error-detect the most likely errors as they occur at the hardware level, have drawn interest on various platforms as a means of achieving scalable quantum error correction with fewer requirements on coherence[1]. The challenge is that such a scheme relies on a high fidelity error detecting measurement.

We solve this problem in the context of circuit-QED for the superconducting dual rail qubit[2], comprising a single microwave photon in two high-Q superconducting cavities, for which the dominant error is photon loss, by engineering a non-destructive measurement of the total photon number parity in the two cavities. This measurement scheme[3] makes use of a strong tunable beamsplitter interaction between the two cavity modes, here enabled by a nonlinear SNAIL coupler[4], and the existing auxiliary transmon qubit used for state preparation. Crucially, we show that this implementation can be made fault-tolerant to both dephasing and relaxation errors on this auxiliary qubit. Further, we discuss how particular operating points of the SNAIL may be used to shield against residual noise originating in this coupler.



SNAIL
(flux-tunable 3-wave mixing coupler)



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Critical Parametric Quantum Sensing

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Abstract

Critical quantum systems are a promising resource for quantum metrology applications, due to the diverging susceptibility developed in proximity of phase transitions [1]. Here [2], we assess the metrological power of parametric Kerr resonators undergoing driven-dissipative phase transitions. We fully characterize the quantum Fisher information for frequency estimation, and the Helstrom bound for frequency discrimination. By going beyond the asymptotic regime, we show that the Heisenberg precision can be achieved with experimentally reachable parameters. We design protocols that exploit the critical behavior of nonlinear resonators to enhance the precision of quantum magnetometers and the fidelity of superconducting qubit readout [3].

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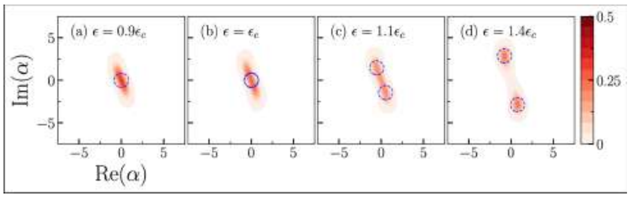

Figure 1: Wigner function of the Kerr resonator system steady-state. The figure shows the transition from the normal (a) to the symmetry-broken [(c) and (d)] phases, taking place at the critical point. The system is highly susceptible in the proximity of the criticality, and so it can be exploited in high-sensitivity magnetometer. The system shows two highly distinguishable phases, corresponding to the vacuum-like (a) and displaced state (d), a feature that can be exploited in high-fidelity qubit readout.

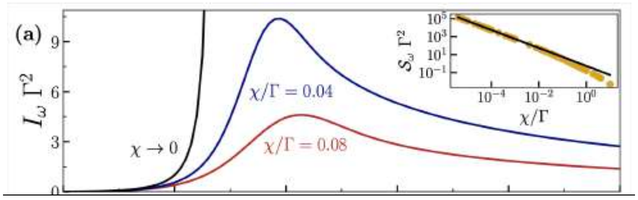

Figure 2: QFI of the estimation of the frequency as a function of the pump, and for various values of the non-linearity. In the inset we show that the Heisenberg scaling is reached for reasonable values of the non-linearity. Homodyne detection virtually saturates the QFI.

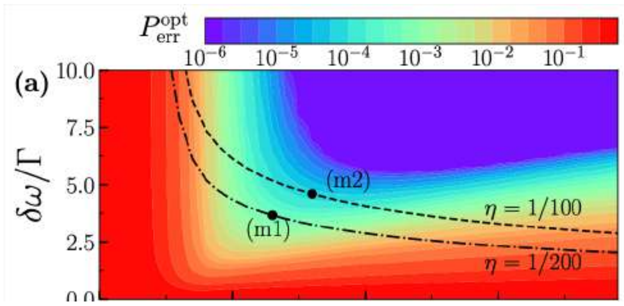

Figure 3: Qubit readout error probability map with respect to the qubit-resonator detuning $\delta\omega$, and for different values of the dispersive parameter η. For η=1/100, we can reach error probabilities values as low as 10^{-4} with the optimal measurement.

A Top-down Algorithmic Test for Comparing Imperfect Quantum Computers

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Abstract

We present a new top-down algorithmic test for quantum computers based on an unsolved math problem first posed by Gauss: finding quadratic nonresidues [1]. We report the results of running this new test on current quantum computers from IBM, IonQ, Honeywell.

No known classical algorithm finds quadratic nonresidues in polynomial time [2], but a new quantum algorithm does [3]. A quantum computer that finds quadratic nonresidues at a rate surpassing the maximal classical success rate provides evidence of quantum computation. Tests of different sizes can be constructed from primes congruent to 1 modulo 8. The smallest test (for $p = 17$) requires only four qubits to run. Arbitrarily large tests can be created from larger primes.

Results of the $p = 17$ test indicate that current quantum computers range from barely escaping the noise floor to providing promising evidence in the best cases. This math based test provides an agnostic comparison between different quantum architectures.

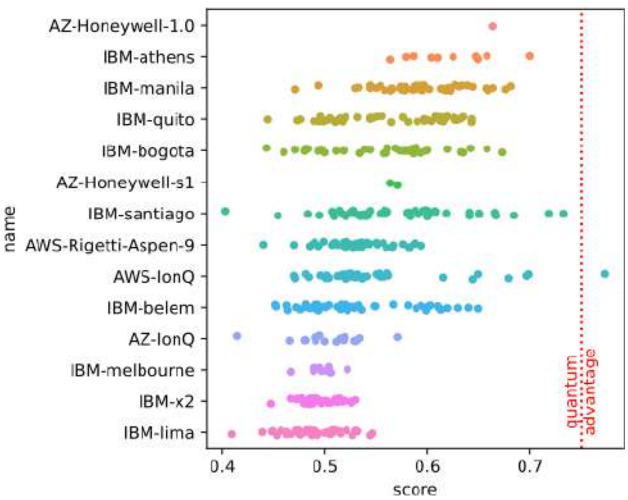

Figure 1. Average success rate of 1000 shot runs. Higher is better.

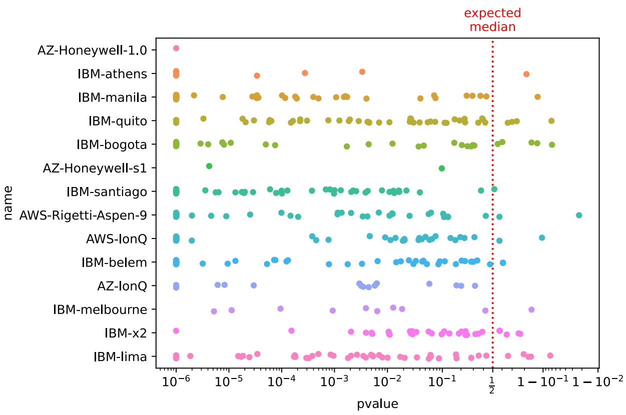

Figure 2. Uniformity score of 1000 shot runs. Higher is better

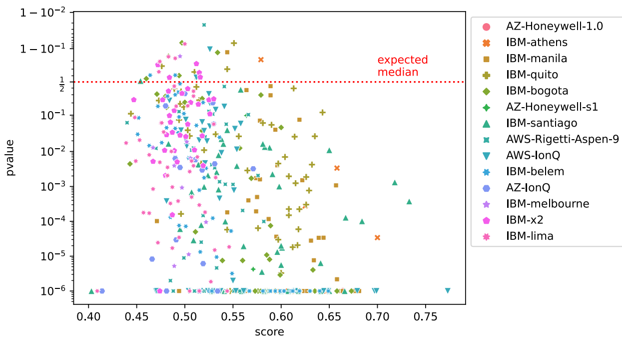

Figure 3. Success and uniformity score for 1000 shot runs. Upper right corner is better.

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Demonstration of long-range state quantum teleportation

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Abstract

Quantum state teleportation is one of the first and most fundamental examples of real-time quantum-classical processing, which includes mid-circuit measurements, classical computation, and feedforward operations, all done well within the coherence time, to achieve transmission of quantum information. Long range quantum teleportation is a more advanced version of quantum state teleportation, which allows transmitting quantum information across a large scale quantum processor using a constant depth circuit. In this work we demonstrate, for the first time, long range quantum teleportation performed across 7 qubits in the Sycamore processor. We demonstrate teleportation across 3, 5, and 7 qubits respectively and compare the result with a SWAP-based protocol. Our results show the feasibility of using teleportation for efficient state transfer across quantum processors of increasing size with nearest-neighbors connectivity. Moreover, our work unlocks the usage of real-time quantum-classical processing for further protocols that could increase efficiency of quantum algorithms towards quantum advantage.

IBM Quantum Platforms: A Quantum Battery Perspective

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We characterize for the first time the performances of IBM quantum chips as quantum batteries, specifically addressing the single-qubit Armonk processor [1]. By exploiting the Pulse access enabled to some of the IBM Quantum processors via the Qiskit package, we investigate the advantages and limitations of different profiles for classical drives used to charge these miniaturized batteries, establishing the optimal compromise between charging time and stored energy. Moreover, we consider the role played by various possible initial conditions on the functioning of the quantum batteries. As the main result of our analysis, we observe that unavoidable errors occurring in the initialization phase of the qubit, which can be detrimental for quantum computing applications, only marginally affect energy transfer and storage. This can lead counter-intuitively to improvements of the performances. This is a strong indication of the fact that IBM quantum devices are already in the proper range of parameters to be considered as good and stable quantum batteries comparable to state-of-the-art devices recently discussed in the literature. The possible extension of this analysis to the case of a three-level system will be also discussed [2] in comparison with state-of-the-art experiments [3].

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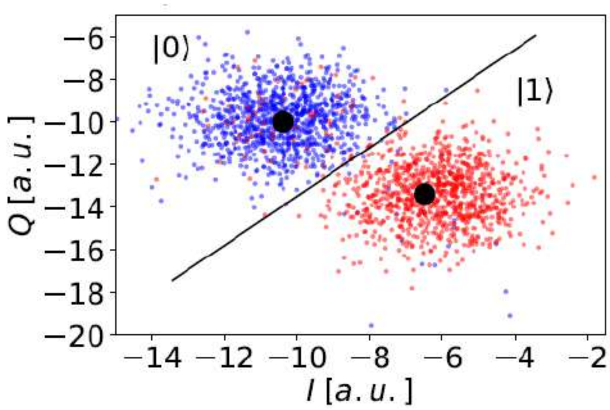

Figure 1: Example of data distribution associated to the measurements of the ground state (blue dots) and the excited state (red dots) in the (I, Q) plane (in arbitrary units) of the Armonk single-qubit device.

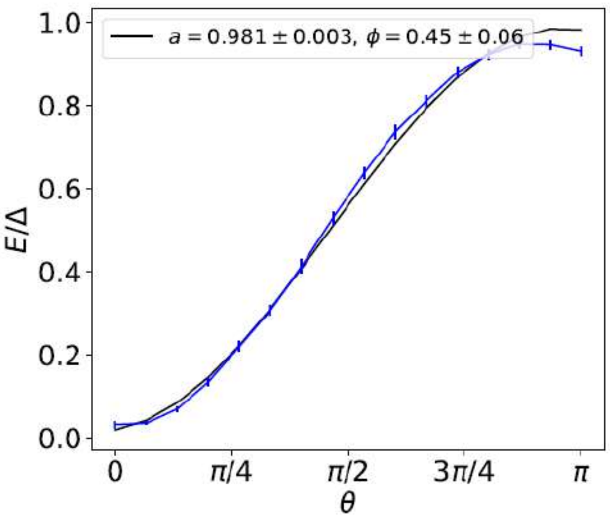

Figure 2: Best fit of the energy stored into the QB (in units of Δ) as a function of θ, time integral of the applied pulse, (black curves).

Quantum non-Gaussian force sensing

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Abstract

The talk will report recent theoretical and experimental achievements opening the door to highly non-Gaussian quantum sensing of single-atom motion. This territory is challenging for investigation, both theoretically and experimentally. We will present recent theoretical and laboratory achievements, mainly the experimental tests of quantum non-Gaussian phononic (Fig.1,2) and photonic states suitable beyond the classical method [1,2,3,4] and their applications in force sensing [5,6,7]. The talk will conclude with other related results and the following challenges in theory and experiments with atoms, mechanical oscillators and superconducting circuits to stimulate discussion and further development of this advancing and prospective field.

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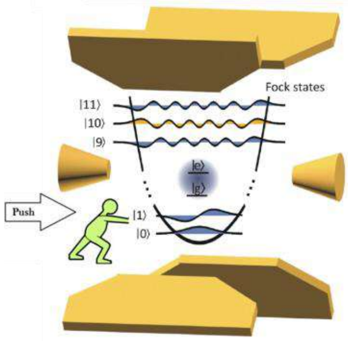

Figure 1: The mechanical force sensing of the axial harmonic motion of a single Calcium ion localized in a linear Paul trap. The generation and analysis of states approaching idealized Fock states illustrated by their corresponding wave functions are implemented by interacting the electronic ground and metastable states with the quantized harmonic motion on the first motional sidebands. The external force action coherently or thermally pushes the axial motion.

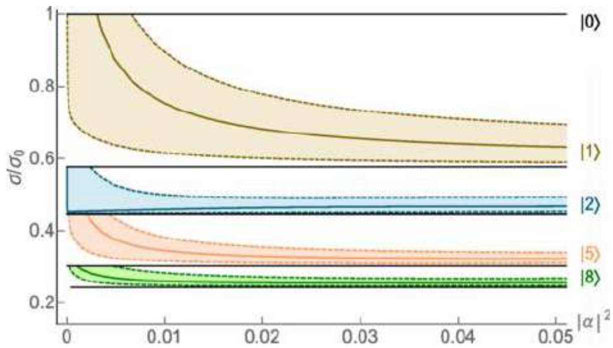

Figure 2: Estimating the metrological advantage of experimentally realized states for sensing a small force. The horizontal axis quantifies the amplitude in the phase space that the force causes. The vertical axis shows the minimal standard deviation estimated by optimization of the Fisher information in Eq. (3) normalized to sensing using a motional ground state. The black lines show that ratio for ideal Fock states. The brown, blue, orange and green solid curves correspond to prepared states approaching the Fock states with n=1,2,5,8, respectively. The coloured regions show the states with the phonon-number distributions within experimental error bars.

Field-Effect Josephson Diode with Anisotropic Spin-Momentum Locking States

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Abstract

The recently observed superconducting diodes generalized the conventional electronic nonreciprocal phenomenon category to a superconducting regime. We theoretically propose a topological Josephson diode, whose topologically protected maximal efficiency is 40% in a single edge and greatly optimized to 90% in a double-edge interferometer. As a transistor, the diode can be switched on/off, and its polarity can be reversed by controlling the gate voltage. The proposal fusing topological materials, superconductivity, and nonreciprocity may have a potential application in topologically superconducting electronics.

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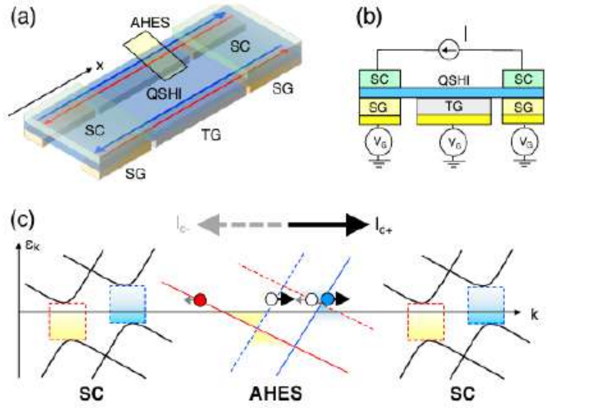

Figure 1: (a)Schematic of a topological Josephson diode (TJD) of quantum spin Hall insulator (QSHI) with anisotropic helical edge states (AHESs). The superconducting (SC) leads and the central normal region are controlled by the super gates (SGs) and the tunneling gate (TG), respectively. (b) A side view of TJD. (c) Schematic dispersions of the top edge states in the normal (central) and superconducting region.

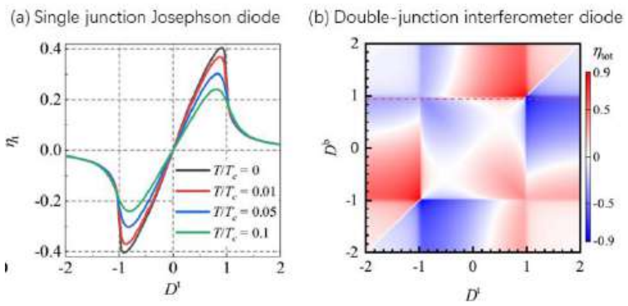

Figure 2: (a) Diode efficiency in a single edge via the electrically induced super gate. (b) Diode efficiency in a two-edge interferometer via the super gates in two edges.

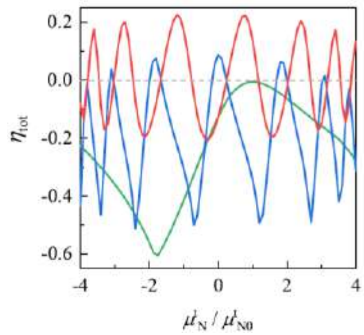

Figure 3: A Josephson diode transistor controlled by a tunneling gate.

Quantum metrology with non-Gaussian spin states

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The well-known spin squeezing coefficient efficiently quantifies the sensitivity and entanglement of Gaussian states [1,2]. However, this coefficient is insufficient to characterize the much wider class of non-Gaussian quantum states that can generate even larger sensitivity gains.

In this talk, we present a non-Gaussian extension of spin squeezing based on reduced variances of nonlinear observables that can be optimized under relevant constraints [3]. We determine the scaling of the sensitivity enhancement that is made accessible from increasingly complex quantum states generated by one-axis-twisting in the presence of relevant noise processes [4,5].

We analytically determine the quantum gain offered by slightly over-squeezed non-Gaussian spin states, which are accessible in state-of-the-art experiments. Our results also produce optimal measurement observables that extract maximal information about the parameter of interest from these states. Using these techniques, quantum metrology measurements can significantly outperform current standard strategies based on Gaussian states (Fig. 1).

When considering the effect of different, experimentally relevant noise processes, we identify a discontinuous scaling law of the optimal sensitivity. Not unlike a phase transition, this transition becomes sharp only in the thermodynamic limit, whereas it is washed out by finite-size effects otherwise.

Our analytical results provide recipes for optimal quantum-enhanced metrology measurements in atomic systems with non-Gaussian spin states in realistic conditions.

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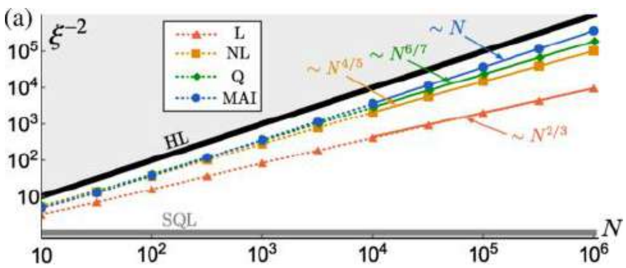

Figure 1: Comparison of the sensitivity scaling of different non-Gaussian metrology strategies (NL, Q, MAI) with that of the standard Gaussian method (L) and the Heisenberg limit (HL).

Strong coupling between a microwave photon and a singlet-triplet qubit

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Spin qubits offer a promising approach towards scalable quantum computing due to their long coherence time, small size, and fast gate operation times [1]. The combination with circuit quantum-electrodynamics could enable interconnectivity between distant qubits by using superconducting resonators as quantum buses, as is standard for superconducting qubits [2]. A promising way to couple the spin degree of a qubit to microwave photons of a superconducting resonator is by exploiting electron-dipole spin resonance which relies on spin-orbit interaction. This simplifies the devices architecture, since it does not require micromagnets [3-5].
In contrast to previous work, we are making use of the intrinsic spin-orbit interaction of zincblende InAs nanowires (NW) [6]. We use NWs that contain a built-in crystal-phase defined double quantum dot (DQD), where the tunnel barriers are grown in wurtzite crystal structure [7]. The DQD is coupled to a high quality, magnetic field resilient resonator [8]. To maximize the photon-qubit interaction [9] we use a high-impedance resonator with an impedance of ~2 kΩ. We investigate the hybrid DQD-resonator system and observe the formation of a singlet-triplet qubit. We reach the strong coupling limit between the singlet-triplet qubit and a single photon stored in the resonator.

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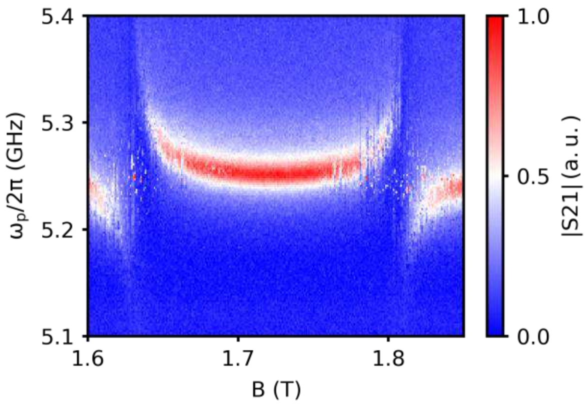

Figure 1: Resonator transmission as function of the magnetic field and the probe frequency revealing an anti-crossing between a resonator and a singlet-triplet qubit hosted in a semiconducting NW QD.

Signatures of classical chaos in driven transmons

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Keywords: circuit quantum electrodynamics, qubit readout, quantum chaos

Abstract: Transmons are ubiquitously used in superconducting quantum information processing architectures. Strong drives are required to realize fast high-fidelity gates and measurements, including parametrically activated processes. We show that even off-resonant drives, in regimes routinely used in experiments, can cause strong modifications to the structure of the transmon spectrum rendering a large part of it chaotic. Chaotic states, often neglected through the hypothesis that the anharmonicity is weak, strongly impact the lifetime of the computational states. In particular, chaos-assisted quantum phase slips greatly enhance band dispersions. In the presence of a readout resonator, the onset of chaos correlates with high transmon-resonator entanglement, and an average resonator response centered on the bare resonator frequency. We define a photon number threshold to characterize the appearance of chaos-induced quantum demolition effects during strong-drive operations, such as dispersive qubit readout. More generally, chaos-induced phenomena such as the ones studied here are expected to be present in all circuits based on low-impedance Josephson junctions.

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[1] Joachim Cohen, Alexandru Petrescu, Ross Shillito, and Alexandre Blais, arXiv:2207.09361references with sequential numbers within [square brackets].

Towards Microwave-Optical Transduction with an Embedded Mechanical Quantum Memory

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Being able to distribute operations on a quantum state over a network composed of spatially distant quantum registers has been a long-time interest for many researchers in the quantum information community [1-3].

To benefit from both the efficient processing of superconducting qubits and the ability of light to transport quantum information over long distances, it requires the ability to transduce microwave quantum states into optical quantum states.

Previous implementations of transduction schemes were limited either to the classical regime, where more than one quanta of input-referred added noise upon transduction was reported [4], or to a regime of low efficiency [5].

Soft-clamped SiN membrane resonators [6] offer long coherence times and can at the same time be coupled efficiently to optical and microwave degrees of freedom.

We have previously demonstrated ground state cooling through both optomechanical [7] and electromechanical coupling [8], signalling high quantum cooperativities >1 sufficient for low-noise transduction.

We here present our work towards building a quantum transducer with an embedded quantum memory using a phononic dimer [9] with two interaction zones.

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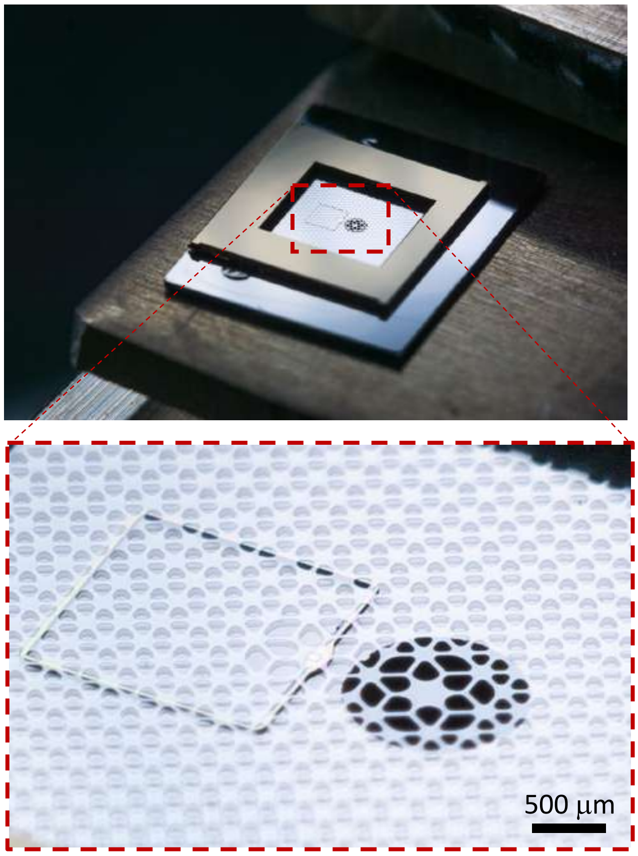

Figure 1: Photograph showing the coherent nanomembrane (patterned) that is coupled both to a microwave cavity underneath (square) and to an optical cavity with light propagation through the hole shown in black.

High cooperativity coupling to nuclear spins on a circuit quantum electrodynamics architecture

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Nuclear spins are candidates to encode qubits due to their isolation from magnetic noise. Yet, their weak coupling to external stimuli makes them hard to integrate into circuit-QED architectures, the leading technology for solid-state quantum processors. Here[1], we study the coupling of Yb^{3+} nuclear spin states in a Yb(trensal) molecule[2] to LC superconducting resonators with characteristic frequencies spanning the range of nuclear and electronic spin transitions. An external magnetic field is used to tune the nuclear and electronic spin transitions on resonance with the resonators. Our results show strong coupling of cavity photons to electronic spin states and a high-cooperativity coupling in the case of nuclear spins[1]. The nuclear spin-photon coupling is enhanced by the hyperfine interaction with the effective electronic spin. Attaining the coherent coupling regime is a requisite to perform non-demolition read-out of the electronic and nuclear spin states[3]. This technology can enable the implementation of quantum error correction protocols[4], in crystals of molecular spin qudits[2,5].

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Figures

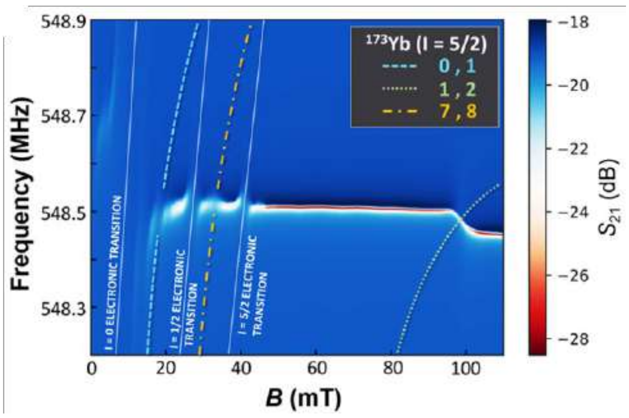

Figure 1: Transmission as a function of frequency and external magnetic field showing several Yb(trensal) spin transitions coupled to a superconducting resonator. Among these transitions, the coloured ones are nuclear spin transitions.

A Two-Node Quantum Network with Silicon-Vacancy Centers in Diamond

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Long-range quantum networks constitute an important enabling technology in quantum information science, with applications in quantum key distribution, nonlocal sensing, and distributed quantum computation [1].
Silicon-Vacancy (SiV) Centers in diamond (Fig. 1) have recently emerged as promising candidates for quantum networks due to their long coherence time, fast and high-fidelity single and two-qubit gates, and efficient spin-photon interface owing to their integration in nanofabricated optical cavities [2]. The integration of all these features into a single device has led to the demonstration of memory-enhanced quantum communication with the SiV [3].
We show here the realization of a two-node quantum network and demonstrate entanglement across the two nodes containing a single SiV each separated by a 20-meter optical fiber link (Fig. 2). This result paves the way for larger SiV-based quantum networks and quantum repeaters.

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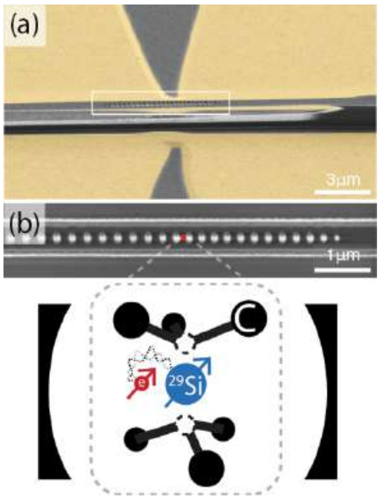

Figure 1: (a) SEM of nanobricated optical cavity, waveguide, and gold striplines for MW delivery. (b) Zoomed in section of the cavity. The SiV is located at the optical mode maximum (red dot).

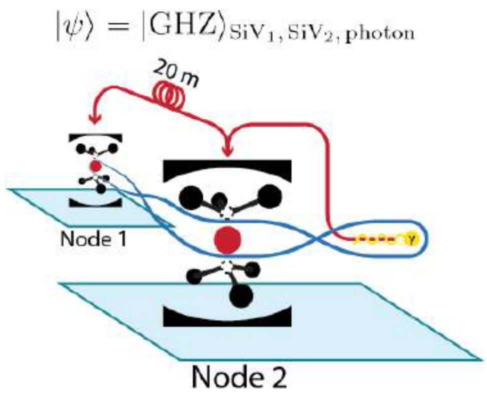

Figure 2: schematic of the two-node setup, with a photon mediating remote entanglement.

DISCRETION: Disruptive SDN enabled by QKD for secure communications for European Defence

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In a military context, information and communications services are of central importance in different areas. These services rely on secure and reliable infrastructure. In an operational or strategic context, these networks are often static and rigid. SDN (Software-defined Networking) allows increased network flexibility, agility and manageability. These properties are very desirable on dynamical environments, and the SDN can extend their benefits to interface with SDR equipment, in tactical networks. In addition, SDN can also ensure redundancy and resilience against network failures and losses. The adoption of an SDN also opens the possibility to have a flexible QKD network [1]. QKD provides a very secure way to distribute cryptographic keys to different points. However, QKD is fairly limited in reach and flexibility, usually relying on point-to-point connections and rigid infrastructures. SDN and QKD thus provide mutual benefits in symbiotic fashion: SDN enables a flexible QKD network, with control and monitoring capabilities, and QKD enables highly secure communications within the SDN.

DISCRETION intends to develop an SDN solution integrating QKD capabilities to support optical secure communications, in a way that European Defence can benefit from these technologies to be effective not only for the network but also for the cyber situational awareness. Cipher Machines will be the components responsible for assuring data protection and network segregation in DISCRETION, enabling real-time data encryption and decryption, using key material provided by the key management system integrated with the SDN-QKD plane as well as pre-shared keys. The red-black architecture of the military networks will be considered to provide the required level of security and segregation. Mobility and tactical scenarios with SDR solutions shall be analysed and integrated into the SDN framework to cover radio network segments and support secure communication services in mobile scenarios (see **Figure 1**). The DISCRETION project, with its programmable quantum key distribution components, will facilitate the improvement of security and resilience in the exchange of information and in communication services in the miliary network.

Figures

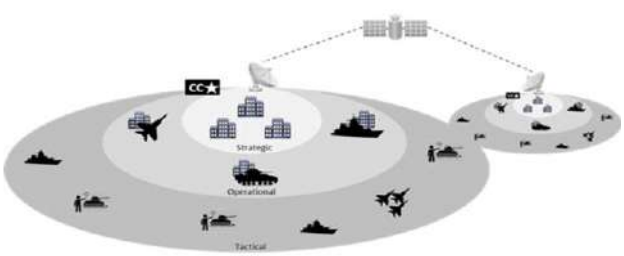

Figure 1: DISCRETION overall abstract scenarios

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Cavity-Assisted highly efficient Atomic Frequency Comb Solid-State Quantum Memory

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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 over a continental scale. Most quantum repeater schemes rely on the storage of quantum bits 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. However, the efficiency for the storage of quantum bits was so far limited to around 30%.

Here, we improved this efficiency by implementing a cavity-enhanced quantum memory in a Pr^{3+}: Y_2SiO_5 crystal. We use the atomic frequency comb (AFC) protocol [1], which offers intrinsic temporal multimodality. The forward retrieval efficiency of this protocol is theoretically limited to 54%. It is known that this limit can be overcome by embedding the crystal in an impedance-matched cavity to enhance the interaction with the material [2]. So far, the highest storage efficiency with this protocol was 56% for storage of classical pulses [3] and 27% for quantum storage [4]. With the setup sketched in Figure 1, we reached 62% efficiency for storing weak coherent states with a mean photon number of 0.2 photons/pulse. Furthermore, we were able to store weak coherent time-bin qubits with 52% efficiency and more than 95 % fidelity. Moreover, we report the first demonstration of cavity enhanced on-demand AFC memories at the single photon level. Currently the performance is limited by the intra-cavity losses and cavity bandwidth, which is dominated by the slow light effect caused by the sharp spectral features we burn inside our crystal.

In future experiments we plan to increase these efficiencies and to store single photons generated from a cavity-enhanced spontaneous-parametric down-conversion source.

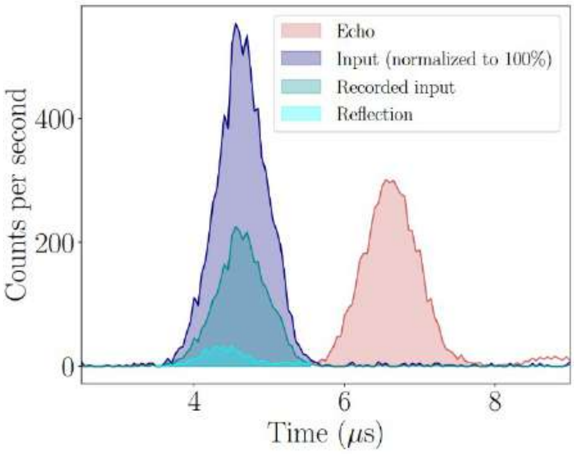

Figure 1: Histogram of both the input (cyan) and echo (red pulse) after 2µs. The mean photon number in the input pulse was 0.2 photons/pulse. The recorded input pulse (cyan pulse) is the reflected 40% of the original input pulse. The dark blue pulse is the input scaled to 100%. The ratio between the echo and the reconstructed input pulse yields 62% storage efficiency. The reflection from the cavity (light blue pulse) was 6%.

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Frequency tunable single Er ions as telcom quantum emitters

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During the past decade, rare-earth ions doped in crystals have emerged as promising candidates for optical quantum memories, owing to their long optical and spin coherence time [1].

Recently, advancements in high-quality factor and low-mode volume nanophotonic cavities have made individual rare-earth ions optically addressable [2, 3]. Furthermore, deterministic qubit detection [4] and nuclear spin control [5] have been achieved, marking a full-stack quantum node. Among all rare-earth ions, Erbium (Er) ions are of great interest in large-scale quantum networks due to their telecom light-matter interface.

In my talk, I will present our results on coupling single Er ions in a lithium niobate host with silicon nanophotonic cavities. Additionally, we have achieved linear Stark tuning of a single Er ion frequency for the first time, which is a crucial element in establishing a multi-node quantum network.

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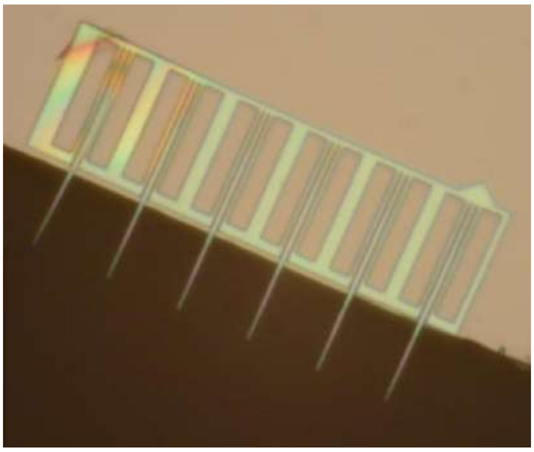

Figure 1: Silicon nanocavities on the Er:$LiNbO_3$.

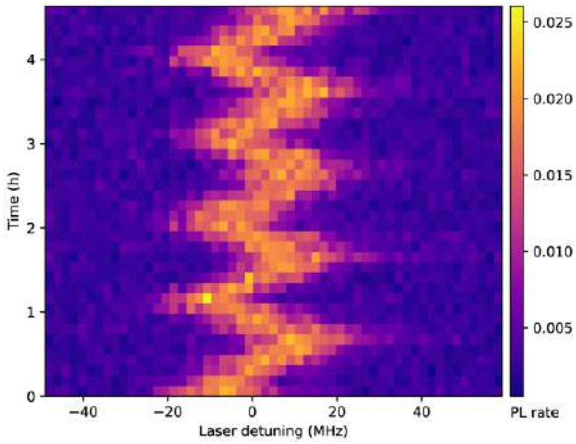

Figure 2: Stark tuning of the single Er ion.

Generation and control of non-local chiral currents in graphene superlattices by orbital Hall effect

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In this study, we present electrical measurements on single-layer graphene Hall-bars that are encapsulated within hexagonal boron nitride thin films and have a controlled twisting angle between the layers. The samples were fabricated using a cryo-etching method [1], which allowed us to achieve unprecedented control over the roughness of the edges. The entire structure was placed onto a thin graphite back gate to prevent dopants or trapped charges that can arise from standard semiconductor substrates [2].

We conducted a comprehensive study of the magnetotransport reponse of the structure at different temperatures, applying an in to-out-of-plane external field and paying special attention to the possible effects arising due to the Moiré pattern.

We present local and non-local signals and report a striking chiral behavior of the nonlocal currents at low magnetic fields resulting from a charge carrier-valley coupling. This behavior is in stark contrast to previous results of similar structures at different twisting angles [3]. The presented chiral response is found to be caused by the orbital valley Hall effect [4,5], with thorough theoretical calculations supporting our experimental results [6].

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Graphene based superconducting quantum circuits

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In the last decades, important efforts were made to improve the building blocks used in superconducting quantum technologies. The key elements are the quantum bit and the parametric amplifier, that allows to measure weak signals at the quantum limit in the microwave regime. Traditionally, these devices integrate a tunnel Josephson junction as a dissipation-free and magnetically tunable source of non-linearity. Recently, new platforms have been proposed to leverage an electrically tunable semiconductor weak link (graphene, InAs nanowire).
In this talk, I will present the first realization of a gate tunable Josephson parametric amplifier by using a graphene Josephson junction [1, 2]. The amplifier shows performances that are comparable to the ones obtained with tunnel junctions, i.e. an operation close to the quantum limit and a gain above 20dB (see Figure).
For Qubits, the most advanced gate tunable platforms is based on InAs nanowires and 2DEGs,
with coherence times reaching several µs [3, 4, 5]. I will present our efforts in developing a gate tunable graphene based transmon and show the specificity of this system, for instance a gate tunable anharmonicity.

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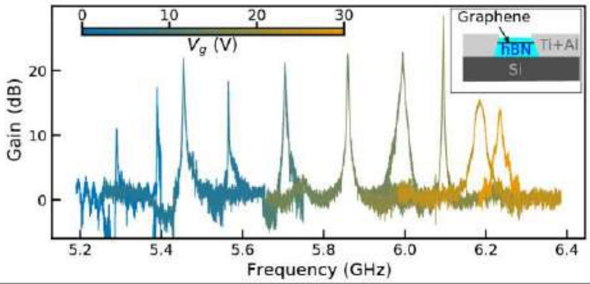

Figure 1: Gate voltage tuning of a Graphene Josephson Parametric Amplifier

Sub-nanometer mapping of strain-induced band structure variations in semiconductor devices

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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.

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]. Importantly, we ensure the obtained results are physically meaningful by removing and cleaning the parasitic signals that can arise when studying the low-loss spectral regime (i.e., Cherenkov radiation). The original methodology was developed and applied to an optoelectronic device based on a planar ZnSe/ZnTe core-shell heterojunction, although preliminary results will be shown on quantum devices, more specifically Ge/SiGe quantum wells for holding spin qubits and Ge/Si nanowires aiming towards topological quantum computing.

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Figures

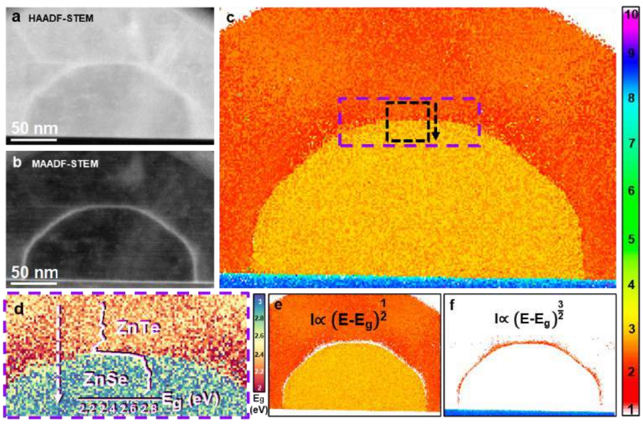

Figure 1: Bandgap maps obtained from applying the proposed methodology to a ZnSe/ZnTe nanowire.

Heavy quasiparticles and cascades without symmetry breaking in twisted bilayer graphene

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Twisted bilayer graphene (TBG) shows a great variety of correlated phases. In particular, cascades in the spectroscopic properties and in the compressibility in a large range of energies, twist angle and temperature have been observed. We have studied [1] an eight (per spin and valley) orbital model for θ=1.08° TBG, including the intra- and inter-orbital interactions [2], within a self-consistent dynamical mean field theory (DMFT) + Hartree approximation. Symmetry breaking is not allowed. We reproduce the observed cascade flow of spectral weight [3,4,5], the oscillations of the remote band energies [3] and the asymmetric jumps in the inverse compressibility [5]. Our results show that the spectral weight reorganization associated to the formation of local moments and heavy quasiparticles, and not a symmetry breaking process, is responsible for the cascade phenomena.

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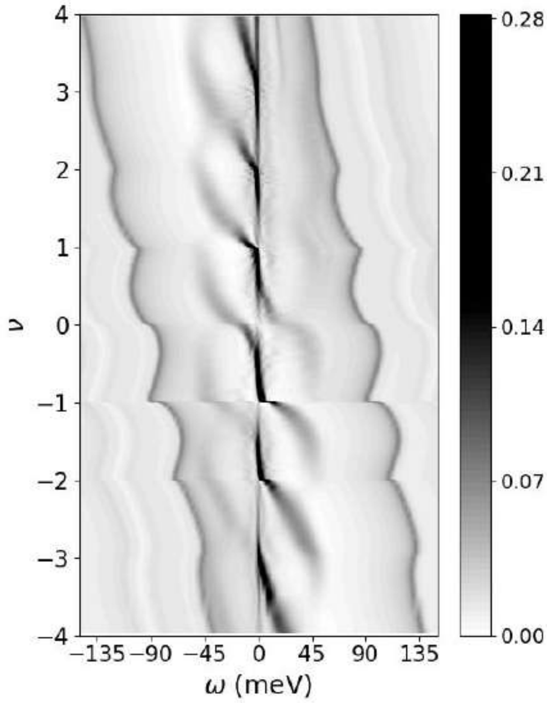

Figure 1: Color plot of the density of states resulting from the DMFT+Hartree calculations as a function of doping and energy showing the cascades. See [3] for the experimental plots.

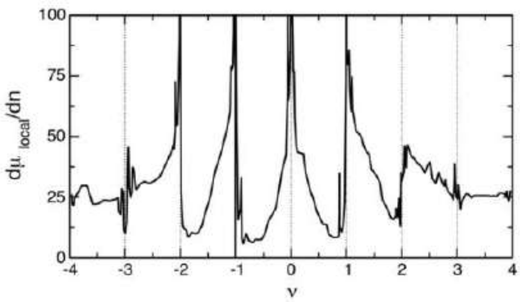

Figure 2: Local inverse compressibility resulting from our calculations as a function of doping. We find the asymmetric peaks observed in [5].

Semiconductor-Superconductor-Ferromagnetic heterostructure as a Platform for Topological Superconductivity

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Hybrid structures comprising semiconducting (SM) nanowires, epitaxially grown superconductors (SC), and ferromagnetic-insulator (FI) layers have been experimentally and theoretically explored as alternative platforms for achieving topological superconductivity at zero magnetic field [1]. In this work [2], we analyze a tripartite SM/FI/SC heterostructure realized in a planar stacking geometry, where the thin FI layer acts as a spin-polarized barrier between the SM and the SC. We optimize the system's geometrical parameters using microscopic simulations to find the range of FI thicknesses for which the hybrid system can be tuned into a quasi-one-dimensional topological regime. Within this range, and due to the vertical confinement provided by the stacking geometry, trivial and topological phases alternate regularly as the external gate is varied, displaying a hard topological gap that can reach half of the SC gap. This represents a significant improvement compared to setups using hexagonal nanowires. Additionally, we propose a specific x-y pattern for the SC that would enable the development of a quasi-two-dimensional topological superconducting phase on this platform. Our results offer new possibilities for designing topological superconducting devices without the need for a magnetic field.

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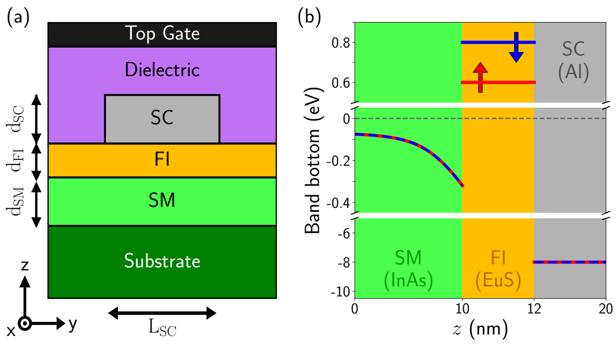

Figure 1: (a) Sketch of the device: 2D semiconductor (SM)/ferromagnetic insulator (FI)/superconductor (SC) heterostructure stacked in the *z*-direction. The top gate can be used to confine the wavefunction below the grounded SC. (b) Schematics of the conduction-band bottom along the heterostructure stacking direction for a specific choice of materials (InAs/EuS/Al). Red and blue colors represent different spin directions.

Ultra-bright single photon source based on an atomically thin material

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Solid-state single photon sources are central building blocks in quantum communication networks and on-chip quantum information processing [1]. Atomically thin crystals were established as possible candidates to emit non-classical states of light [2,3], however, the performance of monolayer-based single photon sources has so far been lacking behind state-of-the-art devices based on volume crystals. Here, we implement a single photon source based on an atomically thin sheet of WSe_2 coupled to a spectrally tunable optical cavity [4]. It is characterized by a high single photon purity with a $g^{(2)}(0)$ value as low as 4.7 ± 0.7 % and a record-high first lens brightness of linearly polarized photons as large as 65 ± 4 %. Interestingly, the high performance of our devices allows us to observe genuine quantum interference phenomena in a Hong-Ou-Mandel experiment.
Our results demonstrate that open cavities and two-dimensional materials constitute an excellent platform for ultra-bright quantum light sources: the unique properties of such two-dimensional materials and the versatility of open cavities open an inspiring avenue for novel quantum optoelectronic devices.

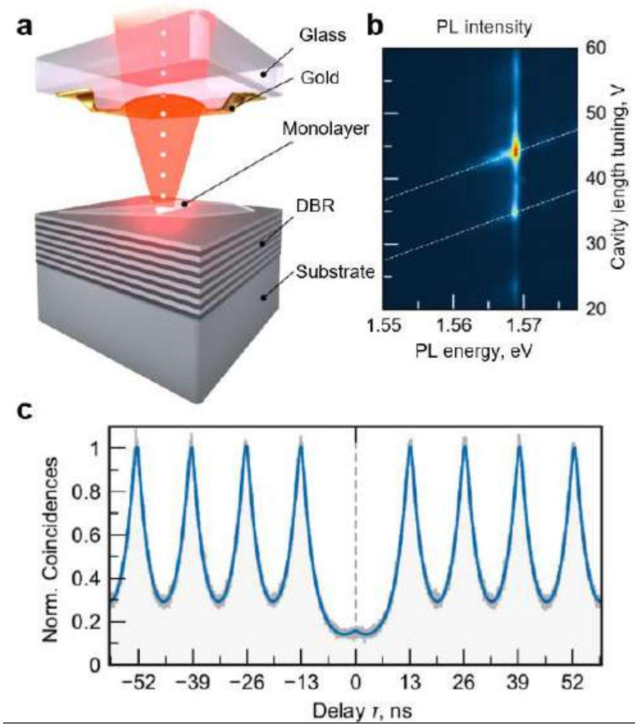

Figure 1: a Single photon emission from a monolayer in a plano-convex open cavity under optical excitation. The relative position of the top and bottom mirror is adjustable by nano-positioners. **b** Photoluminescence spectra upon tuning the cavity optical length for above-bandgap excitation at 532 nm. Cavity modes are highlighted by dashed lines. **c** Second order autocorrelation function of single photons measured in a Hanbury-Brown-Twiss experiment with 76.2 MHz pulsed excitation.

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Emerging Exotic Phases in Unconventional Superconductors with Long-range Interactions

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Continuum limits are a powerful tool in the study of many-body systems, yet their validity is often unclear when long-range interactions are present. In this work, we rigorously address this issue and put forth an exact representation of long-range interacting lattices that separates the model into a term describing its continuous analog, the integral contribution, and a term that fully resolves the microstructure, the lattice contribution [1].
For any system dimension, any lattice, any power-law interaction, and for linear, nonlinear, and multi-atomic lattices, we show that the lattice contribution can be described by a differential operator based on the multidimensional generalization of the Riemann zeta function, namely the Epstein zeta function.
We employ our representation in Fourier space to solve the important problem of unconventional superconductors with density-density long-range interactions. We derive a generalized Bardeen–Cooper–Schrieffer gap equation and find emerging exotic phases in two-dimensional superconductors with topological phase transitions. Finally, we utilize non-equilibrium Higgs spectroscopy [2] to analyze the impact of long-range interactions on the collective excitations of the condensate.
We show that the interactions can be used to fine-tune the Higgs mode's stability, ranging from exponential decay of the oscillation amplitude up to complete stabilization.

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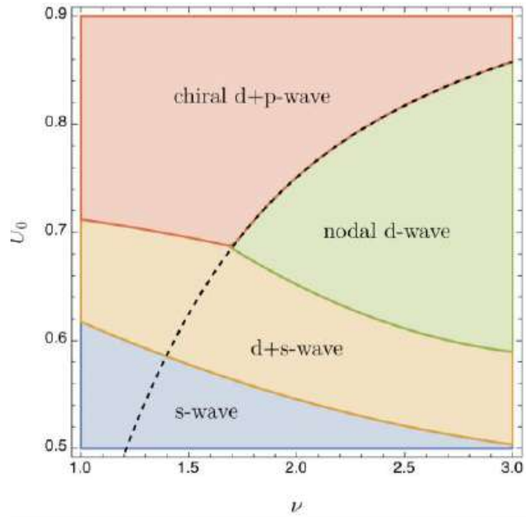

Figure 1: Zero temperature phase diagram for a 2D superconductor depending interaction exponent ν and interaction strength U_0.

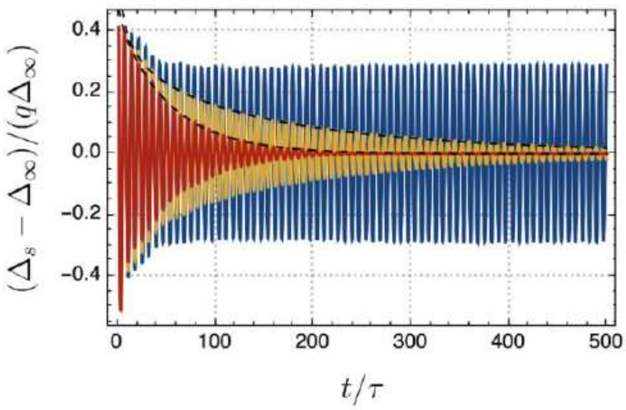

Figure 2: Higgs oscillation of a 2D superconductor demonstrating Higgs mode stabilization depending on the interaction exponent ν.

Implementation of hybrid Al/EuS heterostructures in the superconducting tunnelling devices

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Interfacing thin metallic films with magnetic insulators leads to modification of its electronics structure due to exchange interaction of the conduction band electrons with magnetic ions. Depending on the metal it gives rise to reach variety of phenomena like non-reciprocal transport properties [1,2], cryogenic thermoelectric effect [1,3] or spin hall effect [4,5]. This talk is aimed to present recent results of implementation of the Al/EuS - based superconducting tunnelling junctions (see Fig 1), which display superconducting tunnelling diode effect and cryogenic thermoelectric effect [1-3]. The emphasis will be put on the properties of the Al/EuS interface and on the effect that magnetic properties of thin EuS films have on the exchange interactions on the interface [4,5].

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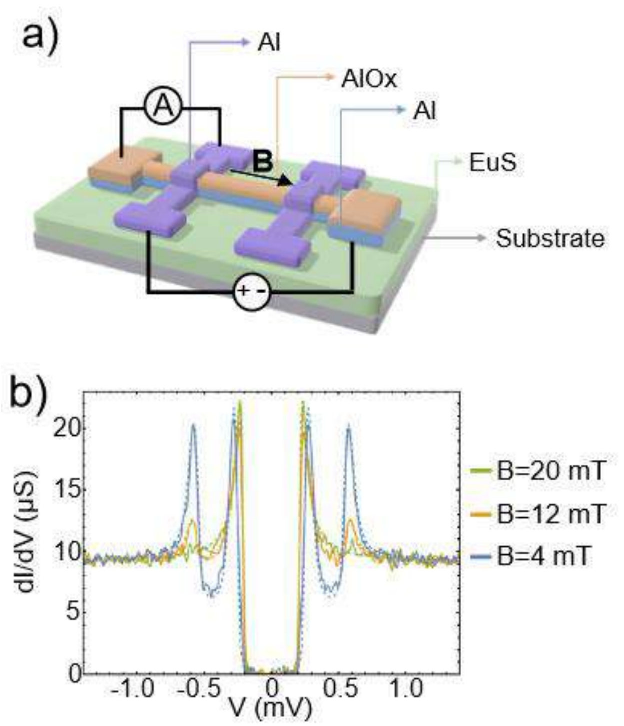

Figure 1: Schematic representation of the Al/EuS-based tunnelling junctions (a). Tunnelling spectroscopy measurements that show spin-split states in the Al/EuS heterostructures (b)

Single nanographenes as quantum emitters

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Recent years have shown an increasing number of studies focused on new light emitters for various applications and in particular for quantum technologies. In this context, nanographenes have great assets since bottom-up chemistry allows a total control on the structure, which opens the way to wide customization of their optical, and spin properties [1–3]. The full benefit from these opportunities needs addressing nanographene intrinsic photophysical properties. To do so, single molecule photoluminescence experiment is a powerful tool [4].

Here, we will focus on small nanographenes where electrons a confined in the three dimensions of space, the so-called graphene quantum dots (GQDs). We will show that our degree of control on the structure allows us to address both the influence of the size and of the symmetry of the GQD on its properties: emission wavelength, polarization selection rules, oscillator strength... We will report on experiments performed at the single molecule level and from room to cryogenic temperatures. We will show that the experimental results are well predicted by extensive DFT/TDDFT calculations combined with molecular dynamics simulations. [5-7].

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A simple quantum circuit using ESR with the scanning tunnelling microscope

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Abstract

A scanning tunnelling microscope (STM) can drive the spin evolution of a single atom, molecule or nanostructure on a solid surface [1]. A tunnelling electron current is localized on a single atom, while the bias is modulated at microwave frequencies. The measured current shows excitations attributed to a spin resonance (ESR). We have developed software to simulate virtually any instance of ESR-STM under realistic conditions of temperature, external fields, and electron conductance [2,3].
Here, we suggest the realization of a quantum circuit that converts a product state to a maximally entangled state (the GHZ state), Figure 1. To do this, the first step of the sequence (a Hadamard gate) is implemented to act on the first spin. Figure 1 shows the evolution of the first spin of our simulation when initialized in the '0' state, transformed into a rotating frame, and then represented on the Bloch sphere. The evolution onto the final state (a Bloch vector pointing on the 'x' direction) demonstrates the realization of the Hadamard gate, plus current-induced decoherence if a longer evolution time is used as shown in the Figure. The right-hand graph shows the time-resolved tunnelling current of the simulated STM, with the interruption of the driving pulse and the fast Larmor oscillation. A similar rotation from the '1' state to the negative 'x' direction on the Bloch sphere is also demonstrated. The CNOT operation is performed on pairs of qubit driving one single frequency as shown in [1]. To characterize our circuit, we evaluate its fidelity on the desired GHZ state. This allows us to discuss the performance of the simulated gate using tunnelling currents and solid state-hosted spins.

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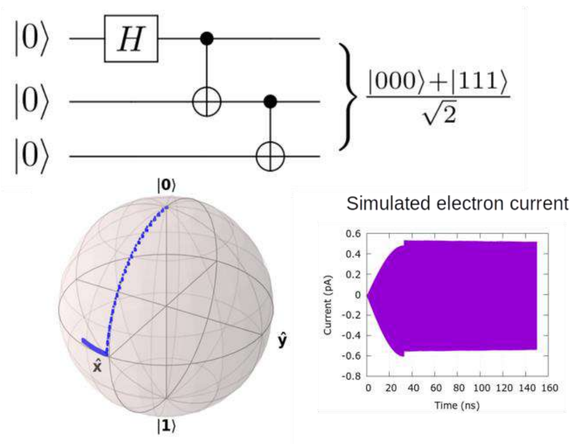

Figure 1: Scheme of the simple quantum circuit converting a product state to a maximally entangled state. The Bloch sphere shows the evolution of the first qubit in the ESR-STM implementation that we proposed, where the electronic current plotted on the right graph is the physical observable of this technique.

Theory of adiabatic charge pump with a topological insulator nanowire device

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Charge pumping can be realised in "almost open" unbiased confined nanostructures by applying two or more slowly varying, periodic potentials. Differently from previous quantum dot-based devices that rely on strong Coulomb blockade interaction, adiabatic charge pumping is applied to non-interacting electronic systems and exploits the constructive interference of the scattering states. The presence of Dirac-like states, which are protected from non-magnetic disorder, at the surface of 3D topological insulators (TIs), makes this material an optimal candidate for the design of improved charge pump devices.

In this work we show how quantised adiabatic charge pumping can be achieved in a confined nanostructure based on a topological insulator nanowire. Differently from two-dimensional TIs, the bulk electronic transport of TI nanowires is highly suppressed. Therefore, the exploitation of these low-dimensional structures can be found beneficial in devices that use their protected surface states. The theoretical study presented here focuses on a recently proposed device where the charge confinement is achieved via a radius variation along the nanowire [1]. The pumping mechanism is studied within the Landauer-Büttiker formalism and involves the use of only electrostatic gates applied to the restricted radius regions (see Figure), avoiding the use of strong local magnetic fields, experimentally difficult to work with. Limitations and possible extensions of the protocol are also presented.

Figures

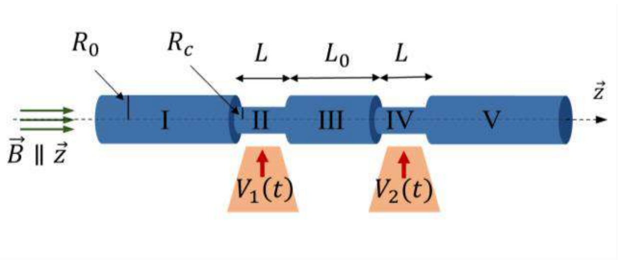

Figure: Schematic of the proposed device: a TI nanowire of radius R_0 is etched in regions II and IV, of length L and reduced radius $R_C < R_0$, leaving region III of length L_0 in between. Regions I and V are assumed of infinite length. To implement adiabatic quantum pumping, two oscillating electrostatic gates with a nonzero phase difference, $V_1(t)$ and $V_2(t)$, are applied to regions II and IV respectively.

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Engineering long-lived vibrational states for an organic molecule

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Single organic molecules are promising contestants for realizing quantum optical networks in solid-state platforms due to their outstanding coherent properties [1]. Such a high degree of coherence is a result of strong zero-phonon lines that are Fourier-limited linewidths. However, their associated timescales are limited to nanoseconds, which implies a significant challenge for practical implementations of quantum networks with such molecular platforms.

In this theoretical work, we propose exploiting the optomechanical character of single molecules in the solid-state to build a new molecular system with quantum coherences up to millisecond timescales [2]. For such purpose we tailor the host matrix of a single organic molecule to the nanoscale and position it on a structured phononic environment that suppress its phononic decay [3] (see illustrations in Fig. 1). We show that the resulting long-lived vibrational states in these systems facilitate reaching strong optomechanical regimes at single photon level, which can be witnessed from strong anti-stokes scattering in the molecular emission spectrum. We exploit such long optomechanical coherence time of the molecule to store and retrieve optical information with proper pulse excitation up to milliseconds (see Fig. 2). The proposed system shows the prospects of organic molecules for reaching unexplored optomechanical regimes and realizing long-lived quantum memories.

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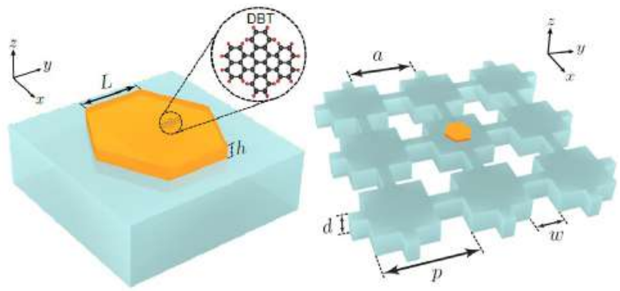

Figure 1: Left: Illustration of an anthracene nanocrystal doped with a single dibenzoterrylene molecule on a substrate. Right: Hybrid cavity formed by the nanocrystal-molecule system on top of a phononic crystal structure with suppressed phonon density of states [3].

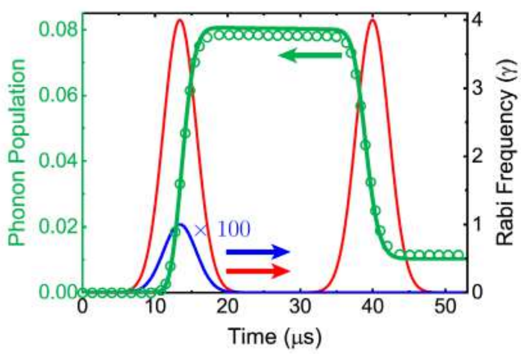

Figure 2: Coherent optical generation of ms-lived phonons by stimulated Raman scattering in the proposed molecular system.

Electronic transport in Weyl semimetals with a uniform concentration of torsional dislocations

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Abstract

In this article[1], we consider a theoretical model for a type I Weyl semimetal, under the presence of a diluted uniform concentration of torsional dislocations. By a mathematical analysis for partial wave scattering (phase- shift) for the T-matrix[2,3], we obtain the corresponding retarded and advanced Green's functions that include the effects of multiple scattering events with the ensemble of randomly distributed dislocations[1]. Combining this analysis with the Kubo formalism, and including vertex corrections[1], we calculate the electronic conductivity as a function of temperature and concentration of dislocations. We further evaluate our analytical formulas to predict the transport coefficients (electrical conductivity, thermal conductivity and Seebeck) of several transition metal monopnictides, i.e. TaAs, TaP, NbAs and NbP.

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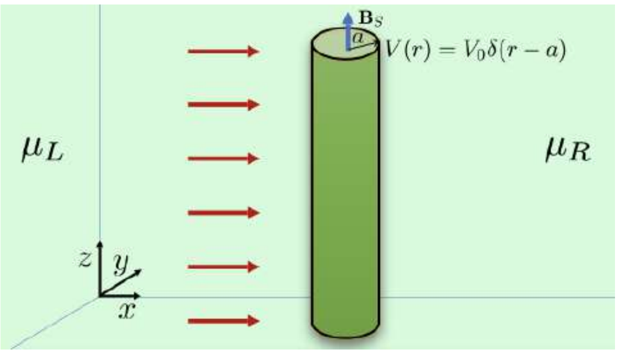

Figure 1: Scattering of Weyl fermions by a single torsional dislocation

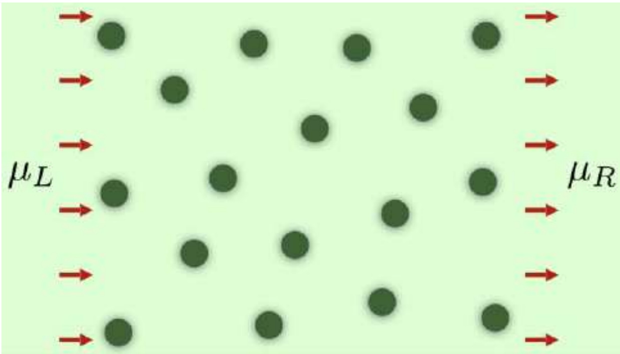

Figure 2: Random distribution of torsional dislocations in a bulk Weyl semimetal (as seen from a plane perpendicular to the dislocation´s axis)

Revealing the exotic statistics of anyons in the fractional quantum Hall regime

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Anyonic statistics is a unique and fascinating property of 2d systems, where fundamental excitations can exhibit a statistics which is neither bosonic nor fermionic, but intermediate between the two. In particular, anyonic statistics should apply to the quasiparticles of the Fractional Quantum Hall Effect (FQHE), as was predicted theoretically more than 30 years ago. The experimental demonstration of anyonic statistics has been elusive for a long time. Only very recently, two experiments studying electronic transport in chiral edge states of the FQHE, but using very different setups, have been able to demonstrate unambiguously the anyonic statistics [1-2]. These impressive experiments have triggered an intense theoretical activity, whose progress will lead to a better and deeper understanding of anyonic statistics and its consequences. However, one obvious drawback of both theoretical proposals and experimental detection schemes for the statistical angle of quasiparticles resides in the fact that the setups typically involve several quantum point contacts (QPC), constituting both a theoretical and an experimental challenge.

In this work, we show that using narrow periodic pulses of voltage, periodically exciting fractional charges, and measuring the Hong-Ou-Mandel noise [3] at the output of a single QPC, one obtains a signal which is directly related to the anyonic statistics. To this aim, we first explain the unique properties of the time-dependent tunnelling current at a QPC when a single fractional quasiparticle is incident, which are associated with braiding of the fractional quasiparticle with the thermal anyonic excitations occurring at the QPC. Our quantitative predictions, obtained with perturbative calculations performed using the non-equilibrium Keldysh Green function formalism, could be checked with current experimental techniques, providing a relatively easy path for the study of fractional statistics.

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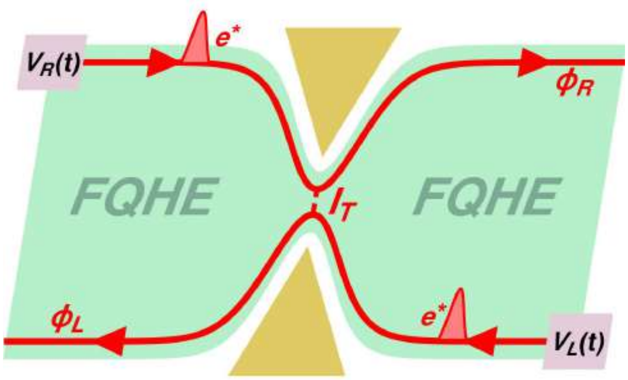

Figure 1: Schematic view of the setup. A Hall bar in the Laughlin series, equipped with a quantum point contact, is driven by two time-dependent potentials.

Controlling the photoluminescence of quantum emitters in hexagonal boron nitride by applied magnetic fields

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Abstract

The recent observation of room temperature spin-dependent photoluminescence (PL) emission from hexagonal boron nitride's (h-BN's) defect centers makes them a highly interesting platform not only for quantum information science but also for quantum sensing applications. In this talk, we will discuss the PL emission dynamics of h-BN's visible single-photon emitters under an external out-of-plane magnetic field at liquid helium temperature. In particular, we found that the PL intensity of the emitters strikingly exhibits strong magnetic field dependence and decreases with the increased magnetic field. [1] A pronounced decrease in the integrated PL intensity of the emitters by up to one order of magnitude was observed when the applied field is increased from 0 T to 7 T. The observed reversible photodarkening of PL emission is in very well agreement with the predictions of a recent joint experimental and theoretical study [2] and can be attributed to the activation of very efficient non-radiative intersystem crossing transitions under applied magnetic field.

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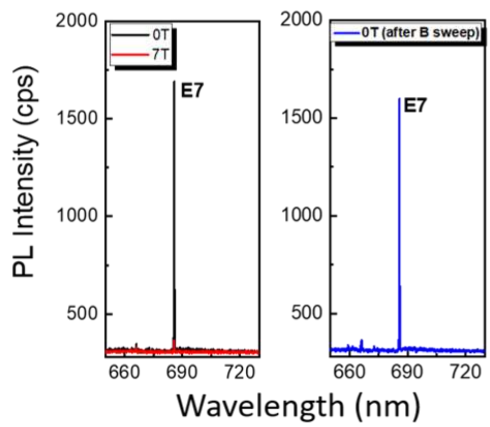

Figure 1: Left panel: Low-temperature PL spectra of h-BN defect emitter with (red line) and without (black line) external magnetic field. **Right panel:** PL spectrum of the same emitter after the magnetic field was removed.

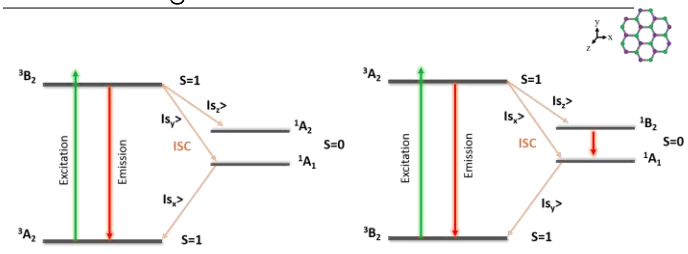

Figure 2: The electronic level structure to explain the observed photodarkening effect in the PL emission of the h-BN defect emitter.

Strain-Driven Bandgap Increase in Twisted 2D Quantum Materials: A Nanoscale Study

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Twisted two-dimensional materials offer a unique platform to realise novel quantum nano-optoelectronics applications thanks to the sensitivity of their local electronic properties with respect to their underlying crystal atomic arrangements [1-4]. However, the limitations of existing techniques to access this subtle structure/property interplay with nanoscale resolution have made it challenging to disentangle the effects that variations in local strain, thickness, and rotation angle between layers have on their electronic properties. Here we present a novel strategy for determining the dependence of the bandgap energy on local thickness and strain fields in twisted van der Waals materials. This is an essential step towards a quantitative understanding of bandgap dynamics at the nanoscale in these materials. By combining electron energy-loss spectroscopy boosted by machine learning [5,6] and 4D scanning transmission electron microscopy using an Electron Microscopy Pixel Array Detector, we evaluated the bandgap and local strain fields in twisted WS_2 with nanoscale resolution. Our findings indicate that the bandgap energy can increase by up to a factor of 30% in regions characterised by sizeable twist angles between layers and hence by marked local strain fields (Figure 1). Our approach provides a novel toolbox in our quest to unveil the relationship between strain and bandgap dynamics in 2D materials. Furthermore, it can also be applied to more complex 2D materials geometries and heterostructures, as required for the development of novel technologies for quantum devices.

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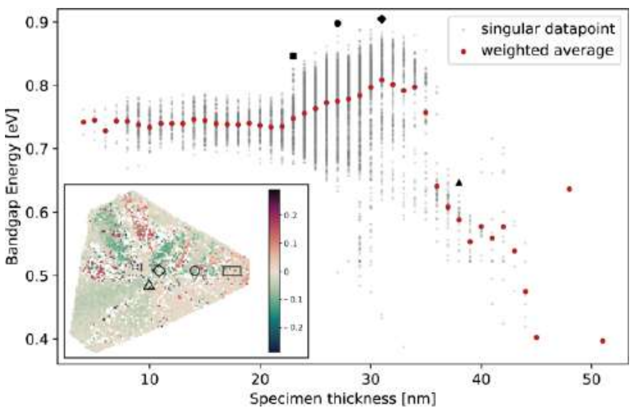

Figure 1: Visualisation of the relation between the specimen thickness and bandgap energy in a twisted WS_2 flake. (inset) local strain map of the ε_{xy} component on the same twisted flake.

Novel Excitons in $MoSe_2$ from Proximitized Charge Density Waves

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Two-dimensional (2D) materials allow for the construction of heterostructures without the constraint of lattice matching. This increased flexibility enables novel proximity effects through the stacking of strongly correlated 2D materials on 2D semiconductors. A general strategy for engineering quantum matter therefore becomes apparent through the creation of emergent states at the interface of different layered materials. Here we use temperature-dependent photoluminescence (PL) microscopy to reveal a new proximity effect where excitons in monolayer $MoSe_2$ interact with the commensurate charge density wave (CDW) in bulk $TiSe_2$ [1]. Below the CDW ordering temperature we observe a new PL emission line (H1) on the $TiSe_2$-$MoSe_2$ interface that is 30 meV higher in energy than the neutral exciton. This observation is unique compared to other examinations of 2D heterostructures where additional spectral features appear at lower energies compared to the neutral exciton. Power and temperature-dependent measurements show that H1 behaves as a free exciton, therefore excluding interface trapping or localization as an explanation. Most interestingly, we find that H1 disappears above the $TiSe_2$ CDW ordering temperature, which suggests that the CDW plays a vital role in activating this previously unobserved exciton. We discuss possible CDW-based origins of H1 and outline future opportunities for using proximity effects in 2D heterostructures to engineer and achieve ultrafast control over novel excitonic states.

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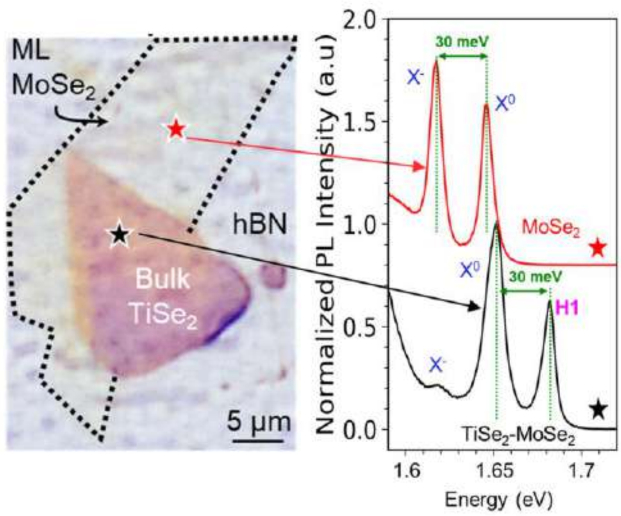

Figure 1: (left) Image of $TiSe_2$-$MoSe_2$ heterostructure. (right) 5 K PL spectra on (black) and off (red) the interface. The negatively charged trion (X^-) and neutral exciton (X^0) are visible in both spectra, however a new emission feature H1 appears 30 meV above the neutral exciton on the $TiSe_2$-$MoSe_2$ interface.

Planar Hall effect in noble metal doped type II Dirac Semimetal $PdTe_2$

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Abstract

The study of planar Hall effect (PHE) in topological semimetals has gained tremendous research interest lately. However, there is no clear picture about the origin of PHE in these systems due to the coexistence of chiral anomaly and orbital magnetoresistance (MR). Palladium ditelluride ($PdTe_2$) is a type-II Dirac semimetal with positive longitudinal MR, which makes it a good candidate to host topological superconducting states [1, 2]. It shows superconductivity below 1.7 K and exhibit topologically non-trivial surface states [3]. The intercalation of 5% Cu enhances the superconducting transition temperature to 2.6 K [4]. Recently there have been reports of PHE in $PdTe_2$ [5, 6], that stimulated our interest in studying the PHE in the Cu and Ag intercalated compound; $Cu_{0.05}PdTe_2$, $Ag_{0.05}PdTe_2$. We observed positive longitudinal MR, linear field dependence of the amplitude of PHE, and the tilted prolate shaped orbits in parametric plot that point toward the importance of Fermi surface anisotropies in understanding the origin of PHE in a system like $PdTe_2$. The existence of positive MR and PHE raises a doubt over the notion of chiral anomaly as an origin of PHE in the systems [7, 8]

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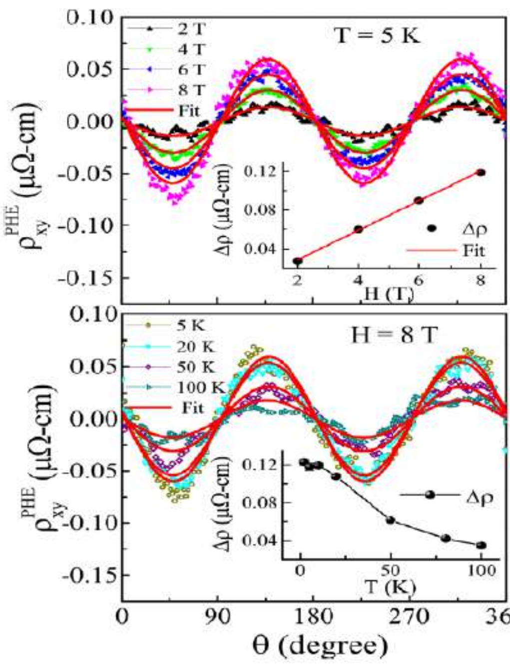

Figure 1: Planar Hall Resistivity at T = 5 K (upper) and H = 8 T (lower) for $Cu_{0.05}PdTe_2$.

High-fidelity quantum information processing and quantum simulation with spin qubits and phonons

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We propose and analyze the implementation of high-fidelity, phonon-meditated gate operations and quantum simulation schemes for spin qubits associated with silicon vacancy centers in diamond. Specifically, we show how the application of continuous spin-echo techniques can substantially boost the coherence of the qubit states while increasing at the same time the variety of effective spin models that can be implemented in this way. Our detailed analytical and numerical simulations show that this technique can be used to suppress gate errors by more than two orders of magnitude and to reach gate infidelities of $\sim 10^{-4}$ for experimentally relevant noise parameters. Therefore, the generalization of this approach to phononic lattices with arrays of implanted defect centers offers a realistic path toward moderate- and large-scale quantum devices with spins and phonons, at a level of control that is comparable to other leading quantum-technology platforms.

Neural-network-assisted quantum magnetometers

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As important branches in quantum technologies, quantum sensing and quantum metrology have experienced significant progress, placing themselves at the forefront of the new generation of technologies harnessing quantum effects. In this presentation, different quantum magnetometers assisted by neural networks are introduced. Our results show that neural networks are valuable in distinct quantum systems for quantum sensing leading to adaptive protocols for quantum detection with broad working regime and high accuracy.

Firstly, the benefits to integrate neural networks are illustrated to decipher the information contained in the sensor responses at the data processing stage of general quantum sensing tasks. We experimentally demonstrate that the combination of $^{171}Yb^{+}$ atomic sensors with adequately trained neural networks enables to investigate target fields in distinct challenging scenarios [1]. In particular, we characterize radio frequency fields in the presence of large shot noise, including the limit case of continuous data acquisition via single-shot measurements. Furthermore, by incorporating neural networks, we significantly extend the working regime of atomic magnetometers into scenarios in which the RF driving induces responses beyond their standard harmonic behaviour [2].

Secondly, the way for the practical use of quantum many-body systems as black-box sensors exploiting quantum resources to improve precision estimation is demonstrated. Entangled quantum many-body systems can be used as sensors that enable the estimation of parameters with a precision larger than that achievable with ensembles of individual quantum detectors [3]. Neural networks faithfully reproduce the dynamics of quantum many-body sensors, thus allowing for an efficient Bayesian analysis. We exemplify with an XXZ model driven by magnetic fields and demonstrate that our method is capable to yield an estimation of field parameters beyond the standard quantum limit scaling.

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Tunable Andreev-Conversion of Single-Electron Charge Pulses

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Electron quantum optics explores the coherent propagation and interference of single-electron charge pulses in electronic nano-scale circuits that are similar to table-top setups with photons [1]. So far, experiments with dynamic single-electron emitters have focused on normal-state conductors. However, the inclusion of superconducting elements [2,3] would pave the way for a wide range of applications that exploit the electron-hole degree of freedom, for example, for quantum information processing or quantum sensing. Here, we propose and analyze a tunable mechanism for the on-demand conversion of single-electron pulses into holes through Andreev processes on a superconductor [4]. To this end, we develop a Floquet-Nambu scattering formalism that allows us to describe the conversion of charge pulses on a superconductor, and we show that it is possible to generate arbitrary superpositions of electrons and holes with the degree of mixing controlled by the magnetic flux in an interferometric setup. We provide a detailed discussion of the optimal operating conditions in realistic situations and demonstrate that our proposal is feasible based on current technology.

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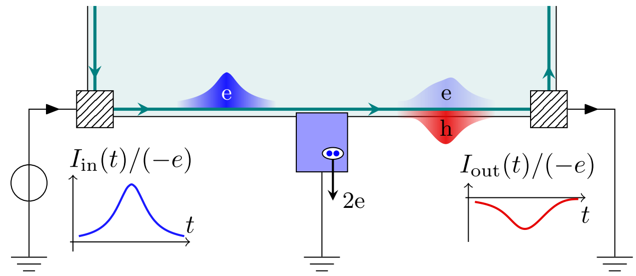

Figure 1: Andreev conversion of a charge pulse. Clean single-electron states are injected into a chiral edge state by applying Lorentzian-shaped voltage pulses to the input contact. Through partial Andreev reflections on a superconductor, the charge-pulses are converted into coherent superpositions of an electron (e) and a hole (h).

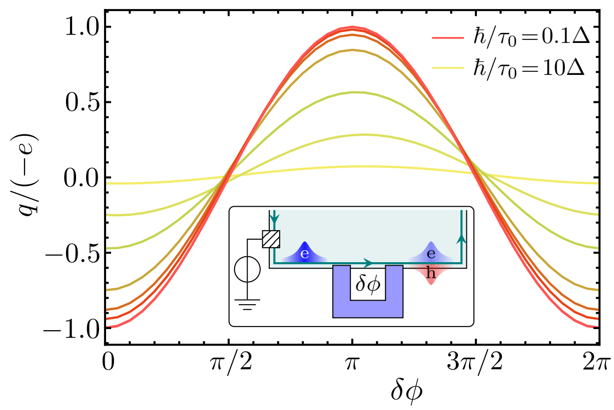

Figure 2: Tunable electron-hole conversion. The degree of conversion can be controlled by the phase difference $\delta\phi$ between two superconductors.

Dynamics Beyond Hard-Core Bosons in Transmon Arrays

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Transmons can be considered as quantum mechanical multilevel systems being promising platforms for quantum information science. Taking the higher excited states into account, arrays of coupled transmons realize the attractive Bose-Hubbard model, see Fig. 1(a).
Here we present the higher exited states dynamics in the phase most relevant to transmon arrays [1] with the main focus on unitary [2] and nonunitary [3] effects. Our method combines high order perturbation theory and numerical simulations.
Since the interaction energy is approximately conserved, we observe various collective effects of many-body unitary dynamics. For example, a few bosonic excitations at one transmon group a single quasiparticle that experiences effective off-site interactions with other quasiparticles, individual bosons, and the edges of the arrays.
For nonunitary case, we distinguish three main processes: many-body decoherence, many-body dissipation, and transitions between the anharmonicity manifolds, see Fig. 1(b). The unitary dynamics is broken by these many-body processes. We describe in detail the numerical and analytical effects generated by dissipation and dephasing processes in transmons arrays dynamics. The dissipation induces transitions between the different boson-number manifolds that occur at a rate proportional to the instantaneous total boson number. Dephasing reduces the coherence of many-body superpositions at a rate proportional to the squared distance between the many-body Fock states. Considering experimentally relevant parameters, including site-to-site disorder, we show that the state-of-the-art transmon arrays should be ready for the task of demonstrating coherent many-body dynamics using the higher excited states.

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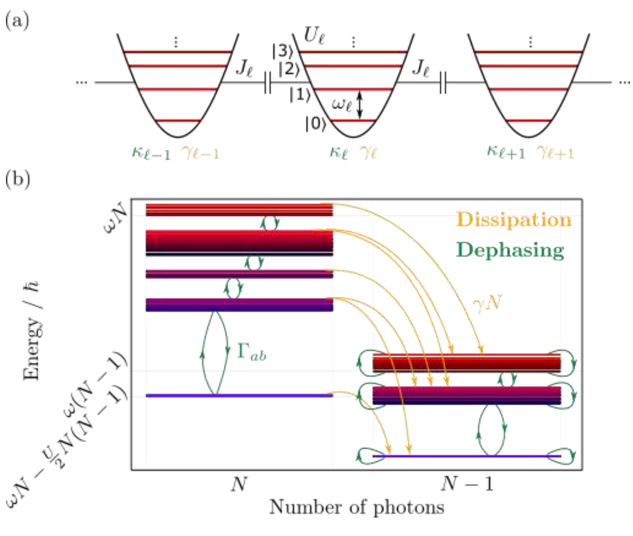

Figure 1: (a) A schematic of a 1D transmon array, where the transmons are represented as anharmonic oscillators. (b) A many-body energy level spectrum of a transmon array and a schematic showing many-body transitions due to the dissipation (yellow) and dephasing (green) processes. The coloured bands denote the anharmonicity manifolds containing several many-body eigenstates. The red and blue colours of the energy levels represent the relative contributions of the hopping energy and anharmonicity, respectively.

Josephson junctions and nanoSQUIDs grown by Focused Ion Beam Induced Deposition (FIBID)

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Focused Ion Beam Induced Deposition (FIBID) is a direct-write resist-free nanolithography technique that enables the growth of high-resolution nano- and micro-structures. FIBID relies on a gas precursor that is injected into the area of interest and decomposed by a focused ion beam. Several precursors have been reported to produce superconducting deposits, as recently reviewed by us [1], among which $W(CO)_6$ is the most popular one. Using $W(CO)_6$, superconducting in-plane nanowires with 20 nm lateral resolution have been achieved [2], as well as three-dimensional superconducting helical nanowires [3]. In this contribution, we will present recent results on the fabrication of Josephson junctions and nanoSQUIDs based on FIBID-grown W-C deposits. First, results of W-C nanoSQUIDs patterned as two large pads connected by two short nanowires will be shown. In these devices, the critical current oscillates as a function of the externally-applied magnetic field, which results in a large output voltage to magnetic flux change (1.3 mV per magnetic flux quantum) [4]. Interestingly, these nanoSQUIDs can be implemented on a cantilever, which would find applications in scanning-SQUID technology. Secondly, experiments on Josephson Junctions (JJs) and nanoSQUIDs based on Bi_2Se_3 micro-crystals and W-C superconducting contacts will be discussed. The obtained results indicate the coexistence of various oscillatory responses corresponding to the individual behaviour of the JJs and to the SQUID interferences [5]. In summary, FIBID has been found to be very useful for the nanoscale direct-write fabrication of superconducting devices for application in quantum technologies [6].

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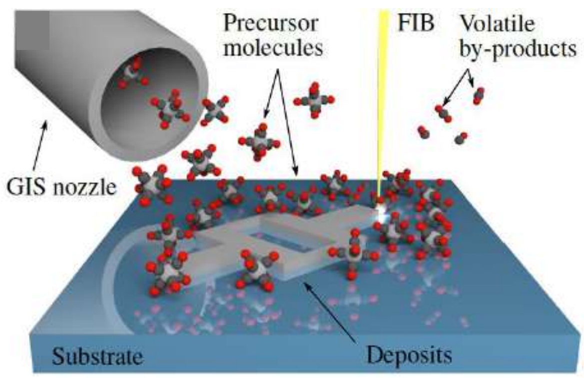

Figure 1: Sketch showing the growth of a W-C nanoSQUID by Focused Ion Beam Induced Deposition (FIBID) technique.

Photoinduced pair correlations in Mott and excitonic insulators

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Recent developments in ultrafast laser spectroscopy have enabled the observation of metal-superconductivity and insulator-metal photoinduced phase transitions and have opened a new venue for the study of strongly correlated electron systems. From a theoretical point of view, however, the simulation of nonequilibrium dynamics involves complex time-evolution calculations and must therefore rely on numerical calculations, such as the time-dependent exact diagonalisation method for small clusters and dynamical mean-field theory. When considering comparisons with the above experiments, it has been desirable to develop numerical techniques for larger systems without mean-field bias.

In this talk, we present a numerical technique based on the tensor-network algorithm [1,2], which allows the computation of nonequilibrium dynamics directly in the thermodynamic limit in the case of (quasi-)one-dimensional systems with translational symmetry. The method is applied to light-induced systems of Mott [2,3] and excitonic insulators [4], revealing photoinduced insulator-to-metal phase transitions.

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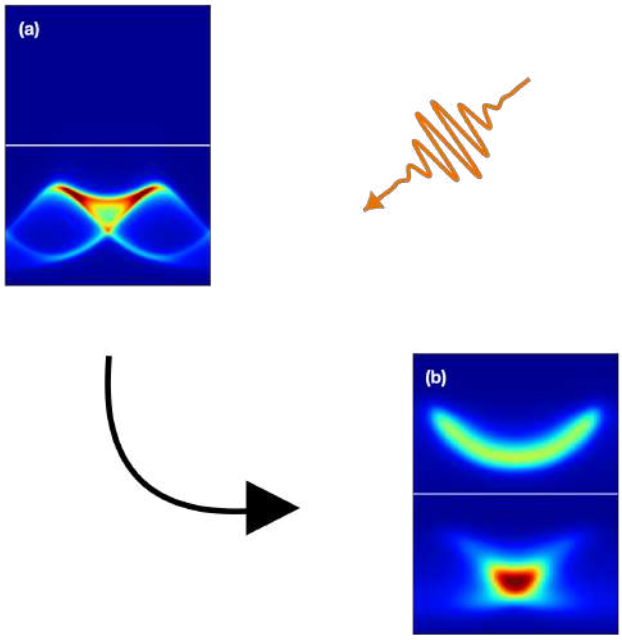

Figure 1: Photoinduced quantum phase transition from Mott (a) to superconducting-like η-pairing (b) states.

Driven-dissipative topological phases in parametric resonator arrays

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The topology of non-Hermitian systems has gained interest due to some new effects with technological applications. Among them, one of interest is topological amplification.
In this talk I will describe the phenomena of topological amplification in arrays of parametric oscillators [1].
I will show the presence of two phases of topological amplification (Fig.1), both with directional transport and exponential gain with the number of sites, and one of them featuring squeezing [2].
I will also show a topologically trivial phase with zero-energy modes which produces amplification but lacks topological protection.
Finally, to physically characterize these phases, I will describe their resilience to disorder, their stability, gain and noise-to-signal ratio (Fig.2). Also, I will discuss their experimental implementation with state-of-the-art techniques in arrays of Josephson junctions [3].

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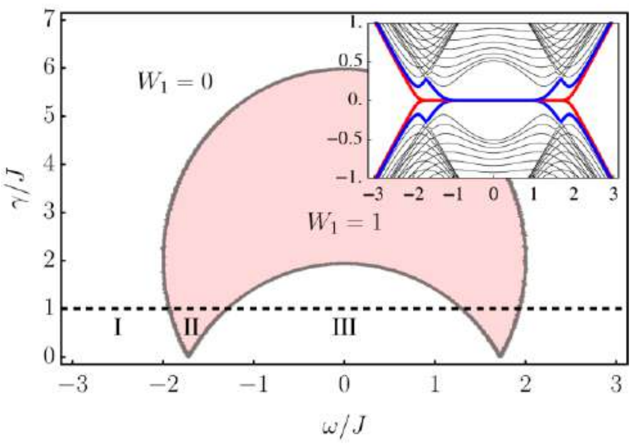

Figure 1: Topological phase diagram as a function of frequency and losses. Inset: Spectrum at the value indicated by the dashed line.

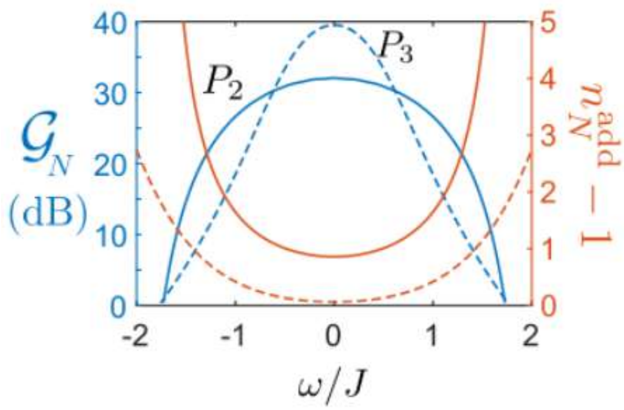

Figure 2: Gain and noise added by the amplifier at different points of the phase diagram.

Single-photon source over the THz regime

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Terahertz (THz) radiation (lying at frequencies from 0.1 THz to 70 THz) has sparked a broad interest recently due to its potential application in a wide array of areas, primarily related to imaging and spectroscopy [1]. We present the design strategy for a tunable source of single photons operating in the terahertz regime. Our proposal transforms incident visible photons into output THz ones through three elements: an optical laser, a nanophotonic THz cavity, and a single polar quantum emitter. The dressing of the latter by the laser fields gives rise to THz transitions in the system, which are coupled to the THz cavity through the emitter permanent dipole moment [2,3]. However, to the best of our knowledge, only classical properties of the THz radiation generated---such as the emission spectrum---or semi-classical lasing limits have been considered. We demonstrate that this scheme can produce strongly antibunched THz radiation with considerable brightness, offering optical tunability of properties such as the frequency of the emission or its quantum statistics by modifying the intensity and frequency of the drive. Beyond antibunching, we show that the emission features a rich landscape of quantum correlations, also featuring multi-photon emission and non-classical cross-correlations among different spectral frequencies. We demonstrate that the implementation of this scheme is feasible with current state-of-the-art photonics technology.

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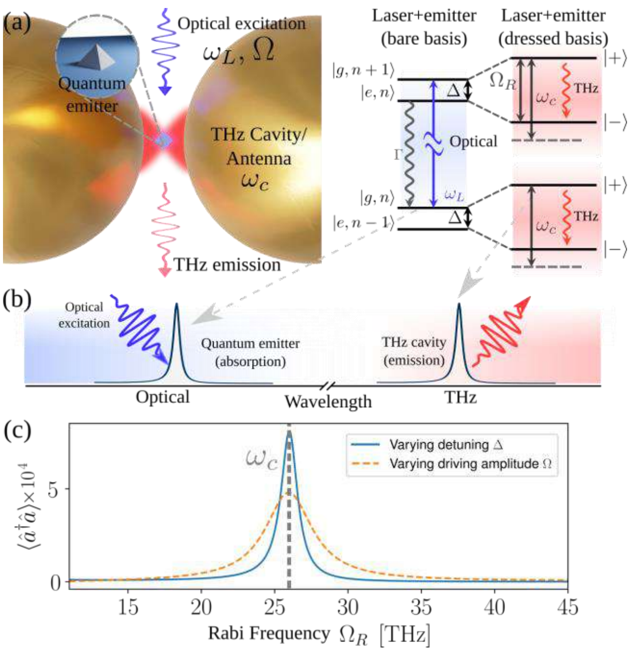

Figure 1: (a) Sketch of the experimental implementation (left) and energy level structure (right): left part represents the bare states basis highlighting energy differences in the optical domain (blue); right side represents the dressed-state basis highlighting THz transitions (red). (b) Absorption and emission properties in the THz and the optical domain. (c) Resonance in the cavity population as the Rabi frequency crosses the cavity frequency.

Variational quantum simulation of frustrated quantum magnets in the thermodynamic limit

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Variational quantum algorithms (VQA), generically characterized by a feedback loop between a quantum device and a classical optimizer, are at the center of current research for their potentiality in providing first useful applications of noisy intermediate scale quantum (NISQ) devices in problems ranging machine learning and quantum simulation. However, various roadblocks have been identified in their optimization, potentially hindering any applicability of VQA. Quantum simulation of two-dimensional (2D) frustrated quantum magnets offers a natural arena for benchmark and development of VQA, for they pose a challenge to state-of-the-art numerical techniques and at the same time host a plethora of phases with implications for quantum computation. In this talk, I will present a VQA to simulate 2D frustrated quantum magnets in the thermodynamic limit. Building upon hierarchical mean-field theory (HMFT) and the cluster-Gutzwiller ansatz, a parameterized quantum circuit respecting square superconducting chip connectivities provides the wave function of the cluster, while information of the infinite lattice is provided through a self-consistent mean-field embedding. After reviewing some long-standing questions in frustrated quantum magnetism and the basics of HMFT, I will provide benchmark numerical simulations of the *quantum-assisted* HMFT (Q-HMFT) on the paradigmatic J1-J2 Heisenberg antiferromagnet on the square lattice showing that the convergence of the algorithm is pushed by the onset of long-range order, opening a promising route for quantum simulation of 2D quantum magnets and their quantum phase transitions to valence bond solid phases with current superconducting circuit technology. I will end by discussing different applications and extensions.

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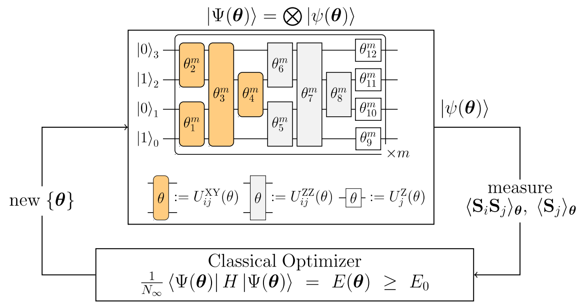

Figure 1: Algorithmic flow of Q-HMFT for a 4-qubit cluster-Gutzwiller.

An Algorithm for Reversible Logic Circuit Synthesis Based on Tensor Decomposition

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An algorithm for reversible logic synthesis is proposed. The task is, for given n-bit substitution map $P_n : \{0,1\}^n \rightarrow \{0,1\}^n$, to find a sequence of reversible logic gates that implements the map. The gate library adopted in this work consists of multiple-controlled Toffoli gates denoted by C^mX, where m is the number of control bits that ranges from 0 to $n - 1$.

The main idea is to view an n-bit substitution map as a rank-$2n$ tensor and to transform it such that the resulting map can be written as a tensor product of a rank-$(2n - 2)$ tensor and the 2×2 identity matrix. The process is iteratively applied until it reaches tensor product of only 2×2 matrices.

Time complexity of the algorithm is exponential in n as most previously known algorithms for reversible logic synthesis also are, but it terminates within reasonable time for not too large n which may find practical uses. Our primary target is to reduce the number of Toffoli gates in the output circuit. Benchmark results show that the algorithm works well for hard benchmark functions, but it does not seem to be advantageous when the function is structured. A working code written in Python is publicly available from GitHub. The algorithm is applied to find reversible circuits for cryptographic substitution boxes which are being used in some block ciphers.

Plasmon-induced switching of the emission mode of semiconductor quantum emitters

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The formation of weak plasmon-exciton coupling on the nanoscale is a prospective way to overcome some limitations of quantum emitters (QEs) based on semiconductor nanocrystals. Realization of the coupling between plasmon resonance and absorptive transitions of QEs allows for an increase in the efficiency of photoexcitation of QE and thus increases the photoluminescence (PL) intensity. In turn, the coupling of plasmon resonance and radiative transition of QE is a prerequisite for the Purcell effect realization, an increase of the radiative rate, and enhancement of the PL quantum yield (QY). Previously we have shown that these effects may be realized and even combined for the stronger enhancement of both exciton and biexciton PL efficiencies and rates in semiconductor quantum dots (QDs) [1-3]. Moreover, our new experiments show that exciton and biexciton PL efficiencies in perovskite nanocrystals and CdSe/CdS QDs may be enhanced or decreased reversibly by real-time changes in the structure of plasmon-exciton hybrid films (Figure 1). However for initially low-QY nanocrystals we observed an irreversible increase in the PL efficiency even after the total elimination of plasmon-exciton interaction. We explained these effects by the plasmon-induced changes in rates of radiative and nonradiative transitions.

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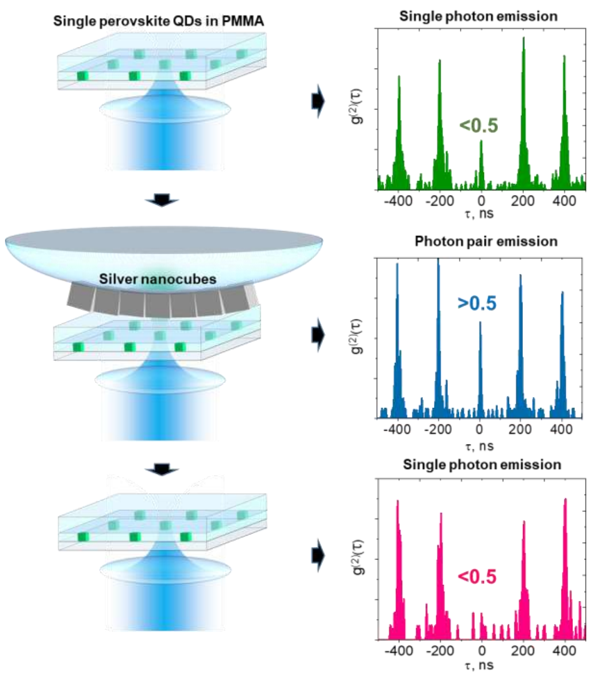

Figure 1: Second-order cross-correlation functions $g^{(2)}$ of the emission from single QD measured in Hunburry-Brown-Twiss geometry, before (green graph), during (cyan graph) and after (pink graph) the interaction with silver plasmon nanocubes.

Accelerating business impact with a problem-centered framework for quantum computing

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In this talk, we will discuss the paramount role of problem life cycle management in the successful translation of quantum experiments and proofs-of-concept to practical applications. We will navigate through the stages of pre-quantum, post-quantum, and business-advantage phases, underlining the importance of a relentless benchmarking approach and seamless integration within the enterprise environment. As we enter an era characterized by fast-paced algorithm evolution, hardware enhancements, burgeoning data volume, and intricate challenges, we will explore how the problem-centered framework provides a novel pathway for businesses and researchers to leverage the potential of quantum computing more effectively.

Algebraic Bethe Circuits

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The Algebraic Bethe Ansatz (ABA) is a highly successful analytical method used to exactly solve several physical models in both statistical mechanics and condensed-matter physics. Here we bring the ABA into unitary form, for its direct implementation on a quantum computer. This is achieved by distilling the non-unitary R matrices that make up the ABA into unitaries using the QR decomposition. Our algorithm is deterministic and works for both real and complex roots of the Bethe equations.
We illustrate our method on the spin-1/2 XX and XXZ models. We show that using this approach one can efficiently prepare eigenstates of the XX model on a quantum computer with quantum resources that match previous state-of-the-art approaches. Moreover, we propose the analytical expressions for the circuit elements building an arbitrary eigenstate of the XX model. We give the exact solution implementing 2 and 3-magnons states of the XXZ chain.
We run small-scale error-mitigated implementations on the IBM quantum computers, including the preparation of the ground state for the XX and XXZ models on 4 sites. Finally, we derive a new form of the Yang-Baxter equation using unitary matrices, and also verify it on a quantum computer.

Spin-squeezed states with ultracold fermions

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Generation, storage, and utilisation of correlated many-body quantum states are crucial objectives of future quantum technologies and metrology. Such states can be generated by the spin-squeezing protocols. In this work [1], we consider the dynamical generation of spin squeezing in a lattice system composed of ultra-cold fermionic atoms in the Mott phase at half-filling. To induce the generation of squeezing, we add the position-dependent laser coupling between the internal degrees of freedom of atoms (Fig. 1). We study the Ramsey-type spectroscopy scheme in which the atom-light coupling is turned on during the interrogation time, as illustrated in Fig. 2. By choosing an appropriate propagation direction of the laser beam inducing the SOC and acting on a fermionic lattice with a sequence of such laser pulses we expect to realise efficient spin-squeezing. We show analytically, using the perturbation theory, how the Fermi-Hubbard model with the atom-light coupling effectively simulates the one-axis twisting model with the tunable axis of squeezing. This paves the way for the simulation of the famous two-axis counter-twisting model when two laser couplings are used during interrogation time. The presented method might deliver gains in real applications like optical clocks.

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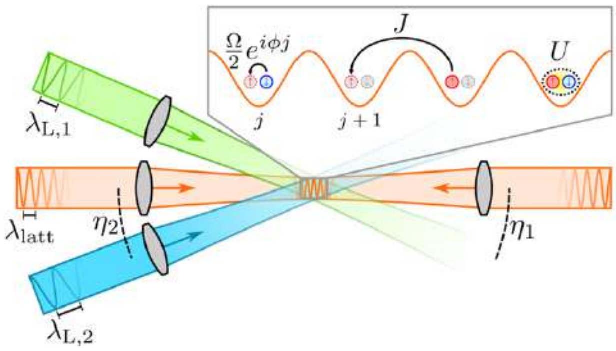

Figure 1: Fermi-Hubbard model for atoms in optical lattices with nearest-neighbour tunnelling rate *J*, on-site interaction *U* and additional coupling between atomic internal degrees of freedom with position-dependent strength $\Omega e^{i\varphi j}$ realised with one or two off-resonant laser beams.

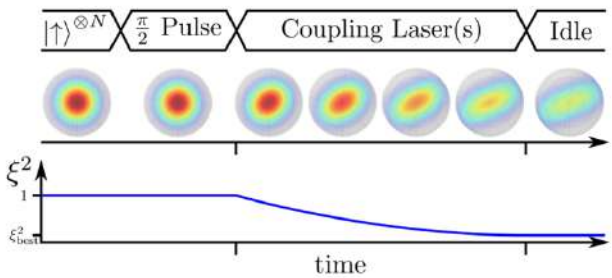

Figure 2: The Ramsey-type spectroscopy for the generation of Mott-squeezed states: (i) preparation of the initial spin coherent state with ultra-cold fermions in the Mott phase, (ii) unitary evolution using the Fermi-Hubbard Hamiltonian with the atom-light coupling reduces the value of the spin squeezing parameter, (iii) freezing the spin squeezed state in the Mott phase when the atom-light coupling is turned off.

Molecular Energies with Electron Correlation from Linear Depth Quantum Circuits

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Abstract

A promising technological avenue of quantum computing is the computation of molecular energies in quantum chemistry, as qubits can map onto spin orbitals of specific electrons. Taking inspiration from Arute et al's method of orbital optimization for the mean field Hartree-Fock energy on a noisy intermediate-scale quantum (NISQ) device,[1] we seek to adapt a similar orbital optimization approach to include dynamical electron correlation energy from second order Møller-Plesset perturbation theory (OMP2) [2] into the molecular energy cost function to be minimized in a variational quantum algorithm. More rigorous methods to recover correlation energy such as the unitary coupled cluster method involve deep entangling circuit ansätze and are thus limited to small molecules. To improve resource efficiency, our NISQ-OMP2 method uses multiple shallow circuits with a QR decomposition of the orbital optimization U(θ) with O(N) depth,[3] and a basis rotation grouping scheme to reduce the number of Pauli measurements from $O(N^4)$ to O(N),[4] as depicted in Figure 1. This work demonstrates the estimating of OMP2 energies of H_2, H_3^+, and LiH using classical simulations with noise models, and on cloud-accessed NISQ devices.[5] Results for H_2 on NISQ devices are summarized in Figure 2.

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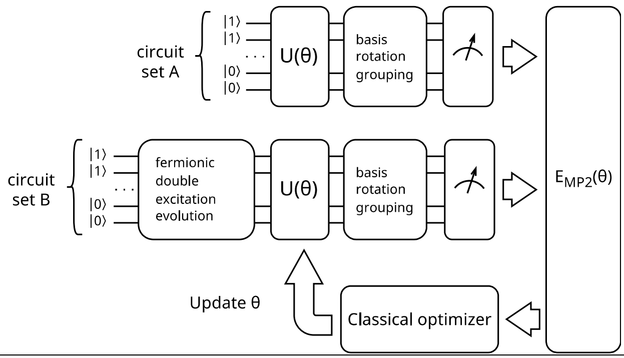

Figure 1: Schematic process diagram showing quantum circuit sets A and B used to estimate orbital-optimized MP2 energies using a variational quantum algorithm.

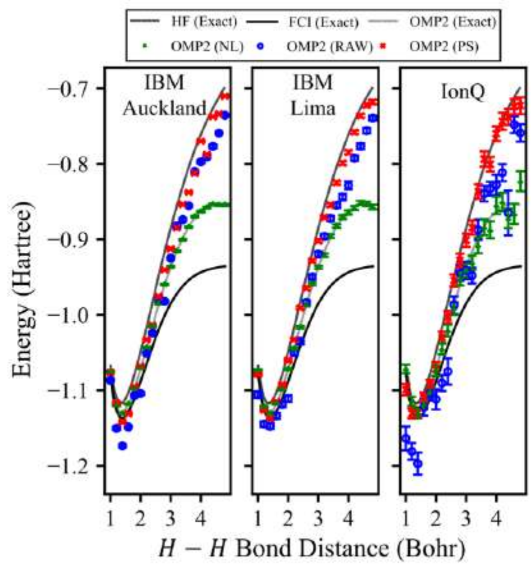

Figure 2: OMP2 Energy of H_2 at various bond distances, estimated using various NISQ devices.

Simulating nuclei with digital quantum computers

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The nuclear shell model is one of the prime many-body methods to study the structure of atomic nuclei, but it is hampered by an exponential scaling on the basis size as the number of particles increases. We present a shell-model quantum circuit design strategy to find nuclear ground states that circumvents this limitation by exploiting an adaptive variational quantum eigensolver algorithm. Our circuit implementation is in excellent agreement with classical shell-model simulations for a dozen of light and medium-mass nuclei, including neon and calcium isotopes. We quantify the circuit depth, width and number of gates to encode realistic shell-model wavefunctions. Our strategy also addresses explicitly energy measurements and the required number of circuits to perform them. Our simulated circuits approach the benchmark results exponentially with a polynomial scaling in quantum resources for each nucleus and configuration space. This work paves the way for quantum computing shell-model studies across the nuclear chart.

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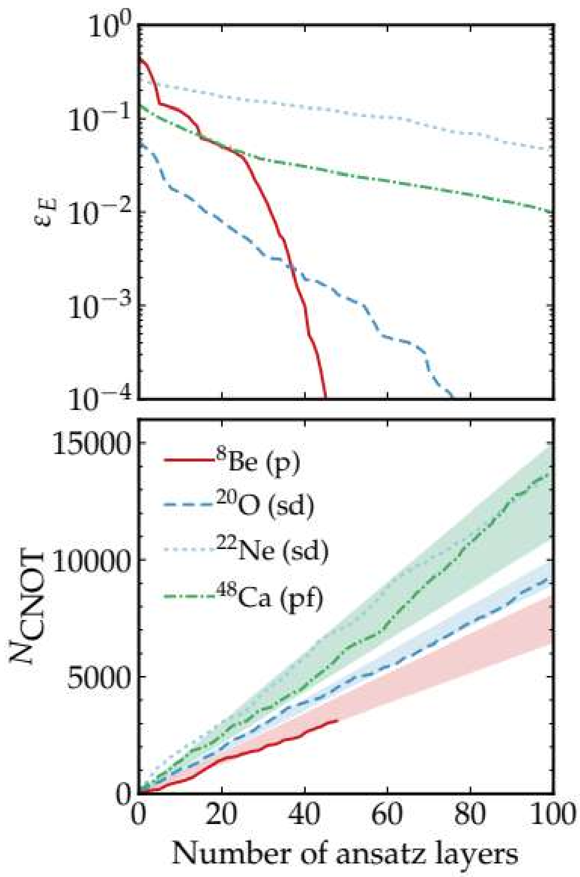

Figure 1: Evolution of the relative error for the ground-state energy (top) and number of CNOT gates in the ansatz circuit (bottom) as a function of the number of ansatz layers for simulations of selected nuclei. As the algorithm adaptively iterates, errors decay exponentially while the number of CNOT gates increases linearly.

Quench dynamics of lattice quantum many-body systems from time-dependent variational Monte Carlo

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The time-dependent variational principle allows one to investigate the dynamics of a lattice quantum many-body system, provided an Ansatz for its wave function (WF). Analogously to what is achievable by state-of-the-art quantum-simulator experiments, in a variational Monte Carlo simulation it is possible to initialize the system in a given state and follow its unitary dynamics after a quench of the hamiltonian parameters. In this framework, we focus on the paradigmatic transverse-field Ising model and on the pair-product, or Jastrow, variational state. We show that, despite its simplicity, the Jastrow WF i) does not suffer from a trivial "entanglement barrier" being capable of dealing with time evolutions featuring a volume law of entanglement growth and ii) is able, even in the extremely challenging one dimensional case, to capture fundamental dynamical aspects such as the light-cone like propagation of space-time correlations, and the essential features of the excitation spectrum, revealing, for example, quantum criticality. Refining the basic Jastrow WF in a physically motivated fashion by explicitly correlating different groups of sites in the Ansatz has the main effect of yielding a better description of the frequency of oscillations and time scales in the evolution of relevant quantities. This improvement is clearly detectable in non local (in space and time) observables such as the quench spectral function, which appears as a meaningful figure of merit for time dependent variational calculations. We finally show that, in two dimensions, the simple Jastrow variational Ansatz, without any modification, may lead to estimates in extremely good agreement with those obtainable via accurate alternative approaches or more sophisticated and computationally demanding WF's.

Thermodynamic Limits of Quantum Search and their implications for quantum-classical cryptography

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Quantum computers fundamentally require thermodynamic work to perform meaningful operations [1]. In this talk I will discuss the resulting work-time trade-off for Grover's search algorithm, and use it to determine the size a cryptographic key needs to have, to be considered quantum-resistant: Even an all-powerful quantum adversary has a negligible chance to recover such a key within a given time.

We apply this limit to devise a hybrid quantum-classical cryptography protocol to encrypt long distance, high bandwidth data channels. In the limit of high loss, the capacity of classical data channels fundamentally exceeds that of an equivalent quantum channel [2]. Hence, the data stream cannot be fully encrypted by one-time-pad, but (symmetric) ciphers are required. Our novel hybrid protocol relies on the same assumptions as conventional quantum key distribution (QKD) and the existence of a secure cipher. It yields comparable security to QKD-based encryption of the data link at substantially reduced technical complexity, offering a route towards quantum-based security for consumer-level electronic devices.

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Flip-chip-based microwave spectroscopy of Andreev bound states in a planar Josephson junction

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We demonstrate a flip-chip-based approach to microwave measurements of Andreev bound states in a gate-tunable planar Josephson junction using inductively-coupled superconducting low-loss resonators [1]. By means of electrostatic gating, we present control of both the density and transmission of Andreev bound states. Phase biasing of the device shifted the resonator frequency, consistent with the modulation of supercurrent in the junction. Two-tone spectroscopy measurements revealed an isolated Andreev bound state consistent with an average induced superconducting gap of 184 μeV and a gate-tunable transmission approaching 0.98. Our results represent the feasibility of using the flip-chip technique to address and study Andreev bound states in planar Josephson junctions, and they give a promising path towards microwave applications with superconductor-semiconductor two-dimensional materials.

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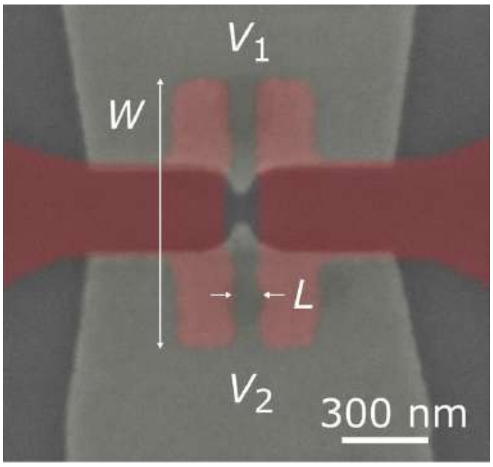

Figure 1: Gate-tunable planar Josephson junction (JJ) defined in a two-dimensional InAs/Al heterostructure was embedded in the rf-SQUID. The Al (red) was selectively removed to form a $L \approx 110$ nm long and $W \approx 940$ nm wide JJ. A split-gate (light gray) was evaporated on top of the JJ for controllable depletion of the weak link in the exposed InAs two-dimensional electron gas (dark gray).

Machine Learning for Parameter Estimation from Continuously-Monitored Quantum Systems

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Here we consider the problem of estimating an unknown dynamical parameter from the signal generated by a quantum system under continuous interrogation, such as the photon-counting signal of the radiation emitted by a continuously-driven atom. It has been shown that the optimum estimation strategy in this case requires a process of Bayesian inference, where the likelihood of the data is obtained by calculating conditional evolutions of the open quantum system [1,2]. These methods extract as much information from the signal as possible, but require a precise modelling of the system, and become computationally expensive in complex systems or for multi-parameter estimation tasks. Here, we demonstrate that deep learning architectures can be trained to estimate unknown parameters in this scenario, without any knowledge of the underlying model. We benchmark the performance of these models and show that they can achieve the same level of sensitivity as the optimal Bayesian inference protocols. Remarkably, the inference process using a trained network is much less computationally demanding than the corresponding process of Bayesian inference.

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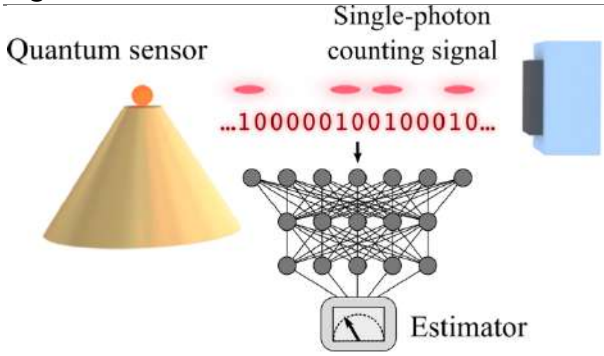

Figure 1: Sketch of a machine-learning estimator applied to the continuous measurement of the radiation emitted by a quantum sensor, e.g. a photon-counting signal with single-photon resolution.

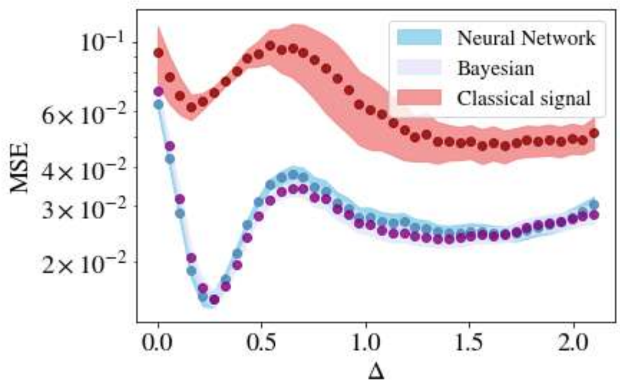

Figure 2: Mean squared error (MSE) in the estimation of an unknown detuning between an atom and a coherent drive from the analysis of a photon-counting signal with single-photon resolution. The MSE of the deep-learning estimator is compared to that of a full Bayesian inference protocol, and with the MSE of a maximum-likelihood estimator applied to a photon-counting signal without single-photon resolution, which illustrates the gain in information obtained when the signal can describe quantum correlations (in this case, photon antibunching).

Interacting Laser-Trapped Circular Rydberg Atoms

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Rydberg atoms, i.e., atoms with a high principal quantum number *n*, are particularly well suited to the quantum simulation of interacting spins, thanks to their strong dipole-dipole interactions, even at a few micron distance. While regular arrays of hundreds of Rydberg atoms have been used in several experiments, the effective simulation time is ultimately limited to a few µs by the ~100µs lifetime of the employed laser-accessible Rydberg levels.

Circular Rydberg atoms, with maximal orbital momentum, have a natural lifetime that reaches several 10ms [1]. Quantum simulation with circular Rydberg atoms could then be run over unprecedented timescales [2], making it possible to study slow spin dynamics, that escape both numerical and current quantum simulations. To benefit from these long lifetimes, however, makes laser-trapping of circular Rydberg atoms mandatory [3].

Here, I will present our latest experimental results regarding the laser-trapping of individual circular Rydberg atoms in a regular array of optical tweezers and the observation of their dipole-dipole interactions.

We use so-called bottle optical beams as hollow optical tweezers (Figure 1) to ponderomotively trap individual circular Rydberg atoms with *n*=52. We demonstrate their laser-trapping over several milliseconds, limited by their 130µs lifetime in our room-temperature setup, and observe their oscillations in the traps. To this end, we have developed an optical detection method of circular Rydberg levels, that is both level and spatial selective [4]. We also use this method to characterize the dipole-dipole interaction between two nearby laser-trapped circular Rydberg atoms [5].

Our results open a new route for quantum technologies with Rydberg atoms, allowing one to exploit the unique properties of the circular levels.

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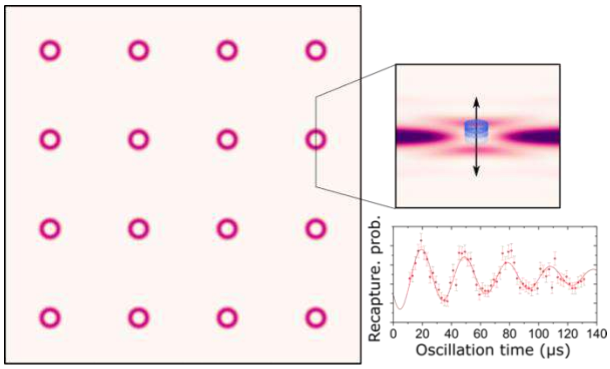

Figure 1: Individual circular Rydberg atoms are trapped in an array of optical bottle beams.

Robust Spin Polarization of the YSR States in Superconductor/Ferromagnetic Insulator Heterostrucures

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Yu-Shiba-Rusinov (YSR) states arise as sub-gap excitations of a magnetic impurity in a superconducting host.

Taking into account the quantum nature of the impurity spin in a single-site approximation, we study the spectral properties of the YSR excitations of a system of magnetic impurity in a spin-split superconductor, that is a superconductor in proximity to a ferromagnetic insulator at zero external magnetic field.
The YSR excitations of this system exhibit a robust spin-polarization that is protected from fluctuations and environmental noise by the exchange field of the ferromagnetic insulator, which can be as large as a few Tesla. We compare the results of this quantum approach to the classical approach, which conventionally predicts fully polarized YSR excitations even in the absence of exchange and external magnetic field. Turning on a small magnetic field, we show the latter splits the YSR excitations in the regime where the impurity is strongly coupled to the superconductor, whilst the classical approach predicts no such splitting.

The studied system can potentially be realized in a tunnel junction connected to a quantum dot in proximity to a spin-split superconductor.

Input-output theory for quantum circuits based on hierarchical equation of motion

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Hierarchical equation of motion (HEOM) [1] is known as one of the most popular and reliable methods of modelling of open quantum system dynamics. This technique can be straightforwardly applied for a broad class of Gaussian environments. Free-pole expansion [2] allows to extend this method for environments sub-Ohmic spectral densities and drastically enhance its performance even in low temperature limit.
HEOM represents a first order in time differential equation for the reduced density operator of the system and so-called auxiliary density operators which contain information about system–environment correlations. The latter are usually disregarded in the end since it is thought that all the system–related observables can be calculated using just reduced density operator. However, for a typical example of open quantum systems, namely superconducting circuits coupled to transmission lines, the only quantities accessible to experimentalists are output fields in these lines, which are observables of the environment rather than of the system. For systems in Markovian environments the solution to this problem is given by input–output theory [3,4] which relates system observables to the output fields. For linear circuits the scattering problem can be solved using just classical approach.
In our work we show that the HEOM can serve as a basis for construction of both non-Markovian and nonlinear input–output theory. Auxiliary density operators play a key role in this theory, since they contain all the necessary information about system–environment correlations. We illustrate our theory on the readout of a recently developed superconducting qubit called unimon [5].

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Highly Efficient Creation of Ultracold Ground-state ^{6}Li-^{40}K Polar Molecules

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Abstract

We report on the first and efficient creation of ground state ^{6}Li-^{40}K molecules using the stimulated Raman adiabatic passage (STIRAP) [1]. Starting from the weakly-bound Feshbach molecules, the STIRAP transfer to the singlet ro-vibrational ground state is achieved via an intermediate state in the $A^1\Sigma^+$ potential [2]. The coherent transfer is facilitated by two narrow-linewidth and low phase-noise lasers. We achieved a single-trip transfer efficiency of 98(2) %, which is the highest compared to other reported bi-alkali species [3]. Our work demonstrates the high efficiency of the singlet STIRAP pathway for the coherent creation of ground state molecules. Combined with the high dipole moment of ground state ^{6}Li-^{40}K, this work paves the way for studying quantum chemistry, quantum simulation of exotic phase of matter and quantum information processing with strong long-rage anisotropic interactions [4-6].

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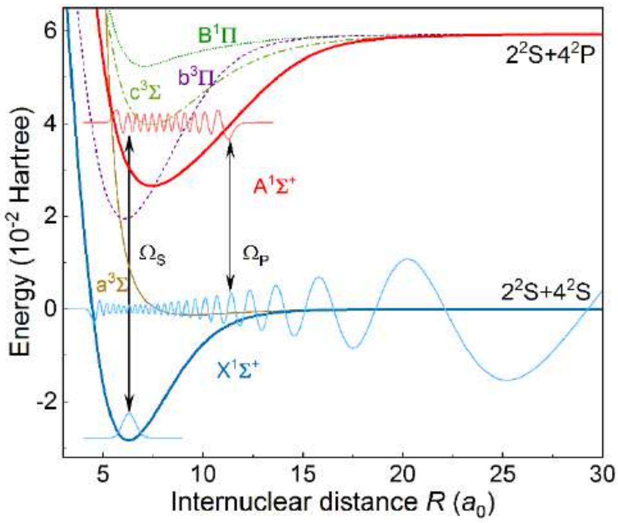

Figure 1: Adiabatic potential curves for ^{6}Li-^{40}K molecules. The singlet pathway connects the $X^1\Sigma^+$ ground state to the Feshbach state near the ground state asymptote via the $A^1\Sigma^+$ potential. The Rabi frequencies of the two coupling laser fields, Pump and Stokes, are indicated by Ω_P and Ω_S.

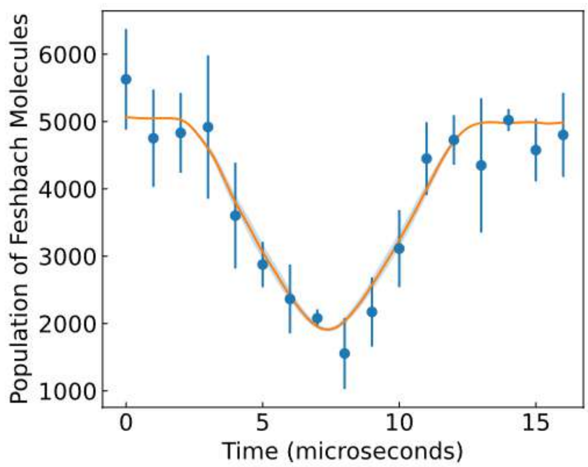

Figure 2: Round-trip trip STIRAP transfer. The single-trip STIRAP duration is 8 μs. The number of Feshbach molecules are detected by absorptive imaging. The detection background is caused by the un-associated Li atoms. Each data point is an average of 4 measurements. From a fit to a model based on the optical Bloch equations, we infer a single-trip STIRAP efficiency of 98(2) %.

Quantum Circuit Optimization and Transpilation via Parameterized Circuit Instantiation

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Parameterized circuit instantiation is a common technique encountered in the generation of circuits for a large class of hybrid quantum-classical algorithms [1, 2]. Despite being supported by popular quantum compilation infrastructures such as IBM Qiskit and Google Cirq, instantiation has not been extensively considered in the context of circuit compilation and optimization pipelines. In this work, we describe algorithms to apply instantiation during two common compilation steps: circuit optimization and gate-set transpilation. When placed in a compilation workflow, our circuit optimization algorithm produces circuits with an average of 13% fewer gates than other optimizing compilers. Our gate-set transpilation algorithm can target any gate-set, even sets with multiple two-qubit gates, and produces circuits with an average of 12% fewer two-qubit gates than other compilers. Overall, we show how instantiation can be incorporated into a compiler workflow to improve circuit quality and enhance portability, all while maintaining a reasonably low compile time overhead.

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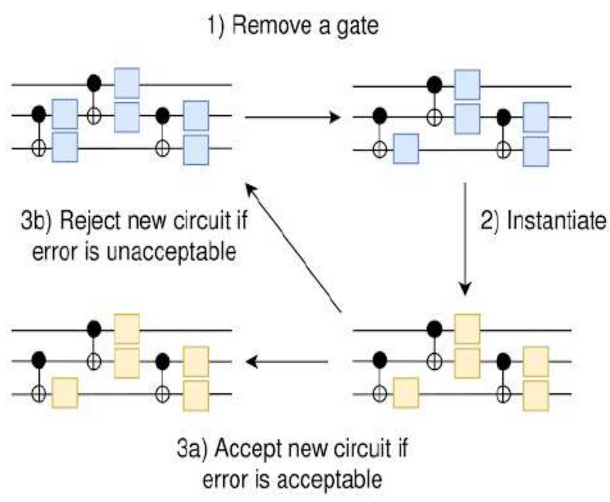

Figure 1: Gates can be removed from circuits through the use of instantiation. This can be done by first selecting and removing a gate, then instantiating the remaining gates' parameters to make up for the loss. This is not always successful. If the error on the new circuit is less than some threshold then the new circuit is accepted, otherwise the circuit is rejected.

Fast Quantum State Tomography in the Nitrogen Vacancy Center of Diamond

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Quantum state tomography (QST) is the procedure for reconstructing unknown quantum states from a series of measurements of different observables. Depending on the physical system, different sets of observables have been used for this procedure. In the case of spin-qubits, the most common procedure is to measure the transverse magnetization of the system as a function of time. Here, we present a different scheme that relies on time-independent observables and therefore does not require measurements at different evolution times, thereby greatly reducing the overall measurement time. To recover the full density matrix, we use a set of unitary operations that transform the density operator elements into the directly measurable observable. We demonstrate the performance of this scheme in the electron-nuclear spin system of the nitrogen vacancy center in diamond [1].

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Dynamical parity selection in superconducting weak links

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Abstract

Excess quasiparticles play a crucial role in superconducting quantum devices ranging from qubits to quantum sensors. In this work we analyze their dynamics for phase-biased finite-length weak links with several Andreev subgap states, where the coupling to a microwave resonator allows for parity state (even/odd) readout. Our theory shows that almost perfect dynamical polarization in a given parity sector is achievable by applying a microwave pulse matching a transition in the opposite parity sector. Our results qualitatively explain key features of recent experiments on hybrid semiconducting nanowire Josephson junctions [1] and provide theoretical guidelines for efficiently controlling the parity state of Andreev qubits [2].

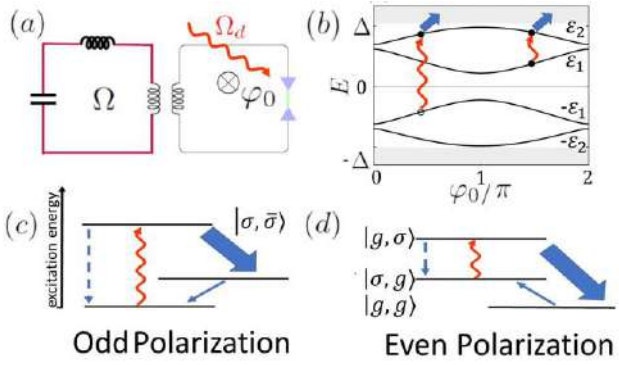

Figure: (a) Schematic setup: phase biased weak link coupled to a microwave resonator (b) Subgap states as a function of phase for a finite length weak link (c-d) Excitation of even/odd many-body states leading to polarization in the odd/even parity sector.

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Modelling non-Markovian noise in driven superconducting qubits

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Abstract

In superconducting qubit quantum computers available today, interactions between qubits and two-level system (TLS) defects in the device are known to be a significant source of noise [1,2]. Coherent qubit-defect interaction can manifest itself as non-Markovian noise in the dynamics of the qubit subsystem. Existing methods to identify such effects involve low-level noise spectroscopy experiments [2,3]. We develop a method based on repeated mirrored pseudo-identity gates to characterise resonant qubit-TLS interactions and include them in a noise model to describe the effects of the TLS defects on the quantum circuits. We run experiments on superconducting quantum computers and find that our method is well suited to characterize such interactions, and that their presence is an important source of noise. Including the non-Markovian components within our noise model allows us to significantly improve the accuracy of the predictions of the noise model when compared to experiments.

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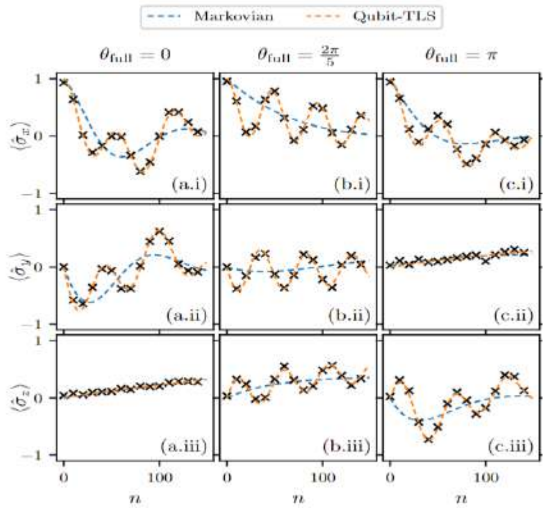

Figure 1: Expectation values of the qubit in different measurement basis plotted against the number of applied pseudo-identities n. The columns correspond to different mirrored-pseudoidentities. The model including the qubit-TLS interaction (orange line) can be seen to fit the experimental data (black crosses) much better than the Markovian model (blue line).

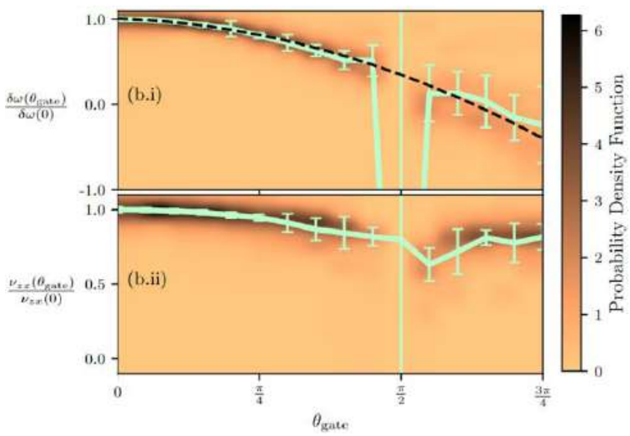

Figure 2: The ratio of the noise model parameters for the driven vs undriven qubit plotted against the amplitude of the applied pulse. The phase error $\delta\omega$ can be seen to change quadratically, while the qubit-TLS interaction strength ν_{zx} changes non-monotonically.

Corrugation driven spin relaxation in graphene

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Abstract

Controlling spin relaxation rate is important to design devices intended to be applied in spintronics. Since spin injection and detection was demonstrated, graphene has been considered to be applied for spintronic devices. One reason is its low spin-orbit coupling, that allows spin to travel further while can be modified via proximity effect with other materials (such as TMDs).
However, studies report spin relaxation times orders of magnitude lower than predicted by theory. This could be due to the appearance of "local" spin orbit coupling due to ripples as reported by Guinea et al. [2]. Here we develop a KPM (Kernel Polynomial Method) real space approach [1] study to estimate the contribution of corrugation to the spin dynamics of a corrugated graphene sample in a wide range of gate voltages and make a discussion based on the main spin relaxation processes known.

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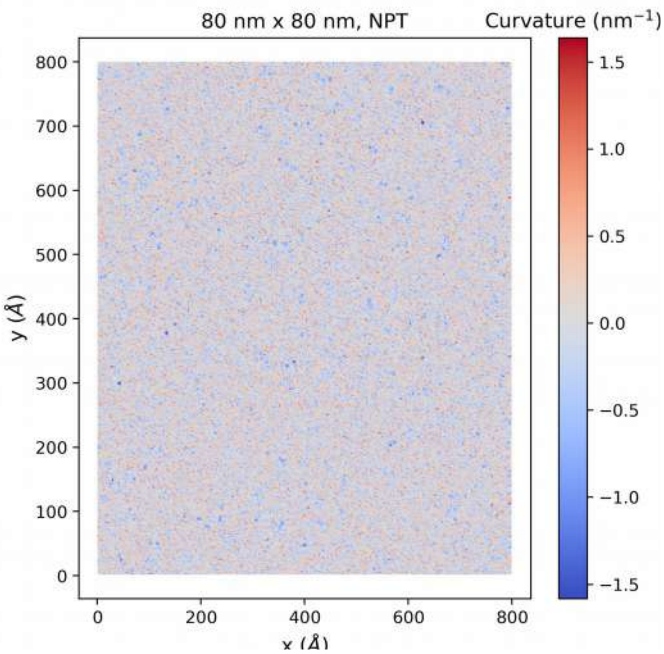

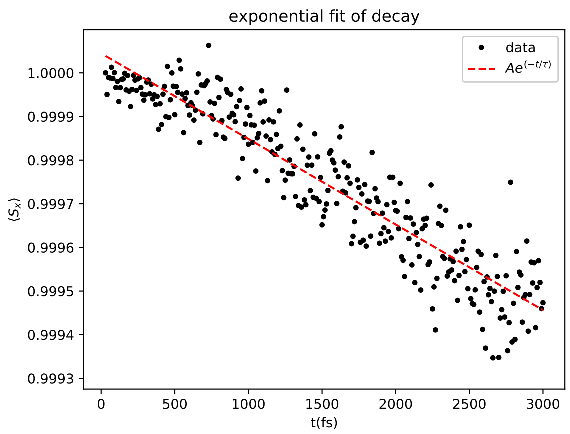

Figure 1: Spin relaxation time for a corrugated graphene sample and characterization of the sample. Top figure curvature profile where blue is for negative curvature and red for positive curvature and bottom figure is a spin relaxation graph fitted with an exponential decay used to obtain relaxation time

Administering an antidote to Schrödinger's cat

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Abstract

In 1935, Schrödinger imagined a cat in a box together with a poisonous substance that could be released based on the decay of a radioactive atom. Owing to it, the life of the cat and the state of the poison become entangled, and the fate of the cat is determined upon opening the box. This work presents an experimental technique that keeps the cat alive on any account, relying on the time-resolved HOM interference of photons generated using single 87Rb atoms in a high-finesse cavity.

Interpreting the first photon detection as the state of the poison and the second photon as the state of the cat, we demonstrate the ability to control the quantum state of the cat by implementing a sudden phase change between the inputs, administered conditionally on the outcome of the first detection.

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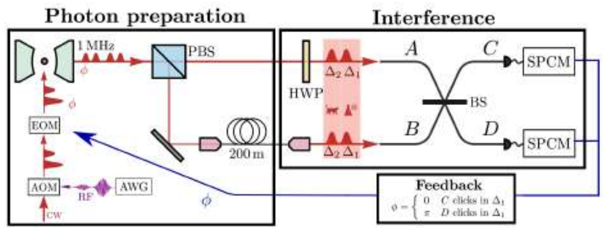

Figure 1: Two long photons with double-humped profiles [3] interfere in a 50:50 beam splitter (BS). Photons are emitted at a repetition rate of 1MHz from an atom-cavity source [4] driven by a laser pulse modulated by an acousto-optic modulator (AOM) and whose phase is changed using an electro-optic modulator (EOM). A fiber delay line of 200m ensures the simultaneous arrival of two sequentially emitted photons.

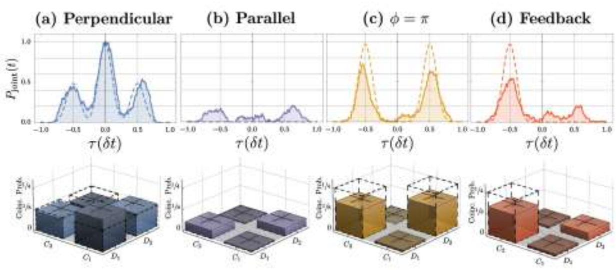

Figure 2: (top) The joint coincidence probability sliding histograms show the theoretical (dashed) and experimental (solid) values for the joint probability amplitude of two-photon detection. Figures at the bottom show the same coincidences sorted following to the exact detector-time-bin detections. (a) shows the random routing of photons with orthogonal polarisations. (b) and (c) show the interference between indistinguishable and fully distinguishable photons, resulting in no coincidences and enhanced coincidences. (d) shows the asymmetric pattern observed under feedback (adapted from [1]).

Generalized quantum PageRank algorithm with arbitrary phase rotations

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Abstract

The quantization of the PageRank algorithm is a promising tool for a future quantum internet. Here we present a modification of the quantum PageRank introducing arbitrary phase rotations (APR) [1] in the underlying Szegedy's quantum walk [2]. We have analyzed the behavior of three APR schemes in scale-free graphs. In these networks, the original quantum PageRank [3] is able to break the degeneracy of the residual nodes and detect secondary hubs that the classical algorithm suppresses. Nevertheless, not all of the detected secondary hubs are real according to the PageRank's definition [4]. Some APR schemes can overcome this problem, restoring the degeneration of the residual nodes and highlighting the truly secondary hubs of the networks. We have also studied the stability of the new algorithms. The original quantum algorithm was known to be more stable than the classical. We have found that one of our new algorithms whose, PageRank distribution resembles the classical one, has a stability similar to the original quantum algorithm.

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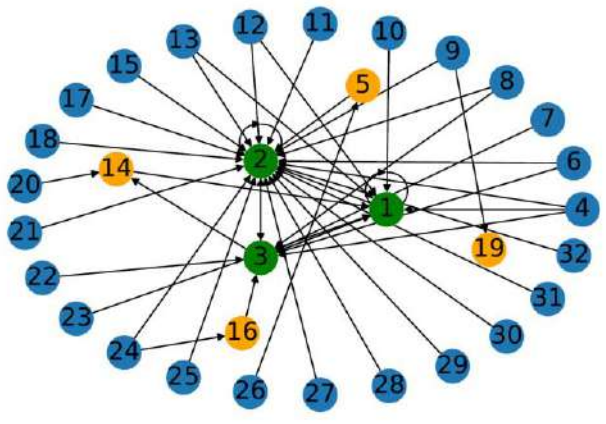

Figure 1: Scale-free network with 32 nodes. The inner (green) nodes correspond to the main hubs. The middle (orange) nodes correspond to secondary hubs. The outer (blue) nodes correspond to residual nodes without links pointing to them.

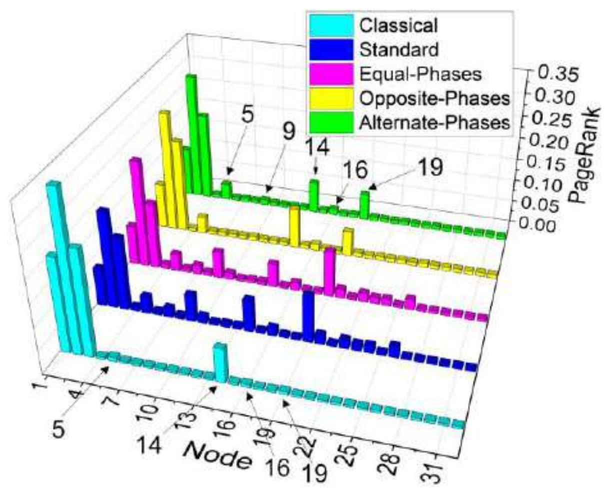

Figure 2: PageRank distributions of the scale-free network. There is a partial restoration of the degeneracy of the less important nodes for the Opposite-Phases and Alternate-Phases schemes.

Dynamical decoupling on a superconducting qubit with a microscopic fluctuator-induced noise model

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Abstract

We examine the dynamics of a superconducting qubit subject to noise that we model as induced by a fluctuator. The fluctuator, modelled by a two level system, is itself coupled to a bath described by a collection of bosonic harmonic oscillators. We employ a second order master equation [1] to study the dynamics of the combined (qubit+fluctuator) system, from which we can extract the behavior of the qubit. The goal of this research is to find mitigation strategies for the noise effects, as characterised by the infidelity of the qubit. To this purpose, we act with dynamical decoupling pulses on the qubit and study their effects in different modelling scenarios [2] and the relation of its effectiveness with the non-Markovianity of the evolution [3].

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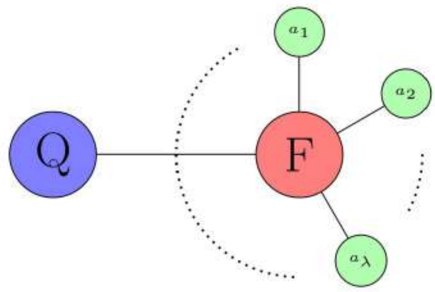

Figure 1: Schematic picture of the model. The qubit (Q) is coupled to the fluctuator (F), which in turn is coupled to its own bath of harmonic oscillators.

Quantum simulator with hot atomic vapors

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Numerical resolution of complex problems remains a challenge for various applications, high performance computation centers reaching their limits in terms of speed in addition to being huge energy consumers. In recent years, important efforts are conducted to realize quantum computers and quantum simulators in order to address these limitations. Many devices presently under construction, exploit many entangled qubits, and are often based on cryogenic or ultra-cold atom techniques, in order to avoid thermal decoherence.
A alternative, though less universal development has thus emerged with the goal of realizing more specialized quantum simulators, able to solve specific problems. In this project we propose to develop a remote-controlled stand-alone device to operate as a wave simulator based on the non-linear interaction of a laser beam with a hot atomic vapor [1]. Initial problems to be addressed include hydrodynamic equations [2]. In parallel, the use of this wave simulator as an optical reservoir computer is under investigation to develop an efficient machine learning device.

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Figure

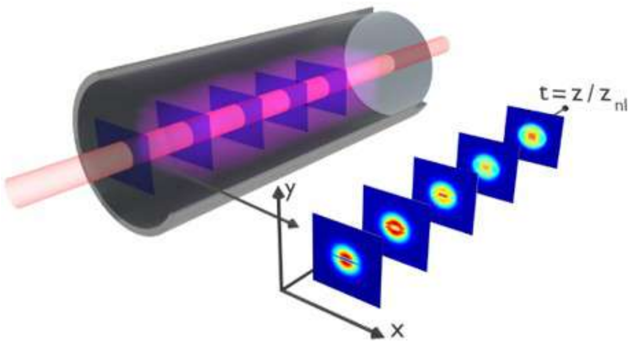

Figure 1: Scheme of laser beam propagating through atomic vapor (nonlinear medium) resulting in the simulation of a 2D fluid of light while propagation axis (z) corresponds to the time evolution of this fluid.

The minimal thermoelectric diode

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Modern electronic devices are currently operated at the nanoscale regime, where overheating becomes a problem. Controlling the undesired heat flows in a useful manner is another less explored way of improving its performance. For this, efficient thermal diodes need to be designed [1]. Usual proposals rely in nonlinear scenarios [2]; here, we identify the minimal conditions for a nanoscale device to rectify the heat and thermoelectric currents, even in the linear regime. This is achieved for asymmetric coherent conductors that allow for some local thermalization of the heat carriers. We quantify the amount of rectification achieved by this mechanism in some proposed systems composed of resonant-tunneling quantum dots and compare (and combine) it with the non-linear scenarios. Finally, we propose feasible experimental realizations of this idea in an elastic conductor where the interplay between thermalization and nonlinearities can be controlled via quantum interference [3].

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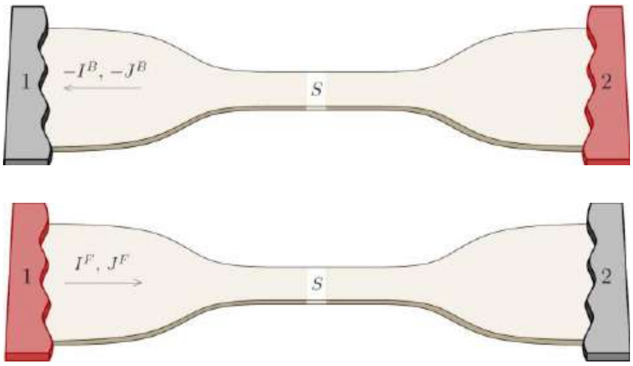

Figure 1: Sketch of the proposed system: two electronic reservoirs are connected by a coherent conductor with a scattering region. Forward and backwards particle and heat currents are represented.

Assessing the potential of perfect screw dislocations in SiC for solid-state quantum technologies

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Although point defects in solids are one of the most promising physical systems to build functioning qubits, it remains challenging to position them in a deterministic array and to integrate them into large networks [1-3]. By means of advanced ab initio calculations we show that undissociated screw dislocations in cubic 3C-SiC, and their associated strain fields, could be used to create a deterministic pattern of relevant point defects (See Fig. 1). Specifically, we present a detailed analysis of the formation energies and electronic structure of the divacancy in 3C-SiC when located in the vicinity of this type of dislocations. Our results show that the divacancy is strongly attracted towards specific and equivalent sites inside the core of the screw dislocations, and would form a one-dimensional arrays along them. Furthermore, we show that the same strain that attracts the divacancy would allow the modulation of the position of its electronic states and of its charge transition levels. Specifically, we find that in the case of the neutral divacancy these modulations result in the loss of its potential as a qubit. However, these same modulations could transform defects with no potential as qubits when located in bulk, into promising defects when located inside the core of the screw dislocations. Since dislocations are still mostly perceived as harmful defects, our findings represent a technological leap as they show that dislocations can be used as active building blocks in future defect-based quantum computers.

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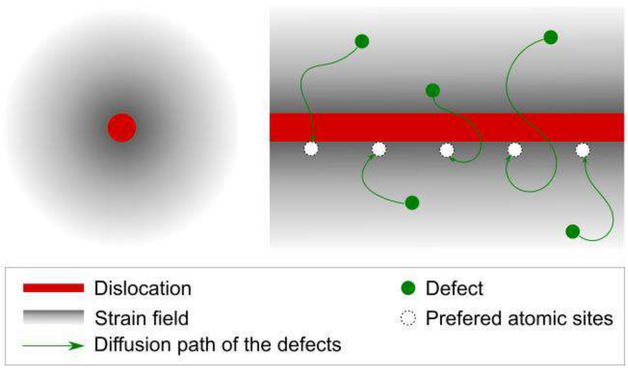

Figure 1: Depiction of a dislocation (red line) attracting defect-based qubits (green dots) due to its induced strain field (gray shaded area).

Analysis of spin-squeezing generation in cavity-coupled atomic ensembles with continuous measurements

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The Standard Quantum Limit of atomic clocks can be surpassed by introducing quantum correlations. Our theoretical work focuses on the generation of spin-squeezed states by coupling three-level atoms to an optical cavity and continuously measuring the cavity transmission in order to monitor the evolution of the atomic ensemble [1]. We perform microscopic simulations of the full conditional dynamics, and show that one can achieve significant squeezing even without the continuous feedback that is proposed in previous approaches [2]. We characterise the different regimes for spin squeezing generation and describe its scaling dependence on the atomic ensemble size, even when the adiabatic removal of the cavity field is not feasible [3].

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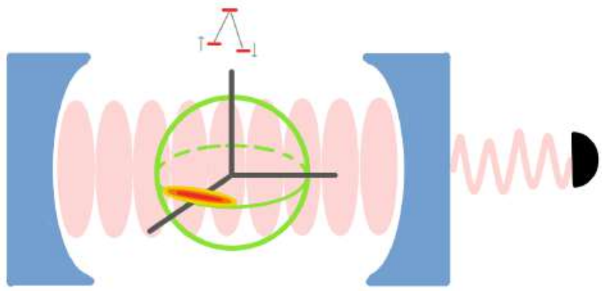

Figure 1: Schema of the modelled system.

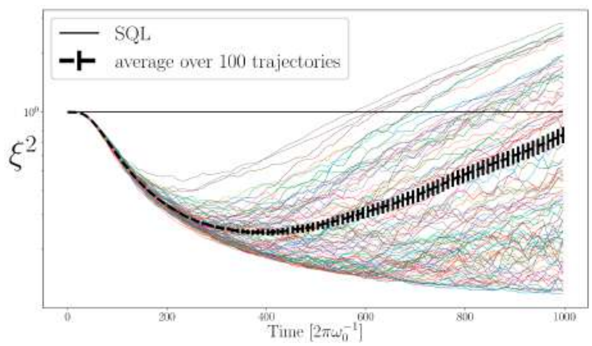

Figure 2: Spin squeezing parameter for an ensemble of trajectories conditioned on measurement of the transmitted light, and its average

Towards on-demand, all-to-all connectivity in a superconducting qubit network using a ring resonator based coupler

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Increased connectivity in a multi-qubit network is beneficial in minimizing gate count when executing any algorithm. However, it is challenging to avoid coherent errors in fixed coupling architectures due to the cross-Kerr effect between all coupled qubits. We recently demonstrated [1] the use of a ring resonator to provide beyond nearest-neighbour connectivity in a planar architecture with fixed coupling between 3D superconducting transmon qubits. We now extend this work by introducing tunable couplers between each qubit and the ring resonator in a 2D planar architecture. This enables on-demand activation of coupling between any of the connected qubits in the network while avoiding the coherent errors due to the cross-Kerr effect as the unused qubits are isolated from the network. The coupler design is a modification of the popular *gmon* coupler [2] with a flux biased Josephson junction. We will present the analysis of this coupler design using finite-element simulations and experimental data to validate its operation.

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Advances in entanglement distribution from space

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Entanglement distribution is the imperative cornerstone for quantum communication methods such as quantum teleportation, highly secure quantum key distribution, and quantum networks such as the future quantum internet. Satellite-based systems are the ideal choice for providing these services on a global scale because their favourable loss scaling makes them superior to terrestrial solutions with respect to the key obstacle of photon loss.

In this contribution, we will summarize and highlight methods to increase the rate of entanglement distribution and its application such as quantum key distribution (QKD) from space. For this purpose, we will provide an overview of different technical and physical solutions to increase the rate at which entanglement can be distributed [1]. We show that exploiting quantum correlations in different degrees of freedom (DoF) of the photons can be exploited to obtain higher rates as well as better quality of entanglement. In particular, we will showcase three different approaches that utilize these additional quantum correlations.
Firstly, we show how color multiplexing is an easy and technical feasible way to achieve high rates of entanglement [2]; see Fig 1. Secondly, we will demonstrate that different DoF can be used to enhance the quality of entanglement by means of single-copy entanglement distillation [3]. Thirdly, we exploit the hyper-entanglement and high-dimensional entanglement for increased noise resistance and rates. In this context, we show experimental results over a 10 km free-space link reaching QKD daylight operation [4]. We will conclude with a short outlook.

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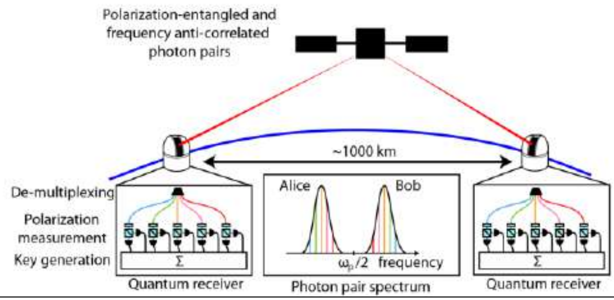

Figure 1: Increased key rates in entanglement-based through color multiplexing [1,2].

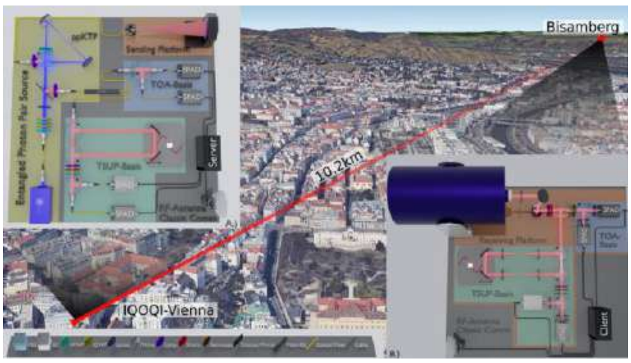

Figure 2: 10 km free-space link realization exploiting hyper- and high-dimensional entanglement [4].

Mapping Strain in van der Waals Nanostructures with Nanoscale Resolution Using 4D STEM

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Abstract

Strain is known to induce changes in the properties of quantum materials, and the emerging field of Straintronics [1] aims to leverage strain in nanomaterials, such as graphene or transition metal dichalcogenides (TMDs), to precisely tune their band structure [2]. While methods like Raman spectroscopy have been used to probe changes in the electronic structure of graphene at the macroscopic scale [3], mapping the local strain and rotation at the nanoscale in complex van der Waals nanostructures, such as twisted flakes and nanotubes, remains challenging due to their intricate geometry, small size, and sensitivity limitations.

In this study, we present a new approach for mapping strain in entire nanostructures with nanoscale resolution, using 4D scanning transmission electron microscopy (STEM) imaging with an Electron Microscope Pixel Array Detector. The method combines electron wave power cepstrum [4] (EWPC) with tracking and clustering of various crystal symmetries [5][6], enabling high accuracy and precision measurements of strain. Our results offer new opportunities for investigating the mechanical behaviour of twisted flake nanostructures and have potential implications for materials science and the bandgap engineering of quantum materials. By enabling precise mapping at the nanoscale, our approach has the potential to advance the field of Straintronics and open new avenues for the development of novel quantum devices.

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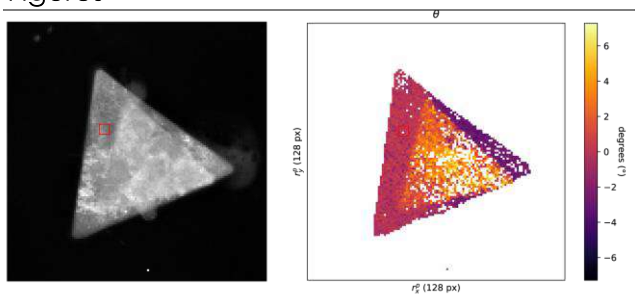

Figure 1: (left) Annular Darkfield 4D STEM image of a Twisted WS_2 nanostructure. (Right) Rotation map of the same WS_2 nanostructure, computed with the same 4D STEM dataset.

Small scale quantum processor with Heavy-Fluxonium Qubit

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Among the various platforms for quantum computation and information processing, superconducting qubits have been a promising candidate for fault-tolerant computation. In the past, multi-qubit processors have only used transmon qubit designs. However, transmon has a fundamental limitation, it sacrifices anharmonicity, a precious quantum resource. Transmon's weak anharmonicity leads to slower two-qubit gates making it prone to decoherence errors. It also limits the scalability of quantum processors, a direct consequence of restricted parameter space of operation, thus motivating to look for alternatives. Recently, fluxonium qubit has emerged as a serious contender for building a superconducting quantum processor. Fluxonium qubits have the potential to excel over transmons due to their inherent advantages of high coherence times and higher anharmonicity [1]. One of the crucial steps in building a fault-tolerant quantum processor is implementing high-fidelity single- and multi-qubit gates. In addition, it is also necessary to have a high-fidelity, quantum non-demolition (QND) readout. Here, we will discuss our implementation of a two-qubit fluxonium gate and experiments to characterize and optimize high-fidelity readout. We will also describe a multi-qubit architecture to build a small-scale quantum processor using fluxonium qubits.

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Edge-Induced Excitations in Bi_2Te_3 from Spatially-Resolved Electron Energy-Gain Spectroscopy

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Abstract

Topological insulators (TIs)are promising materials for developing novel tunable plasmonics at THz and mid-infrared frequencies, with potential applications in quantum computing, THz detectors and spintronic devices. However, to fully utilize the unique physical properties of TI's it is essential to understand the intricate relationship between their nanoscale crystal structure and the resulting physical properties. Here, we deploy spatially resolved electron energy-gain spectroscopy to investigate collective excitations in Bi_2Te_3 and correlate them to the underlying crystalline properties at the nanoscale. Specifically, we use the Monte Carlo replica method implemented in our Python machine learning framework, EELSFitter [1,2], to process spectral images for the removal of the zero-loss peak and the identification of the gain-energy features. We demonstrate the presence of an energy-gain peak located around -1.0 eV, in agreement with a predicted plasmonic resonance of Bi_2Te_3, which exhibits enhanced intensity at the edge-rich regions of the specimen. Our approach to the automated detection of energy-gain peaks makes it possible to stablish clean correlations with the associated local crystal properties. This approach, combined with temperature-dependent EELS measurements, could make possible the determination of estimate the local temperature of specimens with nanoscale-level spatial resolution.[3]

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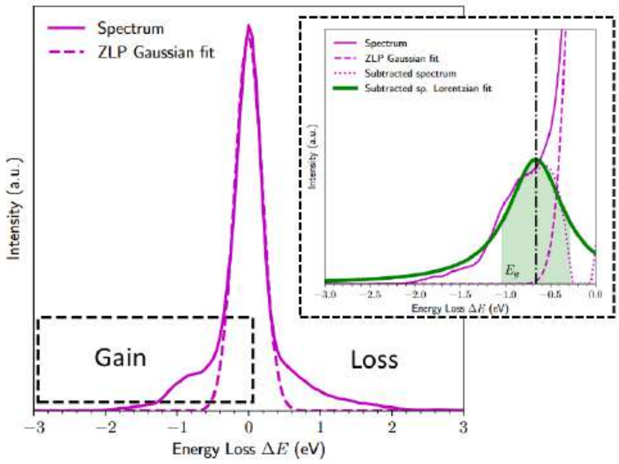

Figure 1: Plot of the zero-loss peak (ZLP) centered around 0 eV. In the energy gain region, an unusual broadening of the ZLP is present. The inset shows a Lorentzian fit of this energy gain feature.

QMS: Quantum Metropolis Center

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Abstract (Century Gothic 11)

The efficient resolution of optimization problems is one of the key issues in today's industry. This task relies mainly on classical algorithms that present scalability problems and processing limitations [1]. Quantum computing has emerged to challenge these types of problems. In this paper, we focus on the Metropolis-Hastings quantum algorithm [2] that is based on quantum walks. We use this algorithm to build a quantum software tool called Quantum Metropolis Solver (QMS). We validate QMS with the N-Queen problem [3] to show a potential quantum advantage in an example that can be easily extrapolated to an Artificial Intelligence domain [4]. We carry out different simulations to validate the performance of QMS and its configuration.

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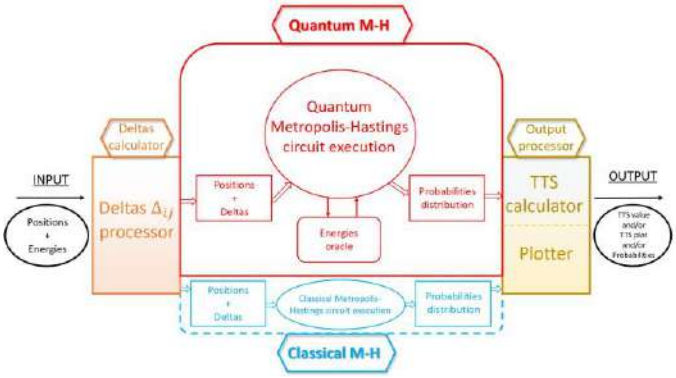

Figure 1: QMS architecture detailing how all modules are connected.

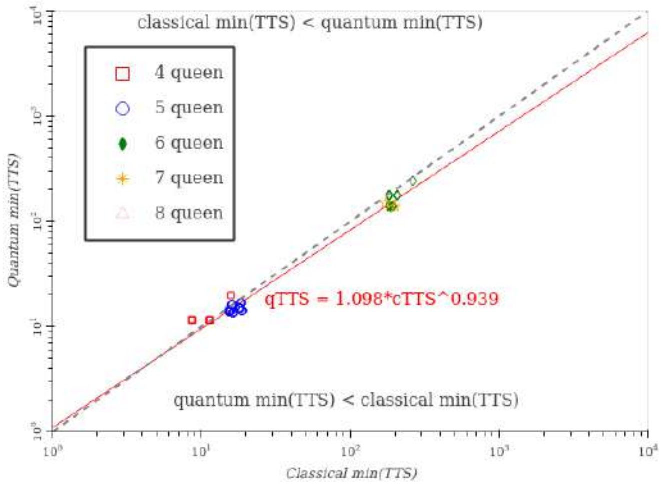

Figure 2: Results of QMS in N-Queen problem. The value is lower than 1 which means that there is a quantum advantage.

Cavity universal control with quantum gates: ECD and CNOD gates at comparison

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Abstract

Circuit quantum electrodynamics (cQED) presents itself as one of the most promising fields to achieve scalable quantum computers. In this field, quantum gates are of particular interest since they allow universal control of the cavities quantum state space, as well as state tomography. Thus, they represent potential tools for multimode cavity control. My project focuses on simulating realistic cQED systems to provide a better understanding of how different quantum gates operate on the system, analysing their strengths and weaknesses in different parameter regimes and noise models. The echoed conditional displacement (ECD) is a well-known quantum gate compared to the novel Conditional Not Displacement (CNOD) gate designed by Diringer et al. The goal is to achieve a better understanding of the similarities and differences between the two quantum gates, and provide a framework of comparison at different parameter regimes. Understanding which input pulses are optimal for the use of each gate is an important step to achieve high-fidelity cavity control.

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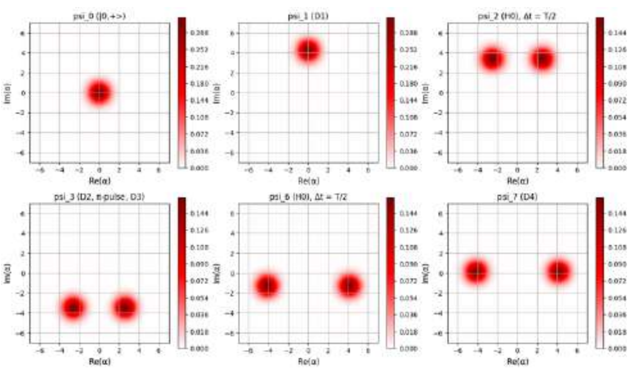

Figure 1: Wigner function representation of a |+> state controlled with the ECD gate. The above is an implementation of the ECD sequence [3].

Tunable $0 - \pi$ Josephson devices with ferromagnetic insulator barrier: the role of spin-orbit interaction and lattice impurities

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Abstract

Josephson π-junctions (π-JJs) are currently subject to intense research activity [1-4] due to their applicability in superconducting circuits [1,3], spintronics [4] and quantum computing devices [2]. In particular, the possible integration of π-JJs in quantum circuits for superconducting qubits is quite promising [2], in view of the increased robustness against noise induced by magnetic field sources and a more compact design [1,2,4], paving the way to scalable and self-biased devices [2]. Superconductor-ferromagnet-superconductor JJs (SFS JJs) are promising platforms to implement π-JJs [1,2,4], and have been widely studied, being proven to exhibit temperature induced $0-\pi$ transitions. Much less is known when the ferromagnetic layer is insulating and more suitable for circuital applications, due to its low dissipation. In this work we investigate the transport properties of ferromagnetic-insulator barrier junctions (SFIS JJs) [1] with particular attention to the temperature behavior of the critical current ($I_C(T)$), that may be used as a fingerprint of the junction. One of the most challenging issues is to find an effective way of controlling the $0-\pi$ transitions in SFIS JJs, through a direct action on their $I_C(T)$ [1,3,4]. We study the specific role of impurities as well as of spin mixing mechanisms, due to the spin orbit, in this kind of task [1,3,4]. $0-\pi$ transitions can be properly tuned, thus achieving stable π -JJs over the whole temperature range [1], that may be possibly employed in superconducting quantum circuits.

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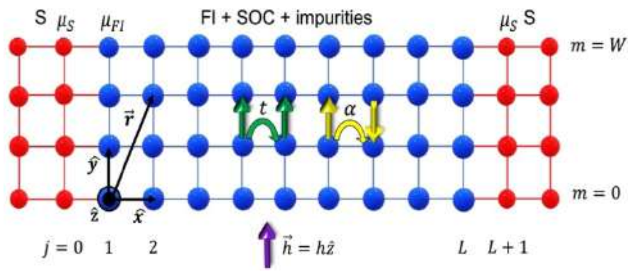

Figure 1: 2-D lattice scheme of the SFIS JJ. Exchange field h, spin-orbit α, hopping t, chemical potentials of FI barrier μ_{FI} and superconducting leads μ_S are shown [1].

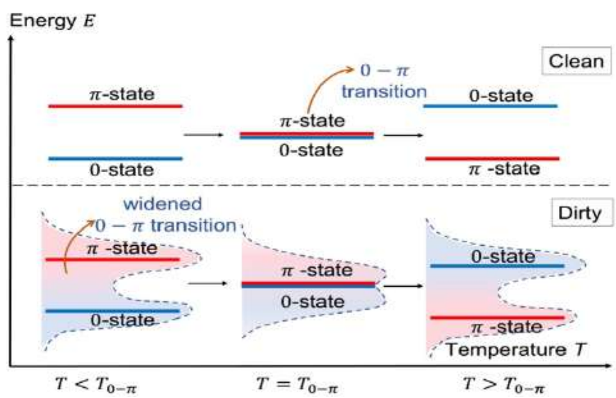

Figure 2: Schematic picture of 0 and π energy levels undergoing a $0-\pi$ transition in the absence (above, clean regime) and presence (below, dirty regime) of lattice impurities [1].

Programmable multi-photon quantum interference in a single spatial mode.

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The interference of non-classical states of light is crucial for a wide range of quantum-enhanced applications. However, the practical implementation of complex quantum protocols on photonic platforms requires a growing number of physical resources, ranging from more photon sources to larger networks and multiple detectors. Here, we demonstrate a highly efficient quantum photonic processor based on a quantum dot single-photon source, a programmable time-bin interferometer, and only one detector (Fig. 2). The time-bin interferometer is based on active and tuneable linear optical elements, and a fibre loop (Fig.1), as proposed in [1]. With our device we observe the interference of up to 8 photons in 16 modes. To provide evidence of quantum interference in our processor, we employed two *Boson Sampling* validation techniques [3,4] against alternative hypothesis for our experimental statistics.
Our results can form the basis for a future resource-efficient universal photonics quantum processor.

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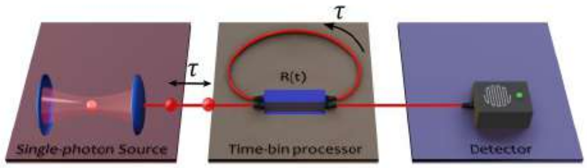

Figure 1: Architecture. A single-photon source is triggered at time intervals τ to prepare a train of n single-photons in m designed time bins along a single spatial trajectory. The photons stream is then propagated through a time-bin processor, the core of which consists of a beamsplitter with time-varying programmable reflectivity. One output of the beamsplitter is connected by a fiber loop to one of the inputs and traverses a delay matched to the arrival of a subsequent input photon at time τ. In this way, the device implements an arbitrary beamsplitter action between consecutive time-bins.

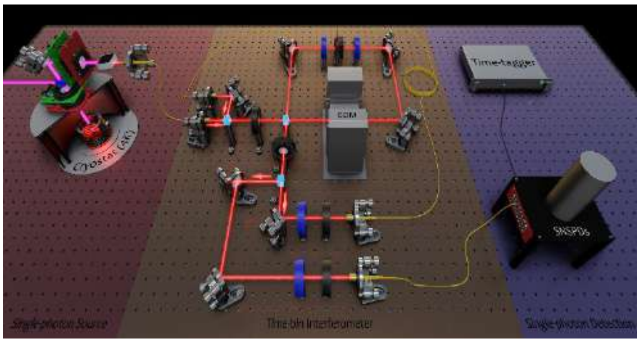

Figure 2: Experimental setup (cfr. Fig.1). The source is an InGaAs quantum dot coupled to a micro-pillar cavity. The tuneable beamsplitter is implemented as a free-space Sagnac interferometer, whose optical paths pass through the electro-optical phase modulator (EOM). The EOM controls the time-varying reflectivity, which can be reconfigured to any value for each time bin. After traversing the fiber loop a number of times, all photons and time-bins exit the processor and are detected with only one detector (SNSPD). The resulting statistics is reconstructed by post-processing events registered by the time-tagger.

Temperature dependent Ga_2O_3 refractive index for nanowire-based thermometers

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Gallium oxide is currently attracting great interest on the semiconductor field as it is a transparent conductive oxide (TCO) with an ultra-wide bandgap (~ 4.8 eV), high thermal and chemical stability and it can be doped with different rare earths ions, making it a very suitable material for high power electronics and photonics applications [1].

In this work, we present our recent results designing, optimizing, characterizing, and applying optical microcavities based on a pair of distributed Bragg reflectors (DBR) patterned by focused ion beam in the waveguiding β-Ga_2O_3:Cr nanowires, which results in widely tunable Fabry-Perot (FP) optical resonances enhanced by the great photonic properties of Cr^{3+} ions, and their use as wide dynamical range temperature sensor (at least from 150 K to 550 K, with a precision around 1 K) based on the thermal position shift of the characteristic R-lines of Cr^{3+} and the FP resonances observed by local photoluminescence [2]. This study has been carried out both experimentally and with finite-different time-domain (FDTD) simulations. Also, the monoclinic crystal structure of Ga_2O_3 results in an anisotropic refractive index, making it necessary a detailed analysis to fully understand the optical behaviour and its temperature dependence. By ellipsometry, we have obtained our own measurements of temperature dependent refractive index of a bulk monocrystalline β-Ga_2O_3 and discuss the validity with another previous work [3] and by using an interferometry method.

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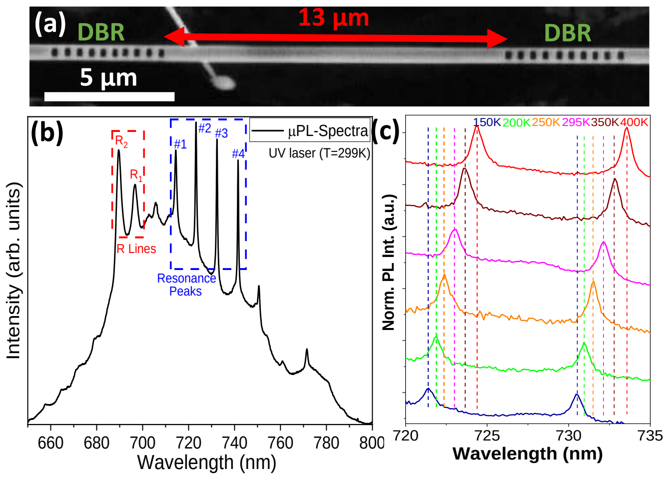

Figure 1: (a) Optical cavity created in a β-Ga_2O_3:Cr nanowire, (b) Room temperature local micro-photoluminescence spectrum, (c) FP peak positions shift with temperature.

Half-integer Shapiro steps in the Al shell of hybrid InAs nanowires

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In the past decade, hybrid superconductor-semiconductor nanostructures have attracted great attention as a promising platform for the search of topological superconductivity [1, 2] and for the development of hybrid superconducting qubits [3]. Recent progress in this field has been enabled by the development of growth methods that warrant a clean interface between superconductor and semiconductor, such as the epitaxial growth of superconductors onto InAs and InSb nanowires [4-6]. Among these cleaner crystals, hybrid InAs-Al wires have been developed first and have been, by far, explored the most. Despite the significant role that the superconducting shell plays in the above experiments, there are few works that fully characterize it [7]. In this work, we present measurements of an intermediate resistance regime in the superconducting Al shell in InAs nanowires when applying a current bias (I_b) and a perpendicular magnetic field ($B_\perp$). We observe that under microwave radiation these regions in the I_b-$B_\perp$ map develop a variety of features reminiscent of Shapiro steps, which are a well-known manifestation of the AC Josephson effect. This behaviour suggests that a weak link is forming in the Al shell when driven out of equilibrium. To the best of our knowledge, this is the first observation of Shapiro phenomena in the superconducting shell of hybrid nanowires. This suggests that the out of equilibrium physics of the superconducting Al shell is yet not fully understood.

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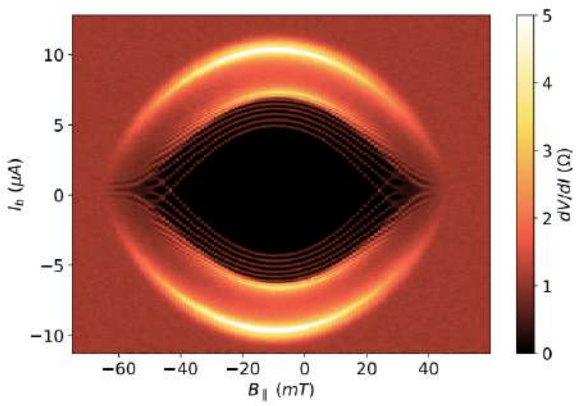

Figure 1: Shapiro steps measurement under an applied $B_\perp$.

Quasiparticles in Superconducting Qubits with Asymmetric Junctions

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Single-particle excitations, known as Bogoliubov quasiparticles, threaten the operation of superconducting qubits. In this work [1], we theoretically revisit and generalize the qubit-quasiparticle interaction, including the gap asymmetry in Josephson junctions, which generally arises in the deposition of aluminum layers with different thicknesses.
We show how the interplay of generation, tunneling, and relaxation mechanisms determines the steady state of non-equilibrium quasiparticles. Two substantially different regimes are identified: 1) small gap difference, where quasiparticles are mainly located at the larger gap energy in both leads and the excited state of the qubit is depleted; 2) strong gap asymmetry, similar to or higher than qubit frequency, with quasiparticles trapped in the lower gap superconductor and reduced relaxation rate. Our results may be relevant to the design of qubits with improved suppression of quasiparticle poisoning.

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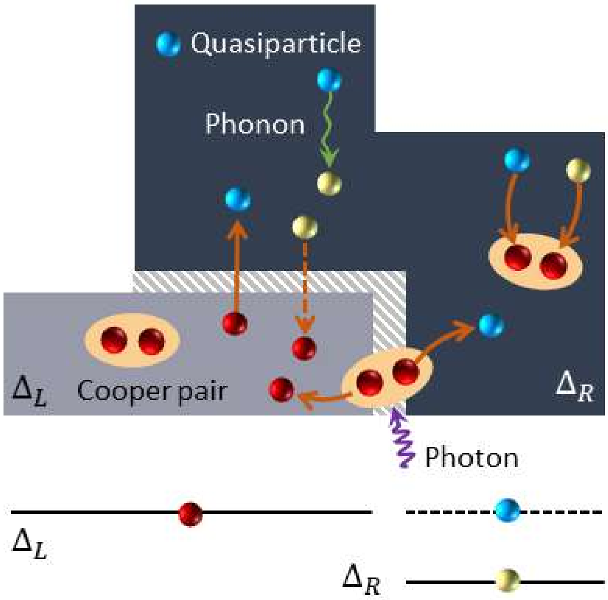

Figure 1: Schematic representation of an asymmetric junction and the relevant quasiparticle processes

Efficient Preparation of Ansatz States on Near-Term Quantum Computers for Quantum Chemistry

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Abstract
Quantum computing has promised quantum advantage in quantum chemistry applications to solve molecular many-body problems. For example, quantum phase estimation has shown to have exponential speedup over its classical counterparts with the success probability that is determined by the overlap of a trial ansatz state with the eigenstate of interest [1]. However, quantum ansatz state preparation was quickly identified as a major bottleneck step that prohibits quantum algorithms from fulfilling their potential [1]. Widely-used quantum ansatzes including the Slater determinants [3] and Unitary Coupled Cluster [4] employ parameterized fermionic excitation gates, with the latter resulting in deep quantum circuits that scale at least polynomially in two-qubit gate depth with the system size *N*, which exacerbate errors due to quantum noise and decoherence. As quantum computers are yet to become fault-tolerant, it is thus important to have depth-efficient preparation of quantum ansatz for near-term quantum computing applications in chemistry. Here we propose an alternate paradigm for fermionic ansatz state preparation [5] inspired by data-loading circuit methods developed for quantum machine learning [6]. We show how a shallow, yet scalable sequence of parameterised fermionic excitation operators $\hat{C}_i$ can be used to prepare Slater determinants and correlated ansatzes yielding subexponential reduction in the two-qubit gate depth compared to previous approaches, as shown in Fig. 1. Moreover, our approach is designed to be compatible on existing quantum devices with planar qubit architectures without requiring any expensive qubit swapping overheads, thereby enabling the use of more qubits needed for high-precision quantum chemistry studies on near-term quantum devices.

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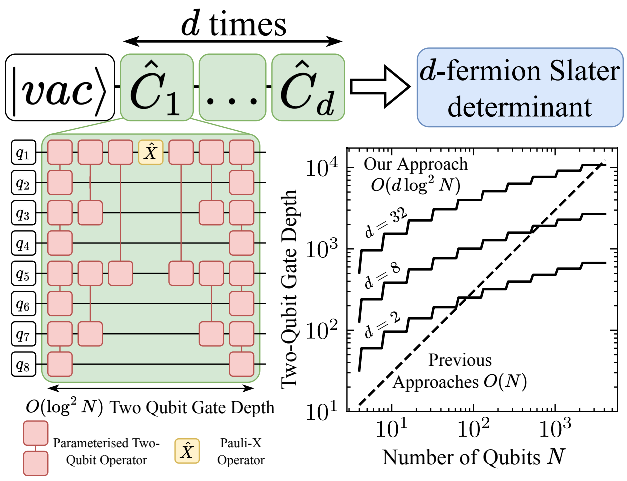

Figure 1: Proposed efficient approach and the estimated two-qubit gate depth for preparing *d*-fermion Slater determinant on a quantum computer with *N* qubits.

Towards Majorana bound states at the edges of spin chains on superconductors

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Scanning tunneling microscopy (STM) has proved to be a mature technique for the study of magnetic impurities on different substrates as quantum sensors and as building blocks for quantum information. Building arrays of spins is of great interest because of their inherent quantum properties [1]. On an s-wave superconductors, Majorana bound states are expected to appear.

I will show recent experimental results with the STM, using single Cr atoms to assemble a 1-D spin chain on a Bi_2Pd surface. Depending on the arrangement of the atoms, different spin orderings can be achieved leading to closing the superconducting gap and approaching a topological quantum phase transition [2]. Our calculations using Bogoliubov-de Gennes theory [2,3] lead us to the conclusion that clear Majorana bound states should appear for relatively small chains in one of the arrangements.

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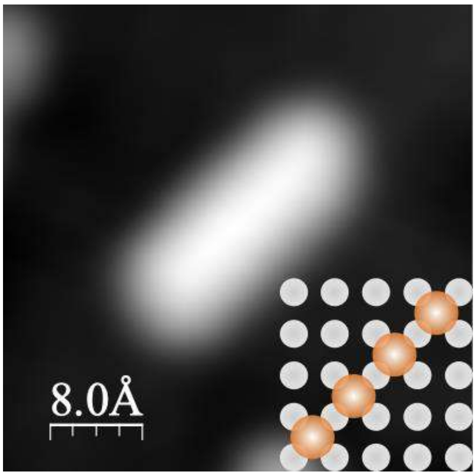

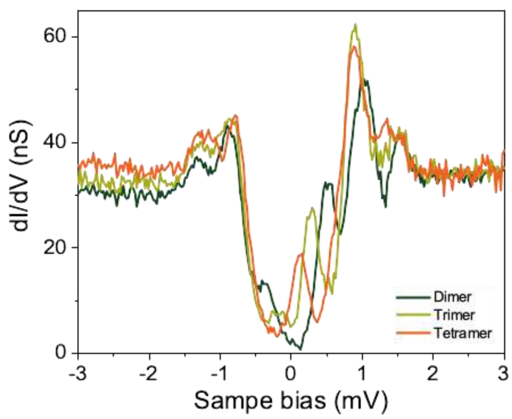

Figure 1: (Top) STM topography of a 4-atom spin chain of Cr on Bi_2Pd. (Bottom) Differential conductance on the edge atom of dimer, trimer and tetramer of Cr on the same surface. As the Cr structure approaches a spin chain, in-gap states approach zero energy [2].

Introducing flux-tunability in high-Q superconducting cavity devices

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Three-dimensional (3D) superconducting microwave cavities have been shown to exhibit long lifetimes of up to several milliseconds, making them promising candidates for storing continuous-variable quantum information. Effective control of these cavities requires non-linear auxiliary circuits. Incorporating flux-tunable elements such as SQUID or SNAIL [1] devices is highly desirable as they can potentially enable fast operations without imparting unwanted dynamics on the cavity modes. However, this integration is non-trivial due to the need to apply external magnetic bias in a 3D superconducting enclosure. Consequently, the implementations demonstrated so far are limited to only either DC [2] or fixed-frequency AC bias [3]. In this work, we realise a device that uses a μ-metal magnetic hose [4] to provide fast adiabatic bias to a SQUID circuit coupled to a cavity. The architecture is compact and has the potential to provide effective biasing of the SQUID element without compromising the coherence times of the cavity. Furthermore, we investigate the possibility of using this device to enact fast resonant control of individual sideband transitions [5] of the cavity. This highlights the value of our architecture in achieving robust operations on 3D superconducting for continuous-variable quantum information processing.

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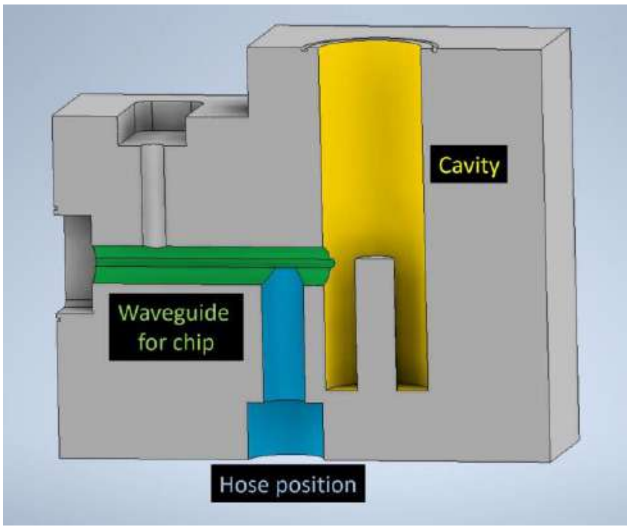

Figure 1: cQED hardware schematic showing: waveguide for a auxiliary circuit chip, slot for μ-metal magnetic hose and storage cavity.

Efficient State Estimation of Bosonic Modes with Quantum Machine Learning

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Bosonic superconducting devices are a promising platform for hardware-efficient and error-correctable quantum information processing. However, typical approaches to characterize bosonic modes, such as Wigner tomography, require a large number of measurements to densely map the phase space of these modes. Thus, Wigner tomography is a resource-intensive technique that becomes practically infeasible when scaling up to multimode systems. To overcome this challenge, we leverage on a quantum machine learning protocol to efficiently estimate arbitrary bosonic states with fewer measurements. More especially, our protocol is based on quantum reservoir processing (QRP). To measure an arbitrary state in the first cavity (Alice), we first scramble its information across a larger Hilbert space via ergodic evolutions, which can be achieved through a programmable beamsplitter interaction that couples Alice to a second cavity (Bob), as well as with displacement, and squeezing operations. We then measure the photon number distribution on Bob and use a previously-trained quantum map to transform the measurement results into a density matrix estimator. Assuming no measurement error, estimating an arbitrary state of dimension *D* with high fidelity only requires $D^2 - 1$ measurements. Hence, for the same number of measurements, QRP reconstructs the initial state with higher fidelity than Wigner tomography.

This project may contribute to establish a new technique for efficient state estimation of bosonic modes, which can become a useful tool to speed up measurements in day-to-day experiments.

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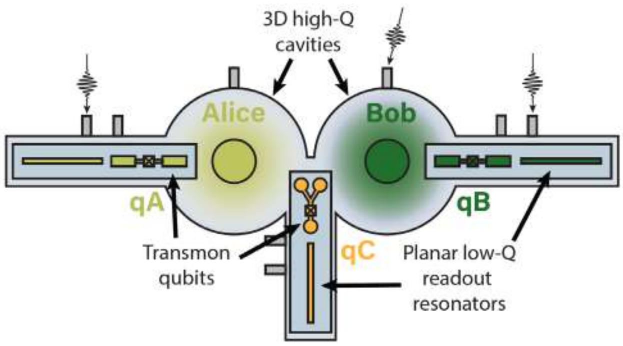

Figure 1: Schematic of the device used to perform the QRP protocol. Two 3D cavities (Alice and Bob) are coupled together through a transmon qubit (qC). Each cavity is also coupled to an individual transmon (qA and qB) for state preparation and cavity readout. Finally, each transmon qubit is coupled to its own readout resonator.

The power of photons: Cavity-mediated energy transfer between quantum devices

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Abstract

We investigate the coherent energy transfer between two quantum systems mediated by a quantum bus. In particular, we consider the energy transfer process between two qubits, and how it can be influenced by using a resonant cavity as a mediator. Inspecting different figures of merit and considering both on and off-resonance configurations, we characterize the energy transfer performances. We show that the cavity-mediated process is progressively more and more efficient as function of the number of photons stored in the cavity that acts as a quantum bus [1]. The speeding-up of the energy transfer time, due to a quantum mediator paves the way for new architecture designs in quantum technologies and energy based quantum logics [2].

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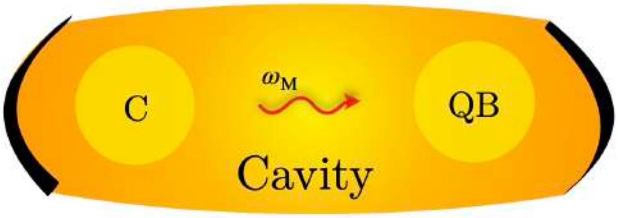

Figure 1: Schematic setup for a cavity-mediated energy transfer between a charger (C) and a quantum battery (QB).

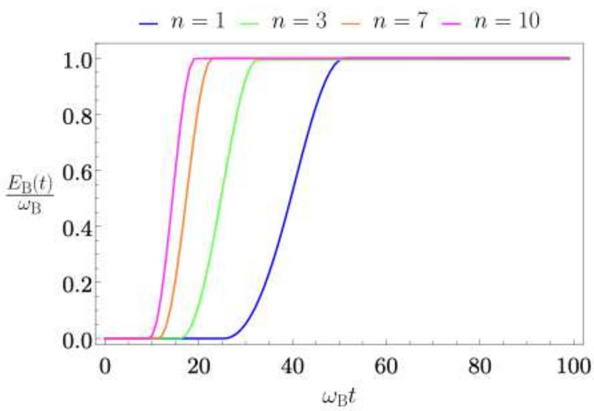

Figure 2: Speeding up in the energy transfer process $E_B(t)$ increasing the number of photons *n*.

Towards Non-Linear Optomechanics with Single Erbium Ions

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Two of the most active and exciting areas of quantum science are quantum optomechanics and individual spin systems, which are often used for quantum networking. Each of them has its own advantages and disadvantages. In optomechanics [1, 2], the optical field and mechanics are effectively linearly coupled to one another. Such systems have emerged as a leading candidate to investigate quantum physics at a massive, macroscopic scale. However, limited by the linear interaction, creating complex quantum states in such systems is difficult. Individual spins in solid-state systems [3], on the other hand, enable advanced quantum protocols thanks to their inherent strong non-linearity. However, due to their small cross section, high-quality optical cavities are needed to realize advanced quantum information processing [4]. Merging these two worlds together brings synergies that leverage their respective strengths and weaknesses, facilitating new insights into the very foundations of physics, as well as enabling novel quantum applications. I will show our most recent findings on the spectrum characterization of Er^{3+} ions implanted in a silicon waveguide.

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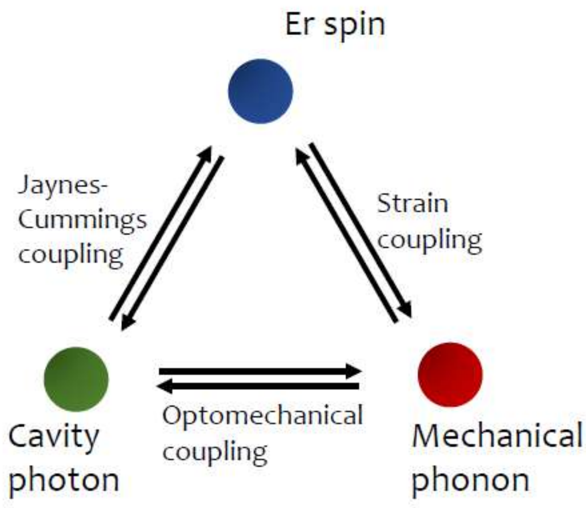

Figure 1: Hybrid system.

On magnetic models in wavefunction ensembles

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Abstract

We recasted thermodynamics in terms of spin-wavefunction ensembles, rather than classical particle configurations or “found” values of Copenaghen Quantum Mechanics. This asks a completely new mathematical treatment. In these ensembles magnetic phase transitions are possible if and only if we consider indistinguishable particles together with a macroscopic non-linearity which blocks macroscopic dispersion (i.e. macroscopic superpositions) by energy conservation (preserving norm and energy).
This non-linearity becomes significant only at the macroscopic level, and hence is of possible interest for the Measurement Problem. The overall magnetic field seems the
right description, what will distinguish one model from another are the symmetry of the wavefunction and the spin values. Results available in [1].

References

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Figures

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The Recursive MWPM decoder

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Quantum computers promise ground breaking effects in several research fields such as cryptography or pharmacology. Thus, a large community of scientists continuously develop new and better optimized quantum algorithms which will hopefully contribute to the advancements a future quantum computer will yield. Nevertheless, for a quantum computer to be reliable in its computations, it must be fault-tolerant. That is, it needs to be able to endure quantum decoherence within its qubits without having its operations compromised. The field of study of fault-tolerance within quantum computing is known as Quantum Error Correction (QEC). A common approach within QEC in order to protect the qubits consists in storing their information within a larger set of qubits named Quantum Error Correction Codes (QECCs). The process of recovering an error which is expected to have been the one which interacted with the code is named decoding. The most popular QECC at the moment is the surface code. Surface codes consist in displaying the qubits which encode the information of the code in the vertices of a 2D-lattice, while other qubits which are used for obtaining syndromes are also displayed corresponding a 2D-lattice structure. Moreover, surface codes are the only type of QECC to be experimentally tested [1,2]. The surface codes can be decoded through various decoding schemes, nevertheless the most popular is named the Minimum Weight Perfect Matching decoder (MWPM). The MWPM method excels in performance for surface codes, but it can struggle when considering realistic quantum channels, such as the biased channel or the independent non-identically distributed (i.ni.d.) error model. For this poster, we cover a variation of the MWPM decoder which significantly improves the performance of the conventional MWPM by considering correlations between errors, the recursive MWPM (recMWPM). Normally, the conventional MWPM decodes a syndrome by considering X and Z-errors independently. Nevertheless, doing so omits the impact of Y-errors, which for mathematical reasons can be considered products of X and Z, and the probability rate of which is considered to be similar to the X-error one. The recMWPM uses the computation of MWPM in one of the two subgraphs to reweight the edges from the other in a recursive manner until both subgraphs agree in the same result. This variation on the decoding consideration significantly enhances the performance of the decoder (as can be seen in Figure 1) at the expense of a complexity parameter, which can be adjusted at will.

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Figures

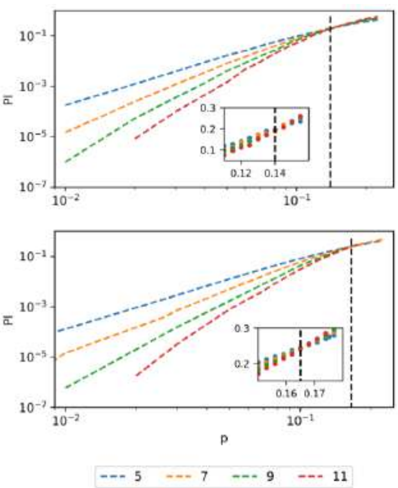

Figure 1: Logical error with dependence on the physical error probability for rotated planar codes under depolarizing noise being the conventional MWPM (top) and by the recMWPM (bottom).

Performance of QAOA for Portfolio Optimization

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Abstract

For the portfolio optimization problem formulated as a quadratic binary optimization problem, we apply the quantum approximate optimization algorithm (QAOA) and study it using its standard and other versions (different mixers) [1] and, moreover its warm start version (WS-QAOA). Evaluation of the algorithm's performance shows improved performance of WS-QAOA compared to its standard version, but lower performance compared to the tests with the different mixers.
In order to evaluate whether the improved performance of WS-QAOA is due to quantum effects, we analyze to which extent its results can be reproduced by purely classical preprocessing of the original problem followed by standard QAOA.
Finally, we extend the discussion by examining the key effects of the various mixers that yield the best overall performance of all tested versions.

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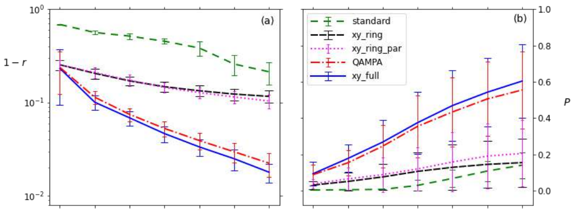

Figure 1: (a) Mean deviation 1 − r of the approximation ratio from the optimal solution and (b) mean probability P of obtaining the optimal portfolio, both with standard deviation (error bars) as a function of the QAOA depth p for 20 randomly chosen portfolio optimization instances, using different mixers.

A novel approach to noisy gates for simulating quantum computers

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Abstract

We present a novel method for simulating the noisy behaviour of quantum computers, which allows to efficiently incorporate environmental effects in the driven evolution implementing the gates on the qubits. We show how to modify the noiseless gate executed by the computer to include any Markovian noise, hence resulting in what we will call a noisy gate. We compare our method with the IBM Qiskit simulator, and show that it follows more closely both the analytical solution of the Lindblad equation as well as the behaviour of a real quantum computer, where we ran algorithms involving up to 18 qubits; thus, it offers a more accurate simulator for NISQ devices. The method is flexible enough to potentially describe any noise, including non-Markovian ones.

References

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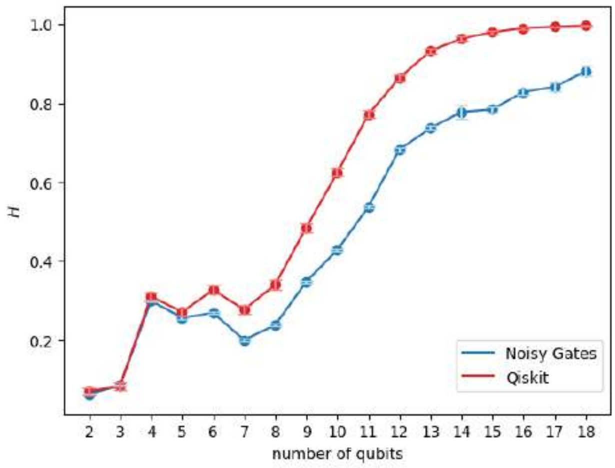

Figure 1: Hellinger Hellinger distance for the QFT† algorithm for n = 2, . . . , 18 qubits. Each value is the mean of 100 independent simulations for the noisy gates, in blue, and for the Qiskit simulations, in red.

Solving constrained optimization problems with multi-objective variational quantum algorithms

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Combinatorial optimization problems (CO) have a strong impact on a wide range of disciplines such as finance, machine learning, logistics, etc. In addition to finding a solution with minimum cost, problems of high relevance involve a number of constraints that the solution must satisfy. Variational quantum algorithms (VQA) have emerged as promising candidates for solving these problems in the noisy intermediate-scale quantum stage [1]. However, the constraints are often complex enough to make their efficient mapping to quantum hardware difficult or even infeasible. An alternative standard approach is to transform the optimization problem to include these constraints as penalty terms, but this method involves additional hyperparameters and has several shortcomings. Our work introduces the Multi-Objective Variational Constrained Optimizer (MOVCO), a new method for solving CO with challenging constraints [2]. MOVCO combines the quantum variational framework with a genetic multi-objective optimization to simultaneously optimize the projection of the variational wave function onto the subspace of solutions satisfying all constraints, and the energy of the feasible solutions. This procedure allows the algorithm to progressively sample only states within the in-constraints space, while optimizing the energy of these states. We test our proposal on a real-world problem with great relevance in finance: the Cash Management problem. We introduce a novel mathematical formulation for this problem, and compare the performance of MOVCO versus a penalty-based optimization. Our empirical results show a significant improvement in terms of the cost of the achieved solutions, but especially in the avoidance of local minima that do not satisfy any of the mandatory constraints.

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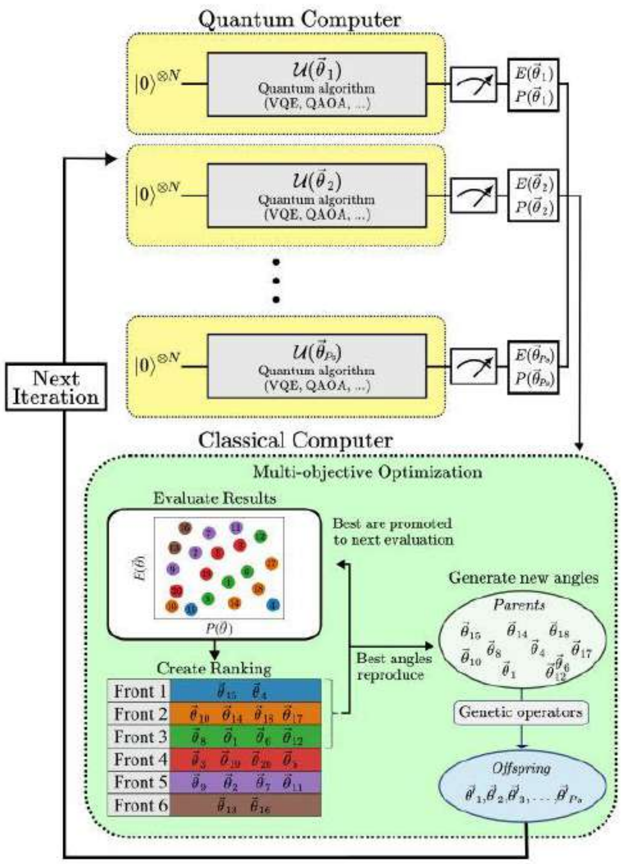

Figure 1: Schematic diagram of the constrained multi-objective variational optimizer (MOVCO).

Magnetically Controllable Two-Dimensional Spin Transport in a Three-Dimensional Crystal

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Two-dimensional (2D) phases of matter have become a new paradigm in condensed matter physics, bringing in an abundance of novel quantum phenomena with promising device applications.

However, realizing such quantum phases has its own challenges, stimulating research into non-traditional methods to create them. One such attempt is presented here[1], where computational and theoretical techniques are used to show that the intrinsic crystal anisotropy in a ``fractional'' perovskite, Eu_xTaO_3 ($x=1/3 \sim 1/2$), leads to the formation of stacked layers of quasi-2D electron gases (2DEG), Fig.1A, despite being a three-dimensional bulk system. Quantum oscillations in charge conductivity and thermoelectric properties, Fig.1B and C, are examined and proposed as routes to experimentally demonstrate the quasi-2D behavior.

Furthermore, these carriers possess topologically non-trivial spin textures, owing to a coupling of two component Rashba fields, Fig.2. These textures are indirectly controllable by an external magnetic field via proximity effect, in a manner analogous to $EuTiO_3$[2], making it an ideal system for spintronics. Lastly, an anomalous Hall effect with a non-monotonic dependence on carrier density is shown to exist, signifying a shift in band topology with carrier doping.

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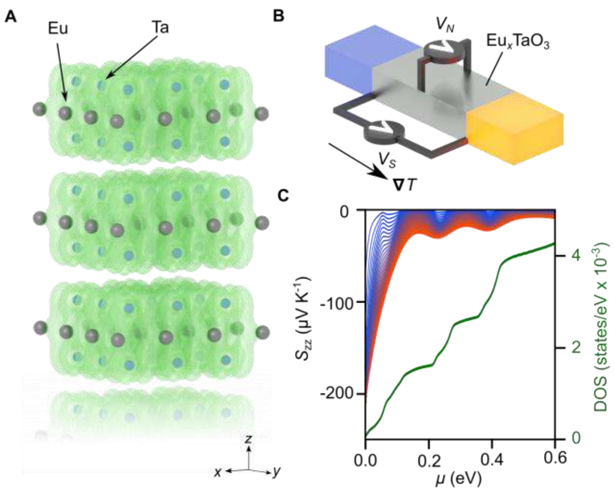

Figure 1: A Confinement of charge density to layers of quasi-2DEGs. **B** Schematic of Seebeck measurement to probe this quasi-2D phase experimentally. **C** Non-monotonic Seebeck effect that arises from quasi-2D behavior.

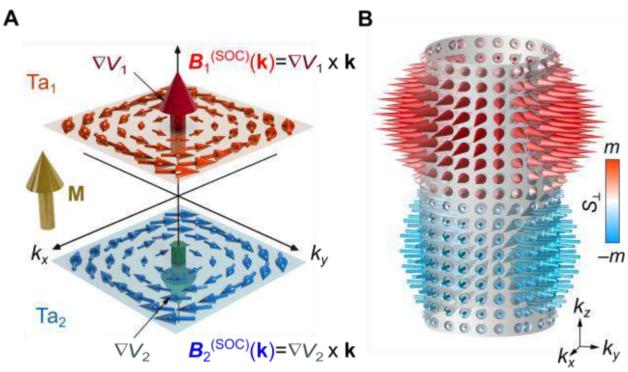

Figure 2: A local Rashba spin orbit fields on Ta sites, with opposite chirality. **B** Example of *k*-space in-plane spin texture, taken from lowest energy band, that arises from non-trivial coupling of Ta sites.

Parameter estimation of gravitational waves with a quantum metropolis algorithm

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Abstract

After the first detection of a gravitational wave in 2015, the number of successes achieved by this innovative way of looking through the Universe has not stopped growing. However, the current techniques for analysing this type of events present a serious bottleneck due to the high computational power they require.
In this talk, we explore how recent techniques based on quantum algorithms could surpass this obstacle [1]. For this purpose, we propose a quantization of the classical algorithms used in the literature for the inference of gravitational wave parameters [2] based on the well-known quantum walks technique applied to a Metropolis–Hastings algorithm. Finally, we develop a quantum environment on classical hardware, implementing a metric [3] to compare quantum versus classical algorithms in a fair way. We further test all these developments in the real inference of several sets of parameters of all the events of the first detection period GWTC-1 [4] and we expose a polynomial advantage in the quantum algorithms, thus setting a first starting point for future algorithms.

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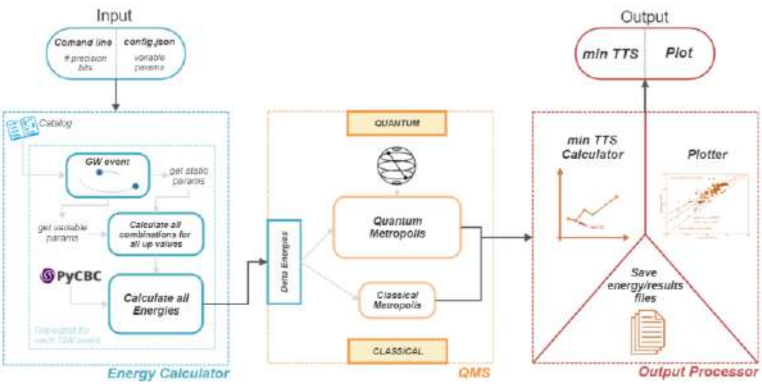

Figure 1: Flowchart of the algorithm implemented.

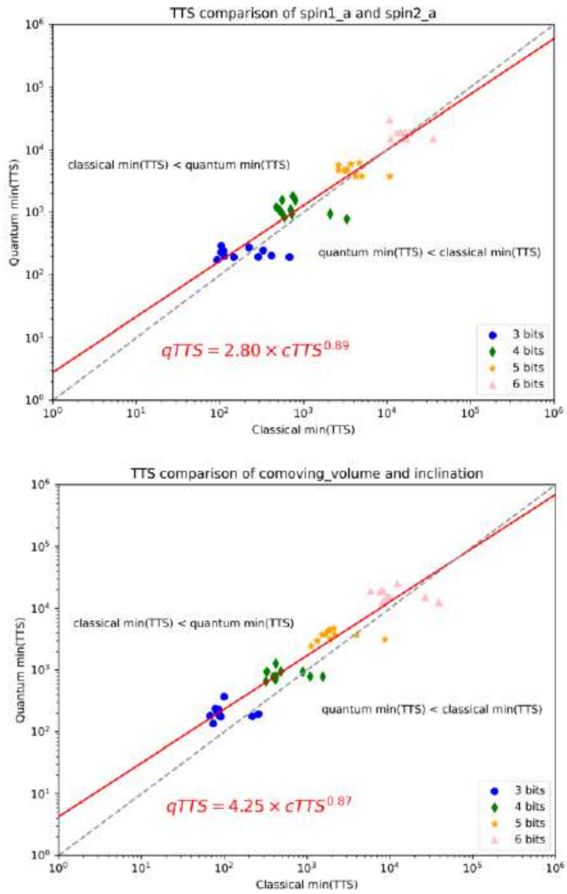

Figure 2: Comparison of the metric for 2-parameter inference simulation for quantum vs classical algorithms, achieving a quantum advantage.

Polarization transfer to external nuclear spins using nitrogen-vacancy centers in diamond and surface electron reporter spins

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The use of nitrogen-vacancy (NV) centers in diamond as a non-invasive platform for hyperpolarizing nuclear spins in molecular samples is a promising area of research with the potential to enhance the sensitivity of nuclear magnetic resonance (NMR) experiments. Transferring NV polarization out of the diamond structure has been achieved on nanoscale targets using dynamical nuclear polarization (DNP) methods, but extending this to bulk samples used in standard NMR poses significant challenges. One major technical hurdle is the presence of paramagnetic defects in the form of sur face dangling bonds, which can interfere with polarization outflow. However, these defects can also be harnessed as intermediaries for the interaction between NVs and nuclear spins. We present a microwave sequence that transfers polarization efficiently and robustly using surface dangling bonds or other localized electron intermediaries via functionalized surfaces, with the potential to increase polarization rates under realistic conditions

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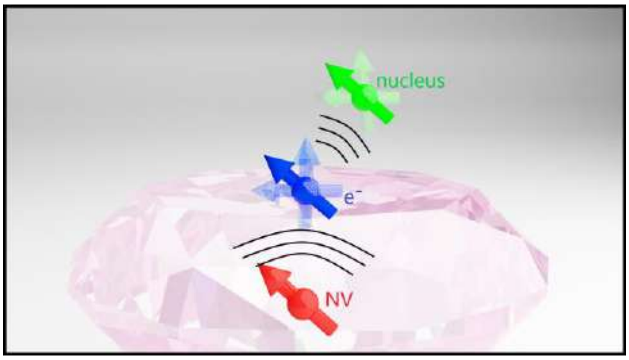

Figure 1: Schematics of the proposed protocol. The NV transfer its polarization state through an intermediate electron at the diamond surface.

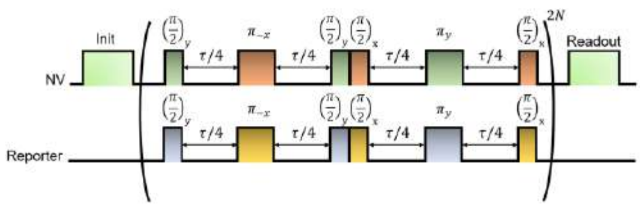

Figure 2: Schematics of the MW pulse sequence on the NV and the electron spin for pulsed polarization transfer.

Multi-qubit time-varying quantum channels for NISQ-era superconducting quantum processors

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Time-varying quantum channel (TVQC) models have been proposed in order to consider the time-varying nature of the parameters that define qubit decoherence [1]. Realizations of multi-qubit TVQCs have been assumed to be equal for all the qubits of an error correction block, indicating that the random variables describing the fluctuations of T1 and T2 are qubit-wise fully correlated [1,2]. However, the fluctuations of the decoherence parameters are explained by the incoherent coupling of the qubits with unstable near-resonant two-level-systems (TLS), indicating that such variations are local to each of the qubits of the system [3,4,5]. In this work [6], we perform a correlation analysis of the fluctuations of the relaxation times of multi-qubit quantum processors ibmq_quito, ibmq_belem, ibmq_lima, ibmq_santiago and ibmq_bogota. Our results show that it is reasonable to assume that the fluctuations of the relaxation and dephasing times of superconducting qubits are local to each of the qubits of the system. Thus, we discuss the multi-qubit TVQC when the fluctuations of the decoherence parameters are local to each qubit, which we name as fast time-varying quantum channels (FTVQC). Moreover, we numerically study the performance of quantum error correction codes (QECC) when they operate over FTVQCs. Finally, we propose the ergodic quantum capacity as a lower bound the asymptotically achievable limit for QECCs over these channels.

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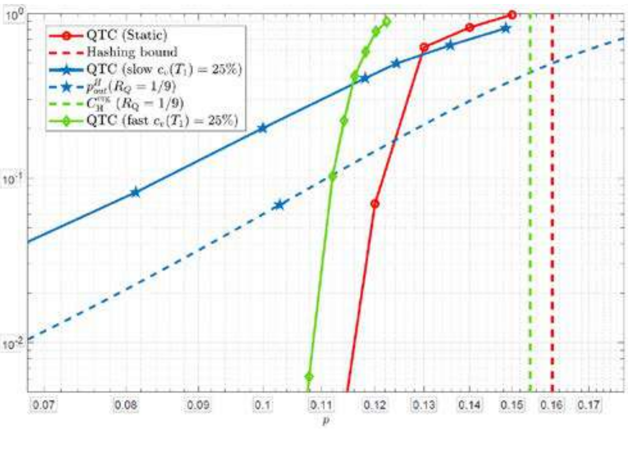

Figure 1: QTC operating over static, Slow TVQC and Fast TVQC.

Homomorphic Encryption of the k=2 Bernstein-Vazirani Algorithm

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The recursive Bernstein-Vazirani algorithm was the first quantum algorithm to show a superpolynomial improvement over the corresponding best classical algorithm. Here we define a class of circuits that solve a particular case of this problem for second-level recursion. This class of circuits simplifies the number of gates *T* required to construct the oracle by making it grow linearly with the number of qubits in the problem. We find an application of these circuits to quantum homomorphic encryption (QHE) which is a cryptographic technology that allows a remote server to perform quantum computations on encrypted quantum data, so that the server cannot know anything about the client's data. Liang developed QHE schemes suitable for circuits with a polynomial number of gates $T/T^{\dagger}$. Following these schemes, the simplified circuits we have constructed can be evaluated homomorphically in an efficient way.

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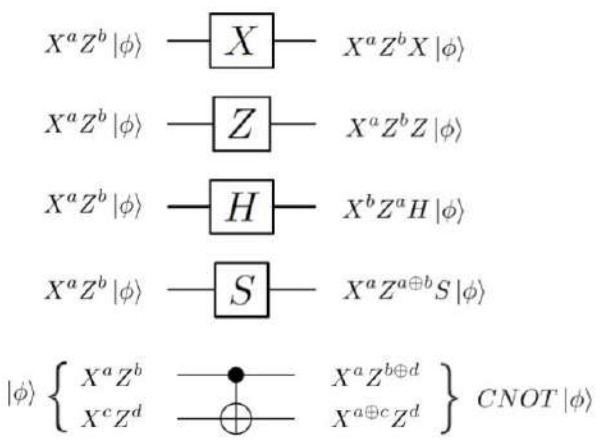

Figure 1: Key updating rules for homomorphic evaluation of Clifford gates

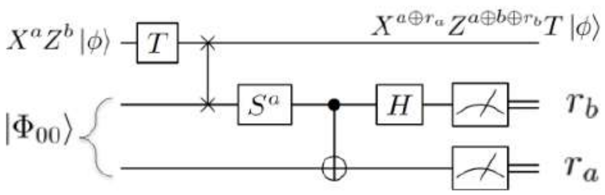

Figure 2: Homomorphic evaluation of *T* gate

Vacuum-field-induced state mixing

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The interaction of an atom with the electromagnetic environment supported by a macroscopic body induces both spontaneous emission and Casimir-Polder energy shifts of the atomic levels, offering control of atomic properties by tuning the parameters of the macroscopic body [1]. Typically, environmental effects are studied for individual atomic levels. However, for sets of near-degenerate states, the induced shifts can become comparable to the energy differences between levels, and it becomes necessary to treat an environment-induced interaction between the levels, which leads to off-diagonal terms in the decay and energy shifts induced by the field. In this study, we propose a method to describe such systems and show that the behavior of an atom near a macroscopic structure can differ significantly from the predictions of the conventional diagonal formulation of the theory. Our methodology is based on macroscopic quantum electrodynamics [2], along with a recently developed Lindblad master equation formalism that can handle near-degenerate levels and avoids some of the issues associated with the Bloch-Redfield equation and secular approximation [3]. This method includes both the well-known Casimir-Polder potentials in the diagonal energy shifts and the off-diagonal couplings. Due to them, the effective atomic eigenstates are linear combinations of the free-space eigenstates, which has physical consequences on, for instance, the atomic decay rates. We have simulated the fine structure of a hydrogen atom coupled to a dielectric nanoparticle and quantify the amount of Casimir-Polder-induced mixing of the eigenstates through the so-called participation ratio. We also gauge the impact of the off-diagonal terms on the dynamics by extracting the eigenenergies and decay rates from the master equation and studying them as a function of the atom-nanoparticle separation. Noticeably, avoided crossings become a new feature of the energy spectrum. As for the decay rates, the enhancement of the Purcell factor leads to the expectation of increasing decay rates for smaller separations. Our findings, however, show this to be wrong, as the mixings induced by the off-diagonal terms lead to the opposite effect within a given range of distances for a particular atomic state. Such effects are not present at all in traditional Casimir-Polder treatments lacking the off-diagonal terms and are necessary to include to properly understand the physics behind quantum applications.

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Long-range transfer of hole spin qubits with shortcut-to-adiabaticity methods

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Quantum state transfer is crucial for modular quantum computing, where communication between different quantum processing units is achieved using quantum buses [1]. The success of these communications relies on their speed, high-fidelity, and noise robustness. In semiconductor spin qubits, linear arrays of quantum dots are used as communication lines, with tunneling between sites serving as the driving parameter. However, the presence of spin-orbit coupling (SOC) in hole spin qubits can negatively impact transfer fidelity by causing spin-flip processes and loss of quantum information. On the other hand, SOC can also be leveraged to allow for one-qubit gates to be performed during particle transfer between distant sites.

In this study, we analyze different state transfer protocols, including CTAP, a linear ramp, and a driving protocol based on shortcuts to adiabaticity (STA) [2]. We investigate how these protocols are affected by 1/f charge noise [3, 4] on the detuning and tunneling rate between dots (see Figure 1). We also explore how the total number of dots impacts the final spin of the transferred particle. By tuning the ratio between spin-conserving and spin-flip tunneling, we can control the one-qubit gate performed during the transfer. Additionally, we extend our study to quantum state distribution [5], where two entangled particles are distributed across distant sites of a linear quantum dot array (see Figure 2). Thanks to SOC, we can adjust the total transfer time to tune the final spin projection [6].

Overall, our work contributes to the development of efficient and robust quantum state transfer protocols, which are essential for the successful implementation of modular quantum computing.

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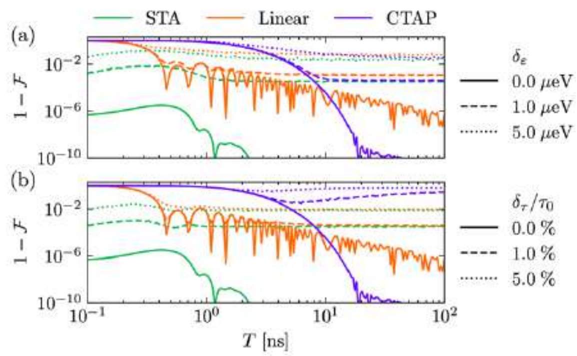

Figure 1: Infidelity of a state transfer versus to total protocol time, for different driving pulses (STA, Linear, CTAP). The transfer in performed under a 1/f noise model in the detuning between dots (a) and in the tunnelling rates (b).

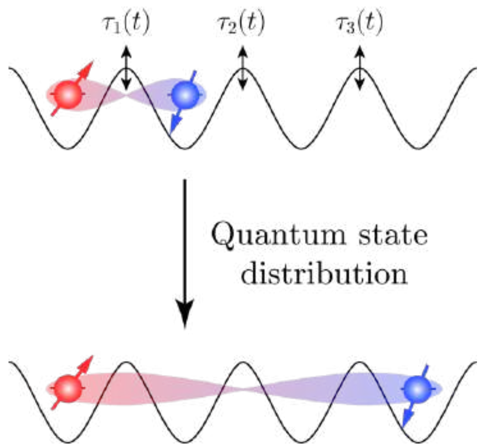

Figure 2: Quantum state distribution of two entangled spin qubits in a quantum bus.

Controllability and Dimensional Expressivity: Two Sides of the Same Universal-Quantum-Computing Coin

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Universal quantum computing requires a quantum system that is operator-controllable [1]. However, the number of resources required for controllability in complex systems is not obvious and, moreover, assessing this property on the systems themselves is a difficult task to achieve in practice. In this project we present a hybrid quantum-classical algorithm, uniting quantum measurements and classical calculations.

The key to our approach is the design of a parametrized quantum circuit (PQC), which can be run on the original system with some extra ancilla qubits. By applying dimensional expressivity analysis we are able to count the number of independent parameters in the PQC [2,3]. This represents the dimensional expressivity of the PQC, which is then linked back to the controllability of the initial system.

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Sensing interactions in atomic quantum systems

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Experiments that cool, trap, and control atoms, ions, and molecules provide a unique testbed. Hybrid ion-atom systems combine the well-controllable platforms of trapped ions and ultracold quantum gases and link them together by the intermediate-range ion-atom interaction. These quantum systems offer opportunities for buffer gas cooling, quantum simulation of many-body systems as well as for state-to-state quantum chemistry [1]. To fully benefit from the combination, it is essential to understand, characterize, and control the interactions between the atoms and ions. Therefore, at TU/e a new experimental setup is being build which combines a trapped ion – Yb^+ - with dipolar atoms - Dy. This poster reports on the development of its design and how it can be used to sense interactions in these atomic quantum systems.

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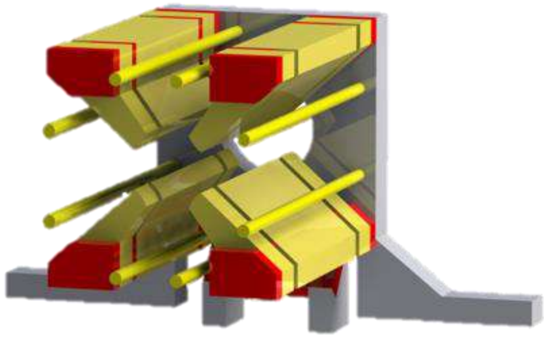

Figure 1: CAD drawing of the ion trap design.

Understanding Localized Spins in Boron-Doped Nanoribbons: Simulating Two Impurities Kondo Effect

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Recently, magnetic moments have been identified in graphene nanoribbons doped with heteroatoms, more specifically in the 2B-7AGNR [1] (see Fig. 1 a). Due to the low spin-orbit and hyperfine interactions, magnetic moments are expected to have long coherence times in these carbon-based systems. Thus, these spin-hosting graphene nanostructures are promising metal-free systems for elementary quantum spintronic devices. So far, the experimental identification of localized magnetic moments in nanographenes has been almost solely based on the observation of Kondo-like features in scanning tunneling spectroscopy (see Fig 1 b). In this context, this work aims at modeling and understanding the basic processes underlying this behaviour. We aim to simulate the Kondo physics of the two-boron center in the 2B-7AGNR. To this end, we propose and simulate a Two Impurities Anderson Model (TIAM) using the Slave-Boson method [2]. The Slave-Boson method is a conserving perturbative technique based in diagrammatic expansion. In this work, we present the theoretical basis of this method and its application to impurity problems. We develop the diagrammatic expansion to first order, named the Non-Crossing Approximation, for the Single Impurity and the Two Impurities Anderson Model. Parameters for the model are obtained from density functional theory (DFT) *ab initio* simulations.

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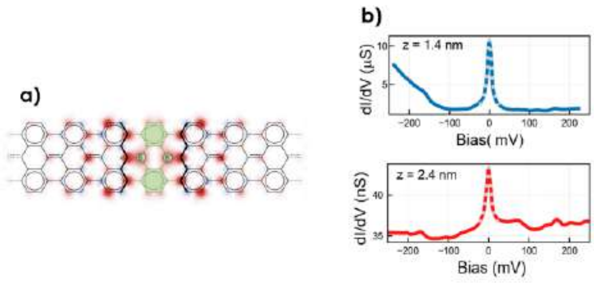

Figure 1: a) Schematic structure of the 2B-7AGNR. DFT computed spin densities in blue and red. **b)** Conductance against bias voltage for two STS measurements for 2B-7AGNR. Extracted from [1].

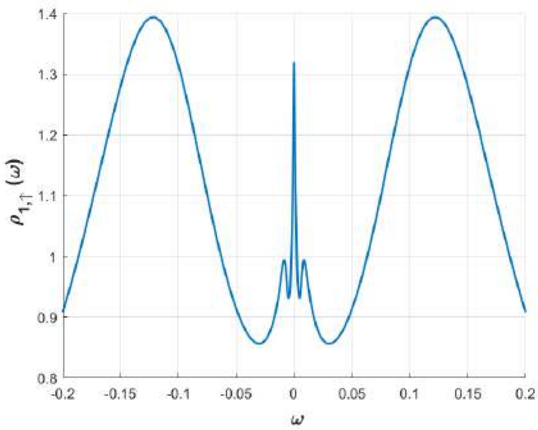

Figure 2: Density of states of the TIAM for the simulated boron center in the 2B-7AGNR. The peak formed around ω=0 is the Kondo resonance. Parameters computed combining DFT calculations with ad-hoc substitutions.

Highly Adiabatic Time-Optimal Quantum Driving at Low Energy Cost

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Abstract

Time-efficient control schemes for manipulating quantum systems are of great importance in quantum technologies, where environmental forces rapidly degrade the quality of pure states over time. In Ref. [1], we recently formulated an approach to time-optimal control that circumvents the boundary-value problem that plagues the quantum brachistochrone equation [2]. In this conference, we show how driven systems, in the form of a Landau-Zener type Hamiltonian [3], can be efficiently maneuvered in a highly adiabatic manner and with a low energy cost. Specifically, quasi-adiabatic dynamics with less than 0.1% deviation from the full adiabatic path can be attained at the quantum speed limit. Furthermore, as shown in Figure 1, the associated energetic cost is orders of magnitude lower than the cost of implementing a counterdiabatic field [4]. In the seek for energy-efficient control protocols [5], the proposed scheme lends itself as a "low-cost" alternative to transitionless driving.

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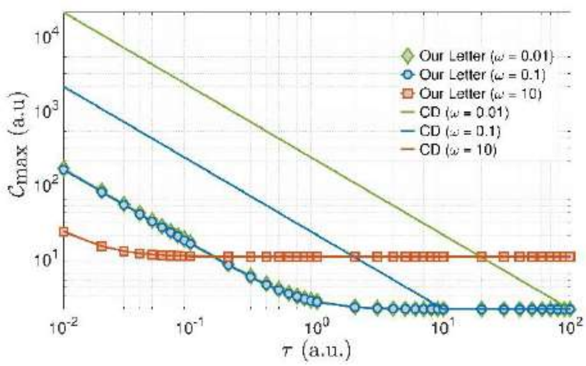

Figure 1: Maximum value of the energy required for implementing the proposed control scheme versus the cost of implementing the counterdiabatic (CD) method as a function of the protocol time.

Qutrit quantum battery: sequential vs coherent charging

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In recent years, the investigation of quantum systems out of equilibrium contributed to the advancement of quantum thermodynamics. In particular, the study of quantum batteries, small quantum mechanical systems able to temporarily store energy and further release it on-demand, recently emerged as a fast-growing subject in this field.

In this framework we have characterized the performances of IBM quantum chips as quantum batteries, establishing the optimal compromise between charging time and stored energy [1].

Considering this result, and motivated by recent experimental observations [2], we have investigated the possibility of realizing charging protocols addressing two excited states of a superconducting qubit in the transmon regime, namely realizing a qutrit quantum battery. This extension allows to store a greater amount of energy in the system and opens the door to a richer variety of charging protocols. We have compared some of them both analytically and through tests on IBM quantum processors with the aim of characterizing their advantages and limitations. Moreover, we have investigated how the charging of a qutrit is affected by crosstalk among the transmons.

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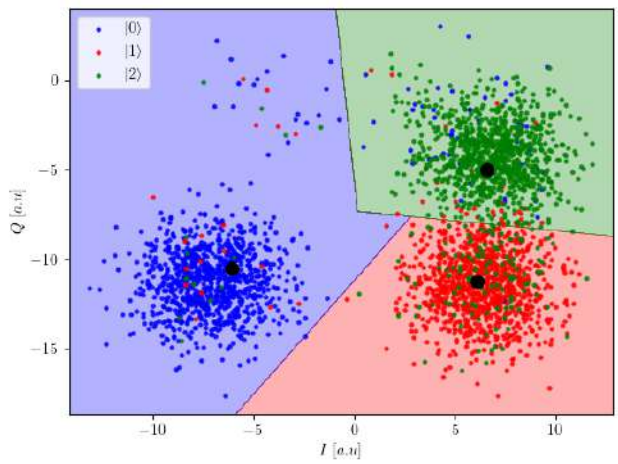

Figure 1: Data distribution associated to the measurements in the (I, Q) plane of the ground state (blue dots), first excited state (red dots) and second excited state (green dots) for one qubit of the Auckland IBM quantum device. Big black dots indicate the mean of each distribution.

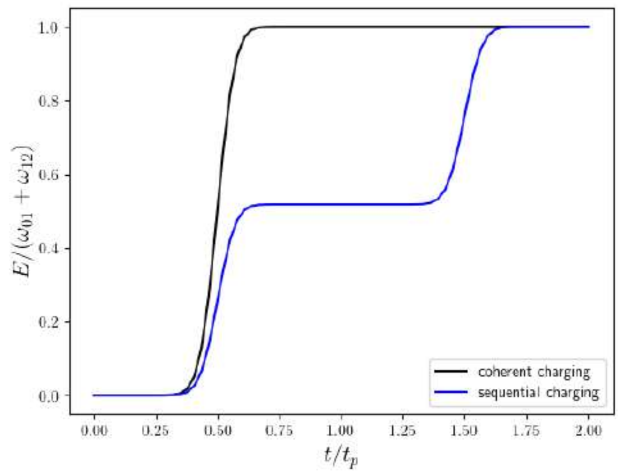

Figure 2: Energy stored in the qutrit quantum battery as a function of time for the sequential (blue) and coherent (black) charging protocol.

Supercurrents in full-shell nanowire Josephson junctions

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Full-shell nanowires (NWs) are under investigation for qubit applications [1]. Josephson junctions based on full-shell NWs can provide an additional tool for quantum operations. Here, we theoretically study the properties of supercurrents in Josephson junctions based on full-shell NWs. We find that in the hollow-core limit the critical supercurrent, *Ic*, can be tuned by an external magnetic flux, and specifically, *Ic* exhibits a characteristic flux dependence which involves the orbital transverse channels. This flux dependence is not related to the usual Little-Parks modulation of the superconducting pairing and can be observed in realistic NWs.

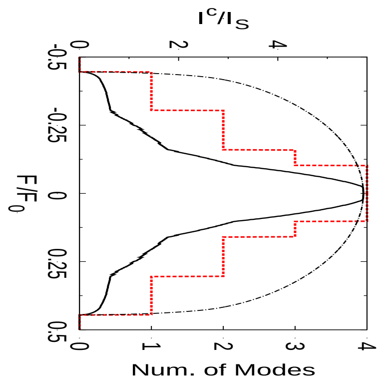

Figure 1: Critical current and number of subgap modes versus magnetic flux in the zero lobe.

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Reinforcement Learning Generation of 4-Qubits Entangled States

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Abstract

Artificial intelligence algorithm with machine reinforcement learning (Q-learning) to construct remarkable entangled states with 4 qubits. The algorithm is able to generate representative states for some of the 49 true SLOCC classes of the four-qubit entanglement states. It is possible to reach at least one true SLOCC class for each of the nine entanglement families. The quantum circuits synthesized by the algorithm may be useful for the experimental realization of these important classes of entangled states. We introduce a graphical tool called the state-link graph (SLG) to represent the construction of the Quality matrix (Q-matrix) used by the algorithm to build a given objective state belonging to the corresponding entanglement class. This allows us to discover the necessary connections between specific entanglement features and the role of certain quantum gates, which the algorithm needs to include in the quantum gate set of actions. The quantum circuits found are optimal in the number of gates by construction with respect to the quantum gate-set chosen. These SLGs make the algorithm simple, intuitive and a useful resource for the automated construction of entangled states with a low number of qubits.

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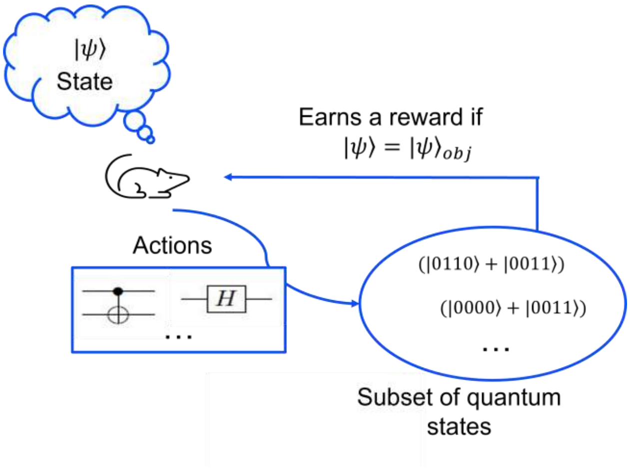

Figure 1: Exploration part of the reinforcement learning algorithm: assigns a reward to the agent to teach it the best action to take in every state, to reach the objective one.

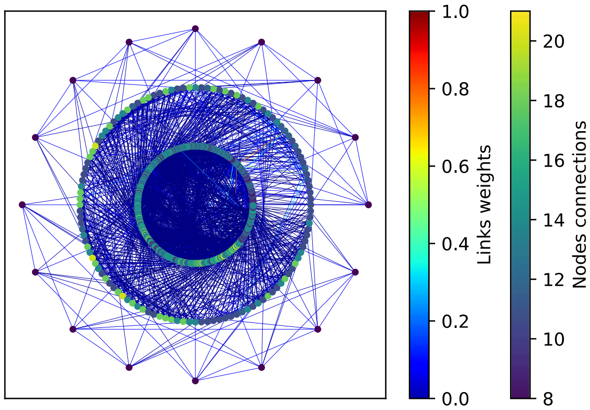

Figure 2: Example of SLG graph after the exploration: the nodes are the quantum states while the links are the rewarded applications of gates.

Multi-photon emission from a resonantly pumped quantum dot

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Resonance fluorescence of natural or artificial atoms constitutes a prime method for the generation of non-classical light. To date, it has largely focused on producing single-photons, however, ubiquitous multi-photon emission is inevitably observed.
We experimentally quantify the multi-photon emission statistics in a two-level artificial atom - a semiconductor quantum dot in a micropillar cavity - pumping with a short optical pulse and measuring autocorrelation functions $g^{(n)}[0,..,0]$ up to the fourth order, for different pumping powers. We measure up to four-photon emitted after a single pumping pulse and, with fine temporally-resolved measurement, we investigate the emission dynamics. Additionally, we back our data with a theoretical model based on a simple quantum trajectories approach, explaining how a two-level system can produce multi-photon states.
Our results aim to deepen the understanding of the full photon-emission in coherently driven atomic systems.

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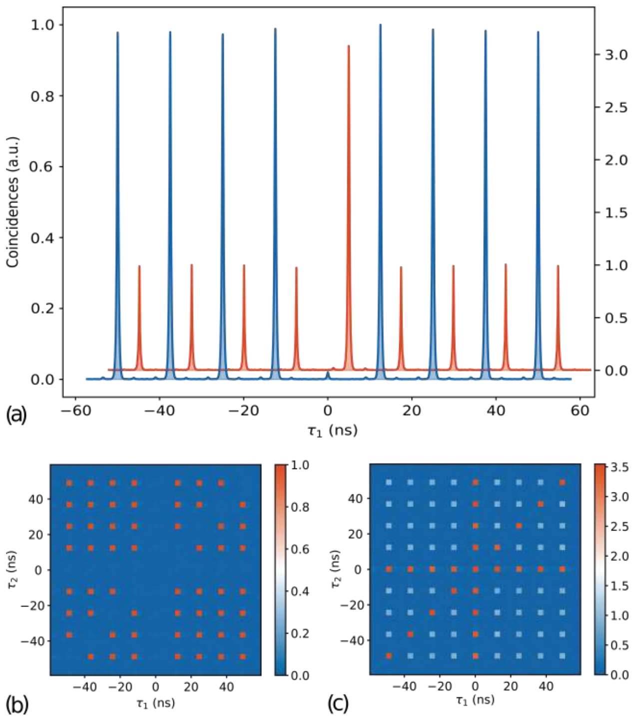

Fig.1 Correlation histograms. *(a)* The blue (red) line shows the second-order cross correlation histograms with a π(2π) pumping pulse area. The extracted values at zero time-delay are: $g^{(2)}_{\pi}[0] = 0.025(1)$, $g^{(2)}_{2\pi}[0] = 4.08(1)$.
(b - c) Third-order cross correlation histograms for a π-pulse (left) and 2π-pulse (right), resulting in $g^{(3)}_{\pi}[0,0] = (5.08\pm8)\cdot10^{-4}$, $g^{(3)}_{2\pi}[0,0]=4.31(18)$.

Tunable-coupler mediated multi-qubit controlled-phase gates with superconducting qubits

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Applications for noisy intermediate scale quantum computing devices rely on the efficient entanglement of many qubits to reach a potential quantum advantage. Entanglement is typically generated using two-qubit gates, with the qubits arranged on a square grid with pair-wise qubit-qubit couplers. Using fixed-frequency transmon-type qubits in combination with flux-tunable couplers allows to realize high coherence qubits with well controllable interactions. Tuning the frequency of the coupler by adiabatic flux pulses enables us to control the conditional energy shifts between the qubits and to realize controlled-phase [1,2].
In this system we optimize the pulse performance by analyzing and optimizing pulse shape parametrization in simulation and closed-loop experiments to realize decoherence limited CPHASE gates.
For the direct implementation of strong multi-qubit interactions, we further extend the scheme to a coupling of three qubits via a single coupler [3]. Here, the full family of pairwise controlled-phase (CPHASE) and controlled-controlled-phase (CCPHASE) gates can be implemented. We describe a gate protocol consisting of adjustable interactions and refocusing pulses. Numerical simulations result in CCPHASE gate fidelities around 99% for typical system parameters and decoherence rates.

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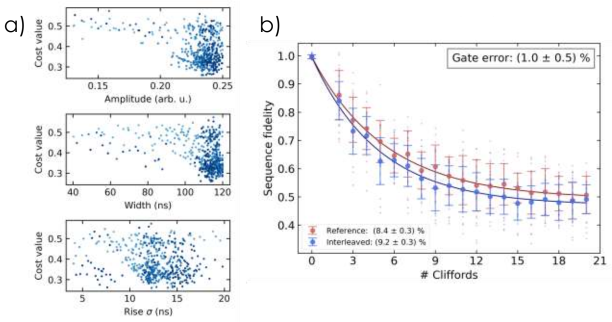

Figure 1: a) Closed-loop optimization of adiabatic two-qubit CPHASE gate, with the evolution of the gate parameters (pulse amplitude, shape width and rise time σ). b) Interleaved randomized benchmarking of optimized gate.

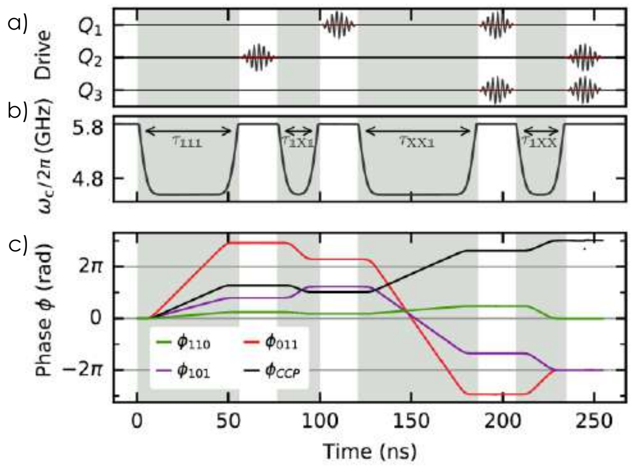

Figure 2: Pulse sequence of adiabatic three-qubit CCPHASE gate with a) microwave drives on the qubits and b) flux tuning of the tunable coupler. c) Evolution of the relative phases during gate execution.

Madrid QCI: a QKD network infrastructure

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Feynman's contributions to the foundation of Quantum Information Technologies were numerous and significant. His ideas and insights helped to inspire and guide many of the developments in this field over the past decades, which leads, among many others, to the concept of Quantum Key Distribution (QKD) in cryptographic networks. This technology is used to create and distribute a secure encryption key. QKD takes advantages of the quantum nature of single photons (in discrete variables or and equivalent in continuous variables) to generate keys Information Theoretically Secure (ITS), ensuring the secrecy of the key, up to a certain threshold.

The technological challenge is inserting this novel cryptographic scenario in current optical networks. Optical networks are used to transmit large volumes of data over long distances with high speed and efficiency and quantum technologies could be disruptive in this environment.

On this basis, our testbed, Mad QCI (Madrid Quantum Communication Infrastructure), have integrated QKD with optical networks to endorse security against future quantum computers to the transmission of information. Thus QKD can be used as an additional layer of security to ensure the confidentiality of communications that are made over the optical network. Moreover, well-known protocols in classical domain were turned into quantum-secure, substituting by QKD the present key-negotiation step.

The Spanish Quantum Communications project is now being developed in Mad QCI, one of the main Hubs in EUROQCI. In the near future, Mad QCI will include QKD fiber networks including QKD and conventional optical communications as well as satellite connections to reach long-distance communications.

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Figures

Figure 1: The UPM leads the Spanish project on Quantum Communications of the Integral Plan for Recovery, Resilience and Transformation, with the participation of the autonomous communities of Castilla y León, Catalonia, Galicia, Madrid, the Basque Country and the CSIC

Measurement of heat capacity in transition metal dichalcogenides by pulse heating technique

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The two-dimensional character of van der Waals layered materials makes them have extraordinary properties compared to bulk materials. Among these properties, the interest in thermal properties in 2D materials has grown in recent years. Having a deep understanding of these properties is crucial for know their behaviour and future applications. Heat capacity is a property that determines the amount of energy required to raise the temperature of a substance. Heat transport and thermal conductivity has already been highly studied but heat capacity has never been measured directly. In this work we will focus on the measurement of $MoSe_2$ exfoliated nanoflakes by using the pulse heating technique to measure the heat capacity. This technique is a calorimetric method used to measure the heat capacity of a sample by rapidly heating it for a brief period, followed by a period of cooling. With this technique we are able to measure the dependence of heat capacity on the number of $MoSe_2$ layers. The measurements will be made with membrane-based calorimeters, on which Pt is deposited, which acts as a heater/sensor. The ultimate goal of this project is to be able to determine the heat capacity of a single $MoSe_2$ monolayer.

Figures

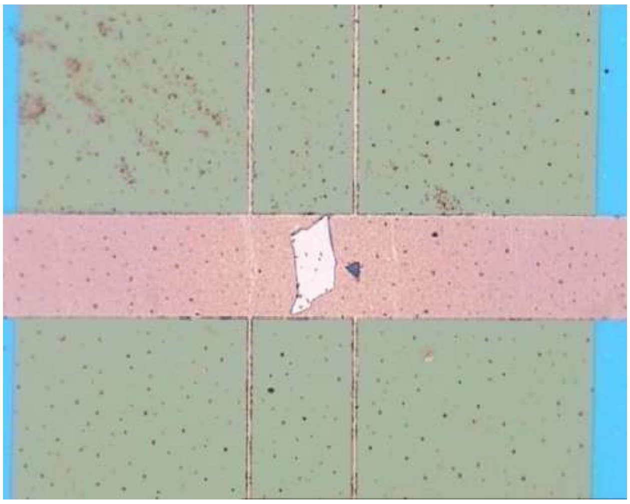

Figure 1: $MoSe_2$ flake transferred over the calorimetric cell

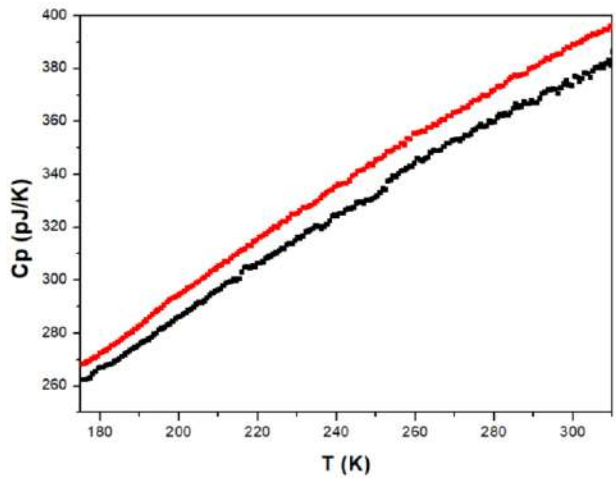

Figure 2: Heat capacity of empty chip (black dots) against the combined heat capacity of the chip and $MoSe_2$ flake (red dots).

Simulating realistic effects on MDI-QKD

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Quantum Key Distribution (QKD) allows two parties to exchange a secret key with unconditional security by exploiting the principles of quantum mechanics [1]. However, one of the most critical problems is that imperfections in real instruments may allow attacks that compromise the security of the shared key. Several relevant attacks exploit the scenario where measurement devices are under partial or total control of a third party [2-3]. The Measurement Device Independent (MDI) protocol proposes a communication scheme that is secure even when the measurement devices are in the hands of a third party [4]. To do so, the two parties that wish to share a key become photon emitters (Alice and Bob), sending their respective encoded signals to a relay station where all the measurements occur (Charlie). After measurements are done, Charlie announces the results so Alice and Bob can distill a key and evaluate whether an eavesdropper has interfered in the communication. One can assume that Charlie is under complete control of a malicious third party and still ensure unconditional security. The security of MDI-QKD relies on the violation of a Bell inequality by Hong-Ou-Mandel interference (HOM), which requires Alice's and Bob's signals to be identical in frequency and arrive at Charlie at the same time. Even though MDI-QKD has proven to be immune to any side channel attack to the detectors, its efficiency is very sensitive to small deviations of the quantum states. In this study, we explore the impact of these deviations on the communication process, the Quantum Bit Error rate (QBER), and the key rate. To do so, we have created a realistic simulation of the protocol by including these imperfections in the detection probabilities. We have also considered other deficiencies such as polarization and phase mismatch, losses in the channel, limited efficiencies of the detector, and their dark counts. Thus, we use this realistic simulation to tune in the parameters of the protocol (width of the weak coherent pulses, intensities of the decoy states, emission frequency…) to increase the efficiency of secret key transmission. This simulation environment is also critical to set the requirements of the devices used in the implementation of the protocol.

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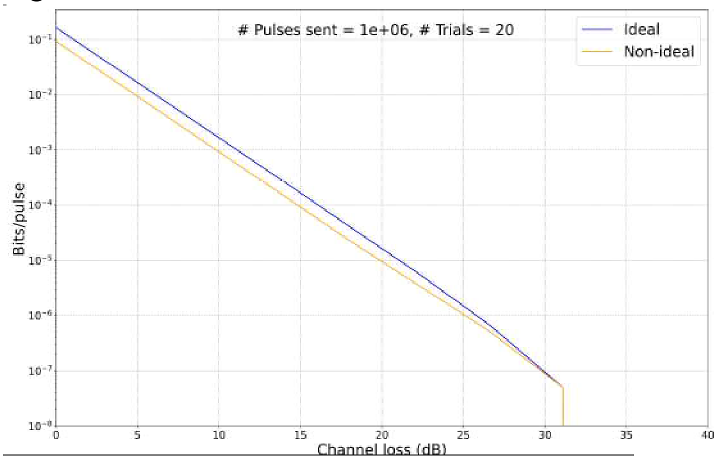

Figure 1: Bits/pulse VS. Channel loss of an ideal a non-ideal stochastic simulation of the MDI-QKD protocol. Imperfections include polarization and arrival times mismatch, fluctuations of laser frequency; efficiency and jitter of the detectors, and dark and solar counts. These flaws decrease the number of key bits generated with the same number of pulses sent, thus decreasing the key rate. The simulation allows to evaluate the impact of the different defects with respect to an ideal transmission scenario.

Measuring single spin noise with single detected photons

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Charged quantum dots are among the best candidate platforms for quantum information processing. Entanglement between the spin degree of freedom of a charge confined in the QD (acting as stationary qubit) and the polarization of single photons (flying qubits) would allow the realization of a quantum communication network. A promising strategy, in this respect, is to take advantage of the giant rotation induced by a single spin on the polarization state of single photons, as in micropillar cavity-based spin-photon interfaces [1, 2]. In parallel, spin-induced polarization rotation has been extensively used, though with very small rotation angles in the absence of cavity enhancement, to study the dynamics of spin ensembles and even single spins using optical spin noise spectroscopy (SNS) [3]. Here we show that by taking advantage of the cavity-enhanced interaction, we can push the measurement of single spin noise to the single photon level. Our system is an InAs positively charged quantum dot embedded in an electrically contacted and deterministically coupled microcavity [4]. A linearly polarized continuous wave laser is sent to the cavity around resonance with the trion transition. The output polarization of the reflected photons is rotated, providing spin-state dependant polarization Stokes vectors. Using the tools of quantum optics, we perform optical SNS using single detected photons via cross-correlation measurements between two photon detection events in orthogonal polarizations. Giant SNS signals are observed at various powers (Fig. 1), and allow us probing the spin dynamics, revealing valuable information on the charge and nuclear spin fluctuations in the QD environment. We will show that measuring the optical polarization and its cross-correlations, in various states of the Poincaré sphere [5] with single photon detectors, provides a very powerful tool to characterize both the coherent and incoherent optical processes in our system. Finally, we will discuss how these results pave the way for the implementation of quantum non-demolition measurements of a single spin with a single photon, and towards deterministic spin-photon and photon-photon quantum gates, exploiting the giant spin-induced Kerr rotation.

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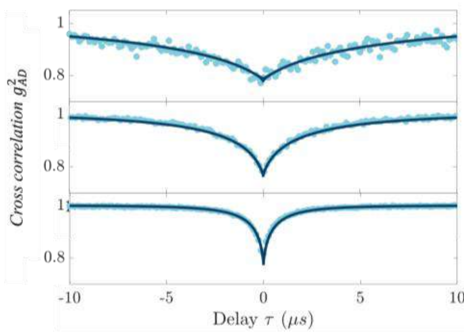

Figure 1: Cross correlation measurement as a function of the excitation power.

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K

l
i
K l

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Optimal control for error mitigation on molecular spin qudits

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Abstract

The most extended approach to fault-tolerant quantum computing is the execution of error correction protocols on multi-qubit devices [1], which requires many physical qubits for few logical information and presents scaling and connectivity issues. Molecular spin qudits have been proposed as a promising alternative [2]. The lifetimes of spins typically outperform other solid-state platforms, and their multi-level character allows for efficient encodings that require less connectivity. Although there exist recent demonstrations of single-spin addressing [3], this technology is typically restricted to spin ensembles, which show shorter T_2 due to the interaction between neighbouring spins. Thus, the coherent control of these systems must be engineered to mitigate errors. Here we apply optimal control techniques to a molecular spin qudit and shape control pulses to maximize the fidelities of certain operations on it [4]. We consider the spin 7/2 of a GdW_{30} molecule, which is coupled to a control field and to the environment (Fig.1), and encode three qubits within its eight energy levels. We model the dynamics as a Lindblad master equation and search for optimal pulses to implement a Toffoli gate. The optimization considers the whole model and therefore accounts for the dissipation. For $T_2 = 500$ ns [5], we find pulses that implement this unitary in tens of ns with fidelities around 90% (Fig. 2), even in the presence of this strong dephasing.

Figures

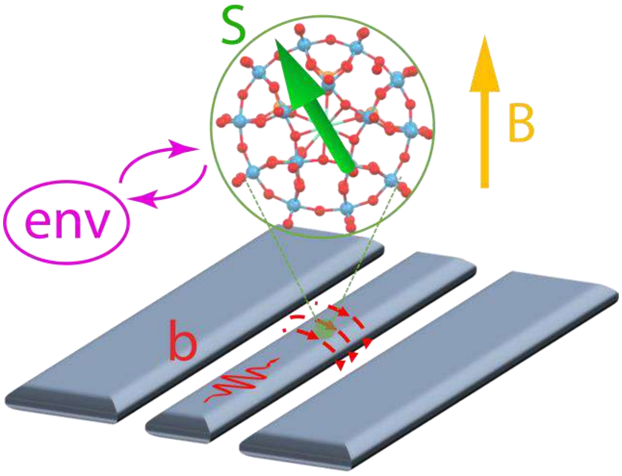

Figure 1: A molecular spin qudit is controlled by superconducting line that routes RF signals to it. The spin level splittings are tuned with an external DC magnetic field. Interaction with surrounding spins yields non-unitary dynamics.

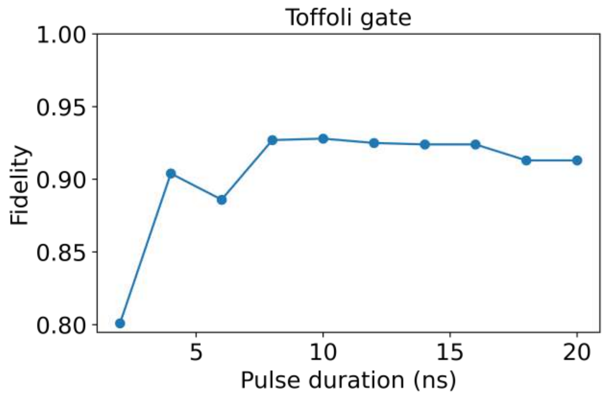

Figure 2: Toffoli gate fidelity, with pulses optimized for different durations up to 20 ns.

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Rare earth ions in molecular crystals for quantum information application

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Rare-earth ions in solid state hosts are promising candidates for optically addressable spin qubits, owing to their long optical and spin coherence times in the solid state [1]. Recently, rare earth ions in organic molecules have demonstrated outstanding coherence properties, while also promising a large parameter space for optimization by chemically engineering of the host molecule [2-4]. We characterize the optical properties of novel rare earth ion based molecular crystals at low temperature using techniques such as photoluminescence excitation spectroscopy, absorption spectroscopy and spectral hole burning. We observe narrow homogenous and inhomogeneous linewidths and long-lived spin polarization, confirming the great potential of molecular rare earth materials for quantum information applications.

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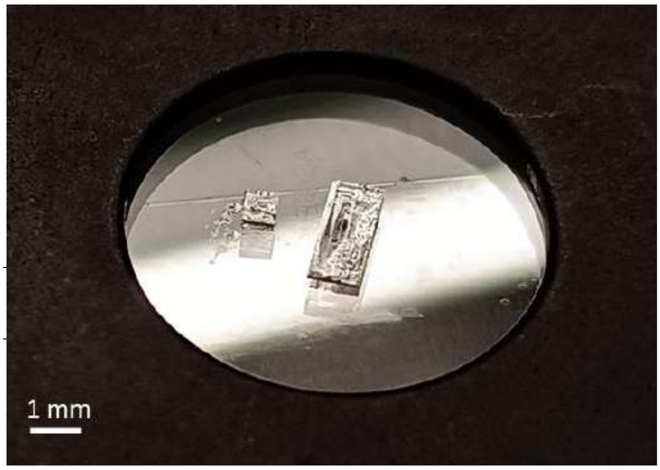

Figure 1: Millimeter size rare earth ion molecular crystal

Towards scalability of high-rate cluster state generation with a 3D-cavity-enhanced semiconductor quantum dot

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Multipartite entangled states such as cluster states are essential ingredients for measurement-based quantum computing, which offers a promising and scalable route towards the development of quantum information and technologies. With the use of a quantum dot confined in a three dimensional micropillar cavity, entanglement between two indistinguishable photons and a semiconductor spin was recently demonstrated [1] in our group, achieving a full first step of Lindner and Rudolph proposal [2] and yielding a high spin-photon and spin-photon-photon entanglement fidelity with an outstanding generation rate.

We extend this study further by investigating the influence of the magnetic field intensity and polarization of the excitation scheme on the generated state in order to improve the entanglement fidelity while preserving a high purity and indistinguishably of the emitted photons. This allows us to have a better control over the generated entangled state, thus providing building blocks for scalable and multidimensional cluster states.

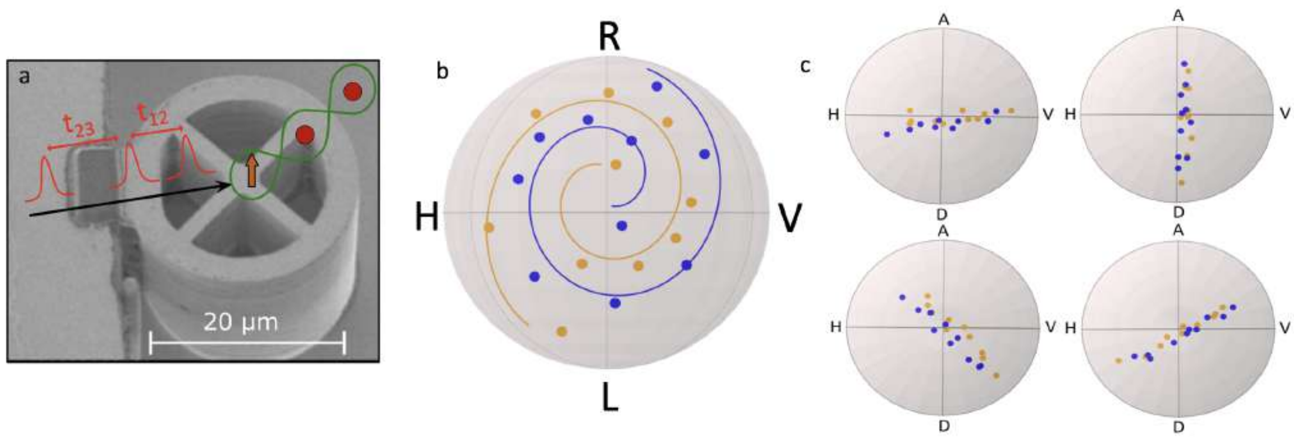

FIG. 1. a. Scanning electron microscopy image of the connected micropillar in which is embedded the InGaAs quantum dot. A train of linearly-polarized pulses leads to entanglement between the quantum dot spin and successively emitted photons. b. Polarization state of the second emitted photon represented in the Poincaré sphere, reconstructed with a full state tomography after measurement of the last photon in R (blue) or L (orange) polarization basis for variable delays between second and third laser pulse. c. Visual representation of the rotation of the second photon polarization trajectory in the Poincaré sphere for different linear polarization of excitation.

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Joule heating effects in superconducting InAs nanowire islands

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Mesoscopic superconducting islands in hybrid superconductor-semiconductor nanowires have been intensively studied in the context of topological superconductivity, motivated by their potential for the realization of a topological qubit [1]. Interesting experimental results have been reported in the past years, including a 2e-to-1e transition in the periodicity of Coulomb oscillations and a related dependence with the island length, which has been interpreted in favor of topology and of exponential protection of Majorana zero modes [2-4]. Theoretical work has also put forward proposals for employing islands for realizing a topological quantum computer [1 and hexon]. Heating effects, however, have not been considered in the interpretation of the above experiments, nor has its impact been evaluated in the context of proposals for quantum devices.

In this work, we study Joule heating in devices based on hybrid mesoscopic Al/InAs islands. To this end, we employ a technique that is able to detect the transition of superconducting parts of a hybrid device to the normal state. Owing to the poor thermal conductivity of such devices, a Superconducting to normal phase transitionmanifest as dips in the differential conductance, reflecting the suppression of Andreev excess current [6], which can be detected by employing typical DC measurement schemes. We use this signal as a tool to study the dissipation of heat generated by the Joule effect in mesoscopic islands. Interestingly, we show that the islands undergo a transition to the normal state at relatively low powers - ~100pW, which could reveal som relevant information regarding the dominant heat transport mechanism in the island. We evaluate the impact of Joule heating for typical device operation conditions.

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Toward High Fidelity Quantum Networks - Silicon Vacancy Centers in Diamond

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Quantum networks combine high security with the ability to scale up the number of qubits, which is essential for large-scale quantum information processing. These networks have nodes that store quantum data. Entanglement can be used to connect these nodes and enable quantum communication. Silicon-vacancy (SiV) color centers in diamond are promising components of optically coupled quantum processors. These solid-state emitters provide an effective optical interface and exhibit protective inversion symmetry. As a result, it is feasible to incorporate them into nanophotonic structures. The entanglement between spin- and photonic qubits can be generated using this approach. Coherent interactions between nuclear spins and the SiV require ultra-low temperatures and strong currents that simultaneously generate radio-frequency fields. Here we present a platform integrating superconducting coils with nanophotonic structures for operation at millikelvin temperatures.

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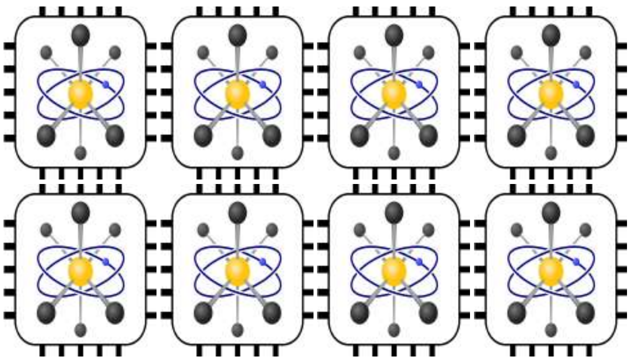

Figure 1: Schematic of a quantum network with SiV-centers as nodes. Connecting the color centers are photons distributing the entanglement.

Rubidium Atoms in Tweezer Arrays for Hybrid Quantum Computing

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Our project has the goal of building a quantum co-processor consisting of neutral atoms in tweezer arrays. This quantum co-processor will form part of an online-accessible hybrid quantum computer tailored for solving quantum chemistry problems.

In this collaborative project between a team at the Eindhoven University of Technology (TU/e) and a team at the University of Amsterdam (UvA) there are three setups: a demonstrator system using rubidium atoms at TU/e, the existing 1st generation strontium-based system at UvA and the 2nd generation strontium-based system at TU/e which is being constructed.

In this poster we present the status of our rubidium-based system, which is used to test various components and techniques which will be used in the 2nd generation strontium-based system. In particular we present our progress towards trapping single ^{85}Rb atoms in arrays of optical tweezers, creating defect-free arrays from stochastically filled arrays via rearrangement, characterization measurements of the trapping potential experienced by the trapped atoms which will be used to feedback on the optical traps to increase uniformity over the array and our plans to implement single qubit rotations on the hyperfine ground states of these atoms by combining global microwave pulses and an AC Stark shifting laser beam for site selectivity.

Proximity effects in graphene on alloyed transition metal dichalcogenides

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Stacked heterostructures of graphene and transition metal dichalcogenides (TMDs) are particularly interesting for spintronics since spin-orbit coupling (SOC) can be induced in the graphene layer by proximity effects with a strong valley dependence [1]. The induced proximity SOC, and associated imprinted spin-valley locking, enable experimentally verified spin-charge conversion and anisotropic spin relaxation effects that are absent in pristine graphene [2-3]. Recent high precision experiments based on currently available water-assisted CVD technique reveal composition-dependent band alignments in alloyed TMD lateral heterostructures with homogeneous intradomain composition [4]. Thus, in graphene/TMD heterostructures the nature and strength of the induced SOC depends on the composition of the underlying TMD layer. In this study we investigate the proximity induced SOC in graphene/TMD heterostructures by deliberate defecting of the TMD layer [5]. We analytically study simple alloyed $G/W_{1-x}Mo_xSe2$ heterostructures with diverse concentrations (x) and geometrical distribution of defects in the TMD layer. Utilizing density functional theory-computed electronic dispersions, spin textures, and an effective medium model, we evaluate the role of locally perturbed SOC on spin- and electronic signatures. We use the gained microscopic insight via tight-binding model to further examine the impact of defects in larger and more realistic heterostructures. We find that despite some dramatic perturbation of local SOC for individual defects, the low energy spin- and electronic behaviour yet follows the effective medium model. Furthermore, we demonstrate that the topological state of such alloyed systems can be feasibly tuned by controlling this ratio.

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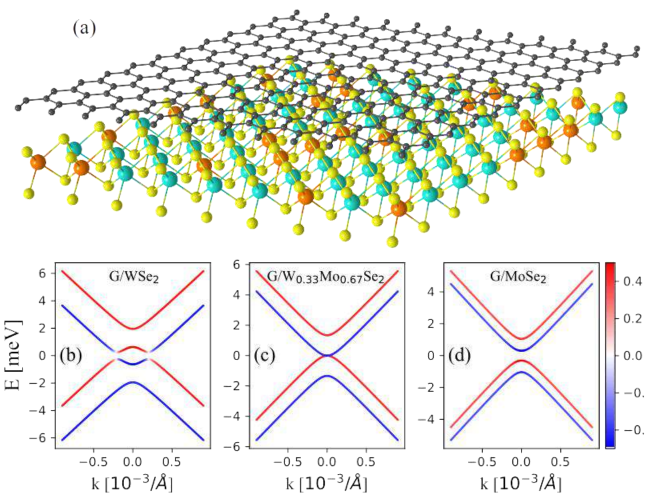

Figure 1: (a) Schematic representation of a composite graphene/TMDC heterostructure. [(b)–(d)] The proximity-induced band structure and topology transition for different TMDC layers.

Direct Detection of Quantum Superposition at a Distance

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In this work, we realise an operational procedure to distinguish a classical mixture from a quantum superposition through an XOR quantum communication game [1]. The task is to determine the effect of an intervention made by a referee on two (superposed) paths without re-interfering them (see Fig. 1). In Ref. [1] the referee was given beam blockers, resulting in a predicted probability to win (P_{win}) of 9/16 for a quantum superposition, whilst for a classical mixture P_{win} is 1/2. In this work, we show that by replacing the beam blockers with phase shifters, we can increase the predicted quantum P_{win} to 3/4. We experimentally implement this task using photon pairs from a Spontaneous Parametric Down-Conversion (SPDC) source and achieve an experimental P_{win} = 0.696 ± 0.009, well above the classical limit. Additionally, we contrast the quantum and classical cases by varying the mixedness of the source particle from a pure state to a fully mixed state and find strong agreement with the theoretical predictions (see Fig. 2). Finally, our work shows that this procedure not only allows us to observe the presence of a coherent superposition but also to extract the value of the relative phase between two paths without interfering them.

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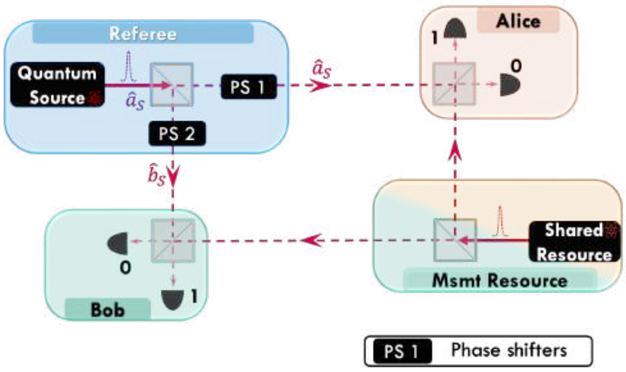

Figure 1: Schematic of XOR game setup. The referee provides an unknown resource (classical or quantum) and challenges Alice and Bob to output the parity of the presence (1) or absence (0) of his phase shifters, PS1 and PS2 (XOR game).

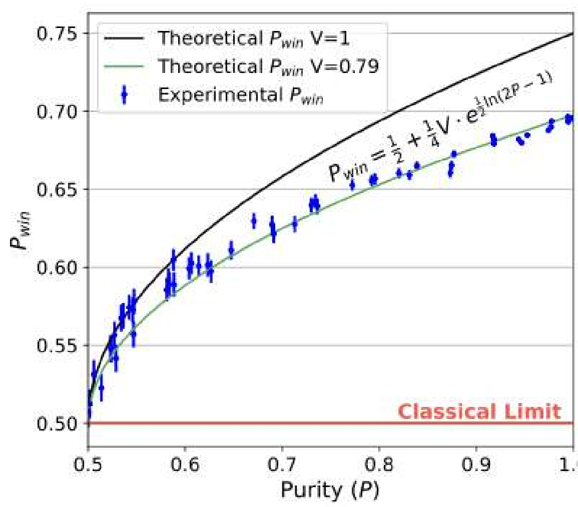

Figure 2: Transition from classical case (P_{win} = 1/2) to the quantum case (3/4 ≥ P_{win} ≥ 1/2) with increasing purity of the source particle.

A Lindblad master equation capable of describing hybrid quantum systems in the ultra-strong coupling regime

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Abstract

Light-matter interaction between confined electromagnetic fields formed in cavities and quantum emitters is of great interest because it allows to change the fundamental properties of the hybrid systems constituents. This topic has been already widely investigated for different types of systems ranging from cold atoms in optical cavities [1,2] to superconducting qubit-oscillator circuits [3]. However, despite a large theoretical effort devoted to considering light-matter interaction in different regimes, the so-called ultra-strong coupling regime [4] still presents significant challenges for theoretical treatments and prevents the use of many common approximations. In the present work, we propose a model that can describe such systems to any level of accuracy for an arbitrary electromagnetic environment. We extend an approach developed in our group for few-mode quantization of arbitrary systems [5] to the case of large light-matter coupling constants and/or ultrabroad-bandwidth resonances and show that even such systems can be treated using a Lindblad master equation where decay operators act only on the photonic degrees of freedom. We also provide a comparison with state-of-the-art master equation approaches, which show quite noticeable disagreement with our model for the considered problems.

Figures

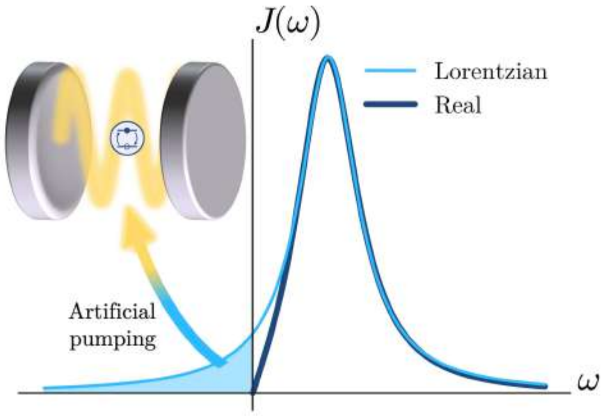

Figure 1: A realistic spectral density at zero temperature and its Lorentz approximation, corresponding to the Lindblad master equation. The spectral tail at negative frequencies causes the artificial pumping of the hybrid quantum system.

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An Algorithm for Synthesizing Reversible Logic Circuit from Arbitrary Permutations

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We present an algorithm that aims to find a sequence of reversible logic gates for synthesizing a given n-bit substitution map using a gate library consisting of multiple-controlled Toffoli gates.

Reversible logic synthesis is very much like solving Rubik's cube. The main idea is to find an intermediate permutation that can be viewed as a smaller problem. See, Figure 1 for visualization.

In this poster presentation, we focus on showing rather detailed processes. What we call 'block' in the paper[1] corresponds to the aligned 2-by-2 sub-cubes in Figure 1. For given permutation, a procedure to form a block will be explained. Complexity of the algorithm naturally follows by inspecting the procedure.

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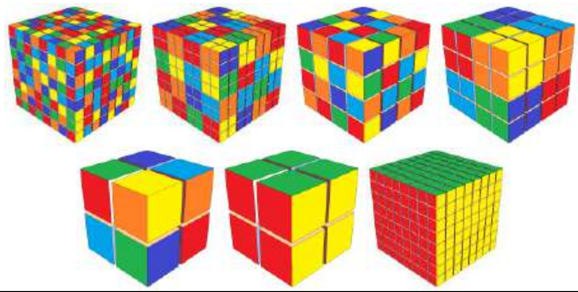

Figure 1: Image example using Rubik's cube for recursive block decomposition.

Transmission expansion planning by quantum annealing

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The transmission expansion planning problem (TEP) [1] is a mixed integer linear problem (MILP) that aims at finding the optimal way to expand the capacity of an energy system. It decides how many components to build in order to satisfy the energy demand on a distributed energy system with a high share of renewable energy sources (Figure 1). The TEP scales badly using classical algorithms and, at the same time, energy system models are getting larger and more complex due to the integration of decentralized weather-dependent renewable energy sources, sector coupling and the increase of storage components. Currently, the problem is often linearized or the scope and granularity of the model are reduced using clustering algorithms. For this reason, any computational time reduction will have substantial implications in closing the granularity gap between what the current models can solve and the desired resolution needed by energy system operators.

With the goal of reducing computational time in mind, we plan to apply quantum annealing (QA) [2] to the optimization of small energy system models. We also plan to decompose the TEP using Benders' decomposition into an integer master problem and a linear slave problem so that we can use a hybrid classical-quantum approach to tackle bigger problems [3]. This would allow us to take advantage of cutting-edge classical algorithms to solve the linear part along with QA to solve the more challenging non-linear part.

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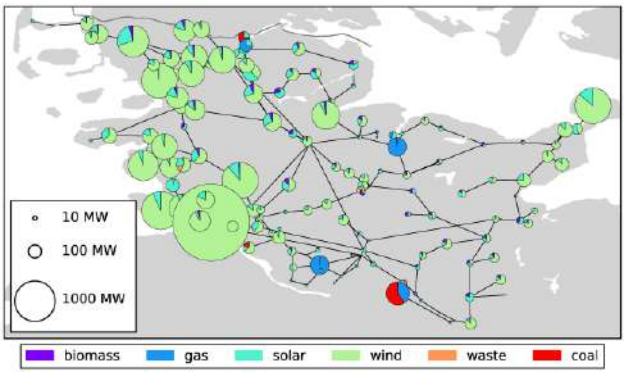

Figure 1: Power grid in Schleswig-Holstein (Germany) with installed capacities for the NEP2035 scenario for 2035 [4].

Diagnosing measurement-induced phase transitions without trajectory post-selection through predetermined measurements

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State-of-the-art quantum devices can be exploited to perform quantum simulations that explore exotic and novel physics. In this sense, a new phase transition in the entanglement properties of many-body dynamics has been described when the unitary evolution is interspersed with measurements [1], thus exhibiting universal properties. These measurement-induced phase transitions can be interpreted as a phase transition in the purification capabilities or error correction properties of quantum circuits, which is especially relevant in the context of state-of-the-art noisy intermediate-scale quantum devices. Measurement-induced phase transitions have been realized with quantum devices based on trapped ions or superconducting circuits [2], although they require large amounts of resources due to the need to post-select trajectories, which consists of keeping track classically of the outcome of each measurement [3]. In this work [4], we first describe the statistical properties of an interacting transmon array which is repeatedly measured and predict the behavior of relevant quantities in the area-law phase using a combination of the replica method and non-Hermitian perturbation theory. Most importantly, we show that, by using predetermined measurements that force the system to be locally in a certain state after performing a measurement, we can make use of the distribution of the number of bosons measured at a single site as a diagnostic for a measurement-induced phase transition (Fig. 1). This indicates that the method of predetermined measurements is a suitable experimental candidate to alleviate post-selection-related issues. We also show numerically that a transmon array, modeled by an attractive Bose-Hubbard model, in which local measurements of the number of bosons are probabilistically interleaved, exhibits a phase transition in the entanglement entropy properties of the ensemble of trajectories in the steady state.

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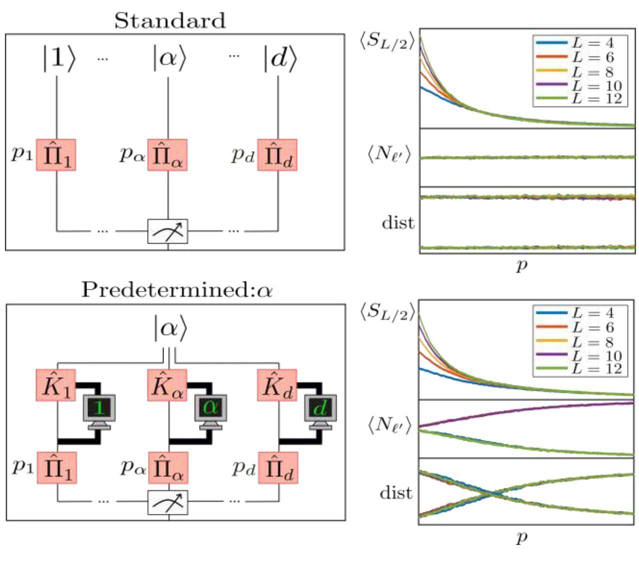

Figure 1: The scheme for the information about critical properties in the statistics of simple observables for standard and predetermined measurements.

Resilient intraparticle entanglement in graphene

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Excitations with high entanglement between spin and pseudospin have been previously reported in graphene [1]. However, it remains an open question how this intraparticle entanglement behaves under random scattering induced by impurities. In this work, we demonstrate that entanglement remains resilient under different types of scattering, including momentum, spin, and intervalley scattering. We also show that the value to which the entanglement converges does not depend on the initial state, as shown in Figure 1. On the other hand, previous studies have suggested a link between this type of entanglement and spin dynamics [2], we further demonstrate this relation with the spin relaxation time, as shown in Figure 2. Additionally, we apply our methodology to AB stacked graphene, which has a controllable band gap via doping or gating [3], allowing us to control the emerging entanglement.

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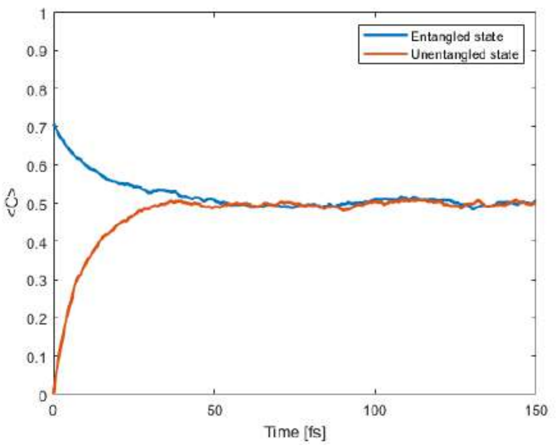

Figure 1: Evolution of concurrence of an initially entangled and unentangled state for a momentum relaxation time of 5 fs, a Rashba spin-orbit coupling of 100 μeV and a Fermi energy of 100 μeV under random momentum scattering.

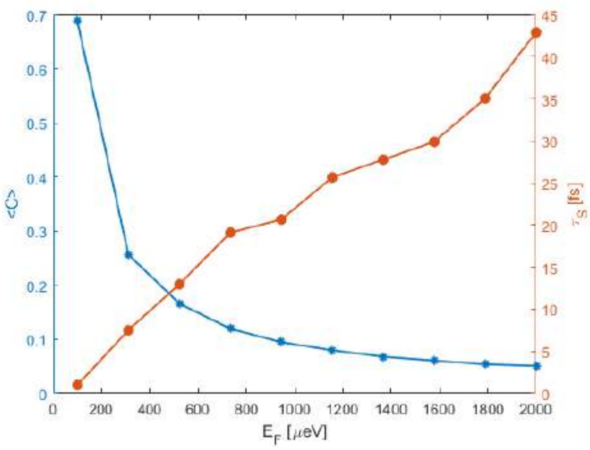

Figure 2: Converged concurrence and spin relaxation time depending on the Fermi energy for a Rashba spin-orbit coupling of 150 μeV and a momentum relaxation time of 5 fs.

Surface Enhanced Raman Scattering from a molecular impurity model

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Surface-enhanced Raman scattering (SERS) allows the fingerprinting of single molecules via their vibrational degrees of freedom. Inspired by its analogy with the field of cavity optomechanics [1], a first model was proposed considering the optomechanical dynamics between plasmonic electric fields and molecular vibrations [2]. This molecular optomechanical approach allowed both, to describe new effects in the field of SERS arising from the dynamical backaction and to offer new possibilities in cavity optomechanics due to the resulting large coupling strengths involved – orders of magnitude larger than in previous configurations. Despite recent experimental works evidencing such optomechanical nature of SERS, large spectral discrepancies have arisen with current theoretical predictions [3] that call for new mechanisms for its understanding. Inspired by the microscopic molecular Hamiltonian [4], in this work we propose an optomechanical SERS model that considers the internal mechanisms of the molecule. In this model, the electronic transitions involved in the Raman processes are treated as a set of two-level systems that mediate the interaction between plasmons and molecular vibrations via electron-vibron couplings [4]. Since such electronic levels typically lie in the ultra-violet range, we can adiabatically eliminate them and recover the original optomechanical Hamiltonian [2]. Beyond such adiabatic approximation, we further consider a near-resonant transition coexisting with the off-resonant ones, showing interesting cooperative behaviours such as enhancements of anti-Stokes lines and modifications of spectral widths. For ultrastrong interaction scenarios with electron-vibron couplings close to the mechanical frequency, we consider the resulting phonon-dressed states in the master equation that show incoherent contributions to the anti-Stokes peaks, decisive for understanding the spectrum. Our model shows the importance of treating the molecular degrees of freedom with equal footing in SERS and offers new perspectives of the mechanisms involved in molecular optomechanics.

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Twisted cuprate van der Waals heterostructures with controlled Josephson coupling

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Twisted van der Waals heterostructures comprising high temperature cuprate superconductors offer a unique platform for engineering the efficient Josephson coupling between cuprate crystals harboring nodal superconducting order parameter. Preparing Josephson junctions with an atomically sharp twisted interface between cuprate crystals is however extremely challenging, and special attention during the fabrication must be given to the role of the oxygen and lattice reconstructions.
Our work addresses properties of the interface superconductivity and Josephson coupling in twisted interfaces between stacked cuprate $Bi_2Sr_2CuCa_2O_{8+d}$ crystals. We realize these Josephson junctions using the recently established cryogenic dry transfer technique, and we additionally encapsulate the interfaces with a protecting insulating layer to eliminate effects of disorder during the fabrication process. We demonstrate in these heterostructures a strong twisting angle and temperature dependence of the Josephson critical current compatible with the d-wave symmetry of the superconducting order parameter. We find that the critical current has its maximum value comparable to that of the bulk intrinsic junctions at small twisting angles, and that it reduced by almost by two orders of magnitudes at twisting angles close to 45 degrees, due to the mismatch between the superconducting d-wave order parameters that suppresses direct Cooper pairs tunneling.

Figures

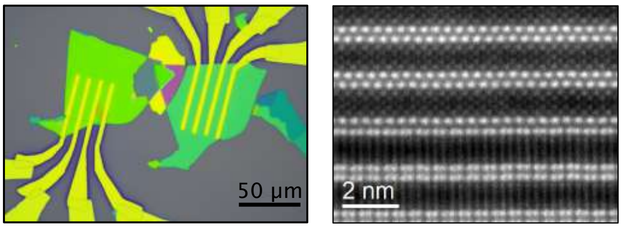

Figure 1: Left) Optical micrograph of a representative device. Right) TEM image displaying the cross section of a twisted junction

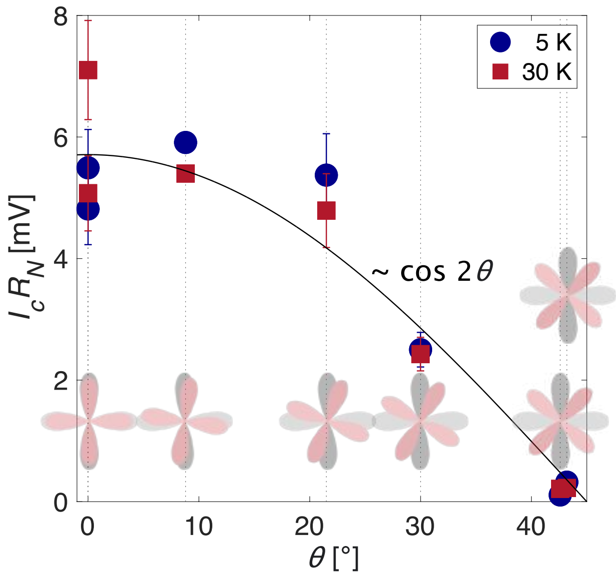

Figure 2: Josephson coupling (critical current times normal resistance) versus twist angle

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Local parity flipping Andreev transitions

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The application of cQED techniques is a convenient approach to probe hybrid superconductor-semiconductor devices: it allows non-invasive manipulation of their quantum states and enables sensing features complementary to those provided by transport measurements.

For instance, microwave spectroscopy has been recently used to map the phase diagram of a quantum dot Josephson junction, where the competition between the induced superconducting correlations and the Coulomb repulsion determines the boundaries between a singlet and a doublet ground state [1]. Here, we analyse microwave measurements of an InAs hybrid nanowire Josephson junction close to the pinch-off (depletion of electrons). As in the case of the quantum dot, the frequency shift of a resonator coupled to the system [2,3] indicates singlet/doublet alternation over certain gate voltage range. Surprisingly, the corresponding microwave induced transitions display sharp dips reaching zero energy close to the phase boundaries, suggesting these transitions connect the singlet (even parity) and the doublet (odd parity): while parity flipping transitions are typical in transport experiments (*e.g.* [4]), they are forbidden when induced by microwave radiation, which can only excite a quasiparticle or break a Cooper pair to create two of them.

We show that these transitions can be theoretically understood by means of an additional localized state isolated in the junction [5], which acts as a reservoir for an electron, thus allowing a local parity flip in the main subsystem.

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Figures

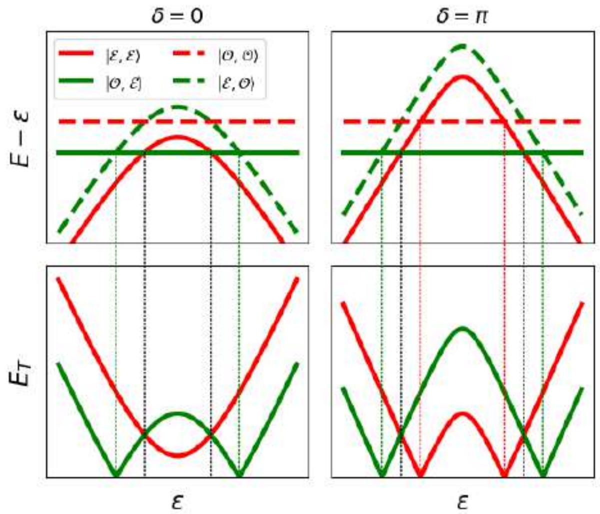

Figure 1: Model of the junction and the ancillary level, at a fixed phase difference δ. Top: energies of the many-body states with even/odd parity in each subsystem. Bottom: corresponding allowed transitions.

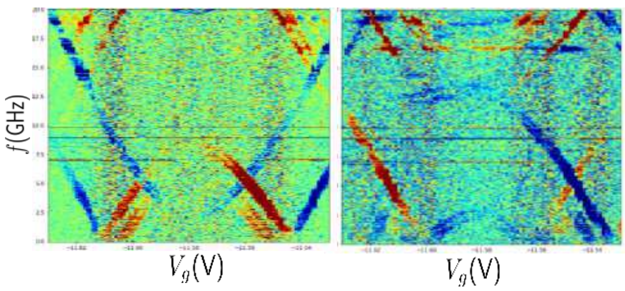

Figure 2: Two-tone spectroscopy over gate.

Thermal diode effect on the surface of three-dimensional topological insulators

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Thermo-electric devices are utilized for nano-scale refrigeration or to harness waste heat to produce electric power in electronic circuits. These devices usually require semiconductor materials or complex geometries to induce thermo-electric effects which may suffer from a narrow range of operation or poor efficiency. To counteract these shortcomings, we propose a simple device consisting of a ferromagnet (F) in proximity to a Dirac semi-metal (N) creating a ballistic NFN junction with a large operating window. We theoretically study the heat and electric currents through the junction and show strong Seebeck and Peltier effects arising from the Dirac physics and Klein tunnelling in the ballistic junction. We use the device's high tunability to create a thermal diode allowing for refrigeration of a hot reservoir or for power production induced by a temperature gradient. Finally, we discuss refrigeration efficiency and the effective electron cooling temperature taking into account the phonon contribution in quasi-two-dimensional materials, like graphene or topological insulators.

Figures

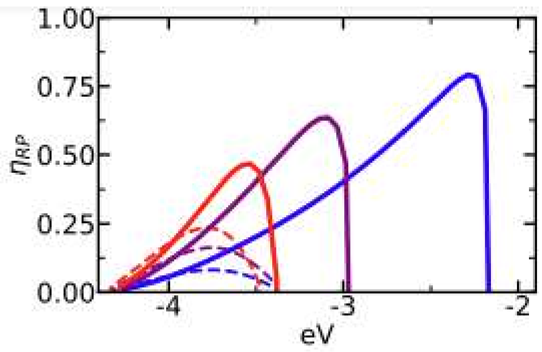

Figure 1: Refrigeration efficiency of the device vs eV, for different temperature gradients. The dashed lines corresponding to a short ferromagnetic junction of 100nm and the solid ones to a long junction of 1μm. The gradient relative to ambient temperature is for the 10%, (blue), 20% (purple) and 30% (red).

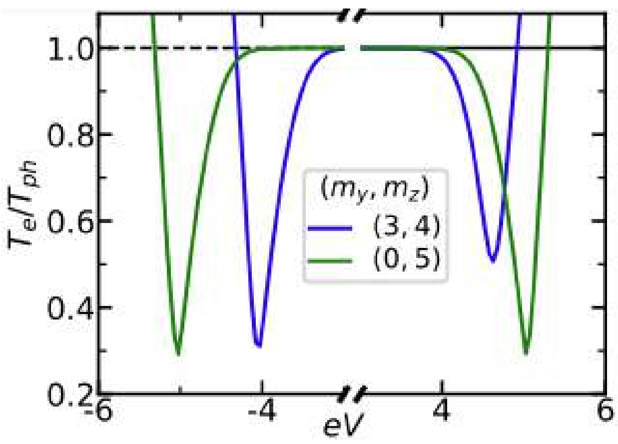

Figure 2: The electron temperature relative to a photonic bath of temperature (T_{ph}) coupled through scattering. We compare two different orientations of the magnetic Zeeman field: along the y-z plane (blue) and out of plane (green).

Are symmetry protected topological states immune to dephasing?

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The hallmark of topology in condensed matter systems are their topological phases in featuring symmetry protected dissipation-less channels. Symmetry protection can give rise to different kinds of topological channels which include, for instance, the quantum spin Hall (QSH) phase, the spin quantum anomalous Hall (SQAH) phase. It remains to be seen whether these states are indeed robust to dephasing effects, and if so, to what degree. Effectively harnessing topological phases and phase transitions is essential in topological electronics.
This work is devoted to the robustness of these topological phases in the backdrop of the topological quantum field effect transition in buckled 2D-Xenes (Ref [1], [2]).The topological transitions involving the quantum spin Hall (QSH) to quantum valley Hall (QVH) and spin quantum anomalous Hall (SQAH) to quantum anomalous valley Hall (QAVH) are studied in detail. We study the effects of dephasing and disorder in the channel on both regimes' ON state. We employ the phenomenological dephasing model using the non-equilibrium Green's function (NEGF) technique [3]. We also explicitly add impurity potentials in the channel and average over hundreds of configurations for the same bandgap in the QSH and the SQAH phases. The results indicate stark robustness: the worst-case drop in conductance for very reasonable dephasing ranges is 0.35% for the QSH ON state and 0.06% for the SQAH ON state.

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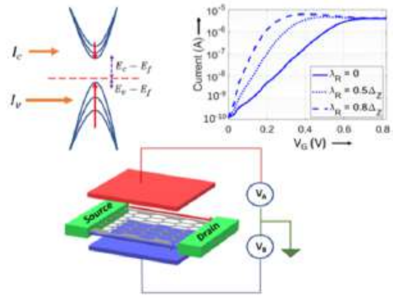

Figure 1: Quantum Field Effect Transistor with dissipation-less ON-state (Ref [2])

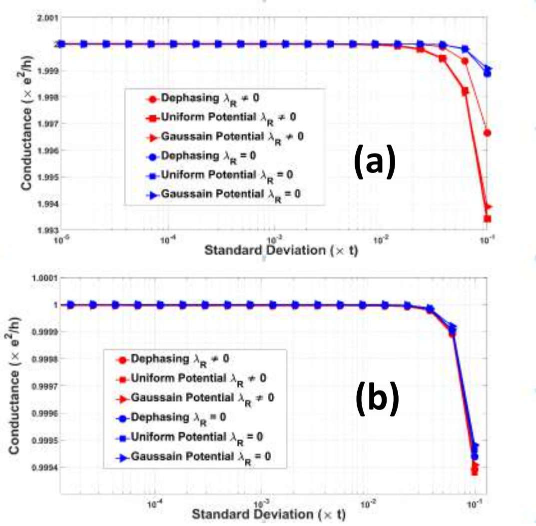

Figure 2: Effect of dephasing and disorder in the channel in the (a) QSH and (b) SQAH phases

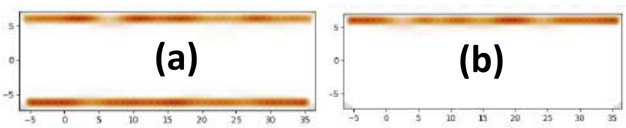

Figure 3: Wavefunction densities under disorder in the (a) QSH and the (b) SQAH phases

Premature switching currents of the superconducting Al shell in hybrid InAs-Al nanowires

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Hybrid superconductor-semiconductor nanostructures have been widely explored in the context of topological superconductivity [1, 2] and for the development of hybrid superconducting qubits [3]. For the above research directions, it is crucial to have a clean superconductor-semiconductor interface, e.g. achieved by means of epitaxial growth [4-5], to warrant a strong superconducting proximity effect. Among the different explored material platforms, InAs semiconductor nanowires covered by an epitaxial Al shell have been arguably one of the most studied systems. Surprisingly, in spite of the large number of experimental works that make use of hybrid InAs-Al nanowires, there are very few studies addressing the superconductivity of the Al shell [6-7]. This is important as the shell is directly responsible for inducing superconductivity on the semiconductor wire via proximity effect. In this work, we provide a detailed characterization of the superconductivity of the Al layer in full-shell InAs nanowires by DC transport measurements. Our results point towards premature switching currents of the nanowires driven by the nucleation of phase slips [8-9] followed by heat dissipation [10-11]. For certain conditions, we observe states with an intermediate resistance between zero and the normal resistance, suggesting the stabilization of a normal state segment within the nanowire (phase slip center).

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Q4Real Project

(Quantum Computing for Real Industries)

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We are witnessing the so-called second quantum revolution focused on exploiting the enormous advances that have been made in recent years in the ability to manipulate matter at the quantum level. These physically formidable developments are driving rapid developments in various fields and, in relation to the present project, especially in the new paradigm of quantum computing. The final goal of the Q4Real project is to create a platform of state-of-the-art digital capabilities for quantum computing that serves to accelerate the deployment of applications with a sustainable impact in the industry. Ibermática an Ayesa company leads a consortium of companies that works on the creation of the Q4Real platform of cutting-edge digital capabilities for quantum computing, which serves to prepare the quantum ready journey for the industry. ITS company and the R&D unit of the Ibermática Group and the Ibermática Institute of Innovation (i3B) are part of the consortium. It is completed with the participation of Serikat, Quanvia, Multiverse, Mercedes-Benz Spain, as well as the agents of the RVCTI, Tecnalia, UPV/EHU and the DIPC Donostia International Physics Center.
To achieve this general objective, the project focuses on the following four specific objectives:

- Formalization and quantum programming of common problems in the industrial domain: distribution and logistics, industry 4.0, Energy and Automotive, Industrial Cybersecurity.
- Computation and deployment the uses cases in the available quantum platforms, Annealers / Universal Quantum Computers, and quantum inspired with hybrid approaches.
- Development of a knowledge base and components for different types of quantum computational problems as Quantum Machine/Deep Learning, Digital Twins Simulation at Industry and Industrial Quantum Process Optimization
- Generation of Quantum SW Engineering practices, transversally in all uses cases, as hybridization of HPC/Quantum systems, testing and verification practices in non-deterministic contexts, performance metrics on classical approaches, quality or sustainability and quantum DevOps processes.
- Bridging the gap with the business solutions market, with several formulation and road mapping methodologies and impact assessments. Strategically, at the end of the project, the first capacities will have been developed with a certain critical mass for the development of quantum computing solutions, contributing to the development of a unique ecosystem in the quantum real industries.

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New avenues for quantum optical simulators

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Abstract

Quantum optical simulators are systems in which ensembles of quantum emitters (e.g., neutral atoms, ions, or excitons) interact with photons propagating either in free space (like in atomic arrays) or confined in an optical cavity or a dielectric material (such as photonic crystals, see Figure 1). Such systems offer the possibility to exploit cooperative and topological effects to improve the scalability of future quantum devices [1, 2].

In this contribution I will first introduce a quantum neural network architecture in the spirit of [3] consisting on an array of single-mode cavities coupled to quantum emitters, where the nonlinearity is provided by the light-matter interactions. I will show how this can be applied to a variety of problems in quantum metrology, such as producing states that maximize the quantum Fisher information while simultaneously reducing their vulnerability to noise.

Next, I will discuss the possibility to couple bosonic atoms to the boundaries of a two-dimensional topological photonic crystal, which act as a multimode topological waveguide [4] (see Figure 2). Under incoherent driving, driven-dissipative topological phase transitions leading to topological amplification can be observed. Our goal is to assess the impact of interactions between the atoms in such a system.

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Figures

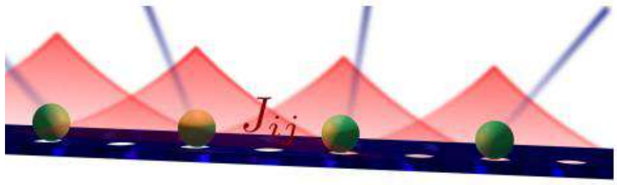

Figure 1: An example of quantum optical simulator: quantum emitters (atoms) are addressed by lasers and coupled to a nanophotonic crystal waveguide (see [2]).

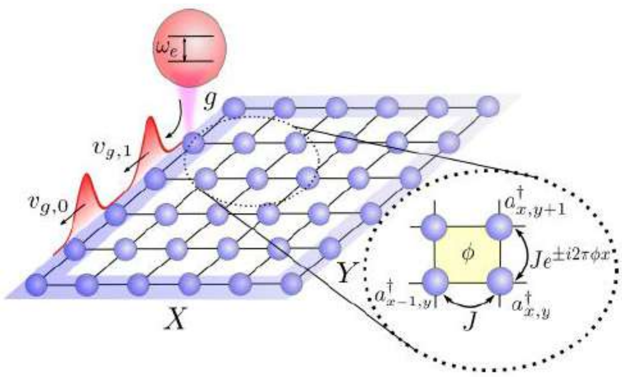

Figure 2: Two-dimensional square photonic crystal subject to an effective magnetic flux (i.e., a Harper-Hofstadter lattice). Quantum emitters are coupled to the topological edge modes of the lattice (figure taken from [4]).

Enhanced Spin Coherence in an Optically-Active GaAs Quantum Dot

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Semiconductor quantum dots [1-4] are promising candidates for photonic quantum technologies such as cluster state generation [5,6] or distant spin-spin entanglement [7,8]. However, the magnetic noise from the host nuclei poses a drawback for spin-photon applications as it leads to fast spin decoherence. While the workhorse system is an InGaAs quantum dot in GaAs, progress has been made recently on droplet-etched GaAs quantum dots. On the one hand, the demonstration of two-photon interference with indistinguishability V > 90% for photons from remote quantum dots validates excellent photonic properties [9]. On the other hand, success on electron spin decoupling from the host nuclei affirms a highly homogeneous nuclear ensemble and T_2^{CPMG} > 100 µs [10].

In this work, we use all-optical cooling [11,12] of the host nuclei of a GaAs quantum dot to tackle the problem of a short electron spin coherence time T_2*. Ramsey interferometry probes the electron coherence time, acting simultaneously as a gauge of the nuclei's temperature. We find a 20-fold increase in coherence time from 3.9 ns to 78.0 ns after Rabi cooling [9] and a 155-fold increase up to T_2^* = 608 ns after feedback cooling [10] (see Fig. 1). This corresponds to a narrowing of the nuclei Overhauser distribution from 104.6 MHz to 0.71 MHz approaching the regime of single nuclear-spin excitations.

Our work shows that a GaAs quantum dot produces coherent photons and hosts a coherent spin. The coherence is maintained for times much longer than the radiative decay time - all at a convenient wavelength. These are ideal properties for a coherent spin-photon interface.

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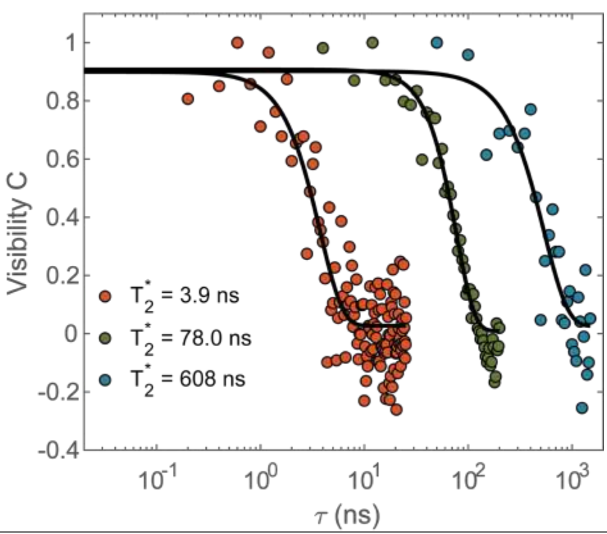

Figure 1: Ramsey visibility before cooling (red), after Rabi cooling (green), and after feedback cooling (blue).

Quantum Error Correction Codes with Spin-Qudits

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Quantum Error Correction Codes (QECCs) are designed to protect information inside a quantum information state, i.e. to protect qubits from decoherence. Many QECCs have been proposed; commonly, they protect logical state of qubits by codifying their information into a larger number of qubits. Stabilizer codes are an example of QECCs where the quantum information is stored in qubits which are eigenstates of a group of Pauli operators. Some examples are the Shor code [1], the Steane code [2] and the 5-qubit code [3], which are able to correct quantum errors of weight 1. We are studying the possibility of preserving the information of a logical qubit by codifying it in a qudit, a quantum information state whose dimension of the Hilbert space (d) is larger than 2, furthermore, we compare it with the aforementioned stabilizer codes with qubits. Codifying a qubit on a qudit has some advantages such as reducing the number of physical systems and the dimension of the Hilbert Space needed to protect it, among others. The Gottesman-Kitaev-Preskill (GKP) code [4] uses bosonic qudits, particles with integer spin, to store and protect quantum information. However, we are focusing on fermionic spin-qudits codes; previous works in this field have studied how to encode a qubit in a 3/2-spin qudit, with a code that is able to correct Z errors of weight 1. In addition, in [5] they proposed a 7/2-spin qudit to correct all Pauli errors of weight 1, whose quantum circuit is represented in Figure 1.

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Figure 1

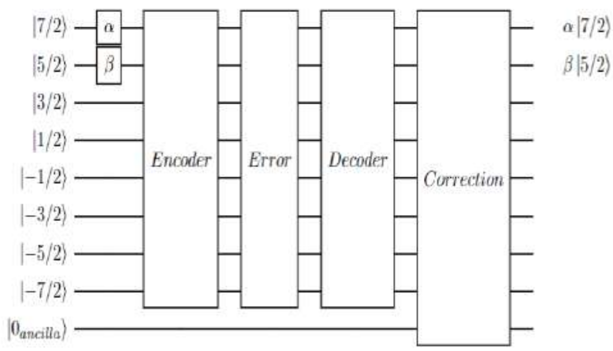

Figure 1: Quantum circuit of a QECC with a Spin-7/2 qudit and one ancilla qubit.

Bound states in the continuum and Majorana zero modes in a parallel double quantum dot: Ghost-Fano-Majorana effect

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Abstract

In the present work, we study a system formed by a parallel double quantum dot (DQD) structure coupled to two normal leads, with each quantum dot independently connected to a topological superconductor nanowire (TSCN) hosting Majorana zero modes (MZM) at its ends. We focus on the linear conductance through the DQD, the density of states, and the Majorana spectral functions, which are calculated employing Green's functions (GFs) formalism. In addition, we focus on identifying signatures of quantum interference phenomena, MZMs leakage into the QDs-BICs, and the interplay between MZM and the so-called Bound states in the continuum (BICs) by direct control of the magnetic flux over all the bound states of our setup. Our results show that both MZMs and BICs appear in high-symmetry configurations, i.e., depending on the QD-MZM coupling strength and the length of the TSCN. Also, we find a transport suppression anomaly in the linear conductance as a function of the magnetic flux. This phenomenon appears for the same symmetric configurations mentioned above. We also find that the magnetic flux can control both the MZMs leaking into the QDs and the BICs, suggesting that this external parameter will suffice for manipulating the above states.

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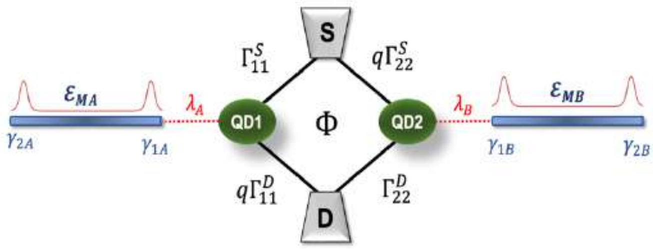

Figure 1: Schematic view of the system under study: TSCN-DQD-TSCN. Each QD (green) is coupled to a TSCN (blue tones). The TSCN A(B) is connected to the QD1(2) The DQD is coupled to two normal leads, labelled as S and D (solid gray), and an external magnetic flux Φ across the interferometer is considered.

Towards polynomial convergence for Variational Quantum Algorithms using Langevin Dynamics

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One of the most promising types of algorithms to run on noisy intermediate-scale quantum computers are variational optimization algorithms [4]. In those algorithms one deals with a parametrized quantum circuit whose outputs are then a parametrized family $\mathcal{F}$ of n-particle quantum states.
Given an n-body observable H, that can be efficiently implemented (e.g. a locally interacting Hamiltonian), the goal is to obtain an approximation of

$$\min_{|\psi\rangle\in\mathcal{F}} F(|\psi\rangle) = \langle\psi|\mathrm{H}|\psi\rangle. \qquad (1)$$

The goal of this paper is to study the continuous Langevin Dynamics (see [1, 2]) in a rather general setting, shown in Figure 2. Proving convergence results in such a setting may potentially lead to poly-time algorithms to solve (1) on depth-2 quantum circuits with gates acting on $\log L$ sites, with L being the system size (Figure 1). Moreover, our results should be applicable to other circuits, under certain assumptions on

$$F(|\psi\rangle) = \langle\psi|\mathrm{H}|\psi\rangle.$$

We generalize [3] to the Lie Group $SU(n)$; we prove that for any values $\varepsilon, \delta \in (0,1)$, for

$$\beta \geq \Omega\left(\frac{d^2 \log d}{\varepsilon} - \frac{\log \delta}{\varepsilon}\right)$$

we get that the Gibbs distribution ν associated to our Markov process satisfies

$$\nu(F - \min_{y\in SU(n)^{\times r}} F(y) \ \geq\ \varepsilon) \leq \delta.$$

Furthermore, we prove that our setting satisfies a logarithmic Sobolev Inequality, which guarantees exponential convergence of the process Z_t to ν (see [1]).

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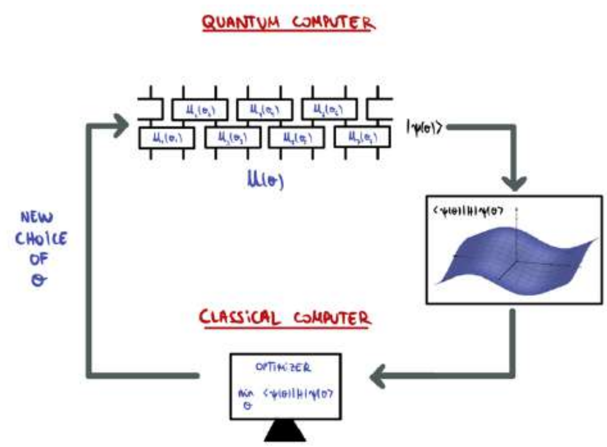

Figure 1: General Variational Quantum Algorithm Scheme.

$$\min_{x\in \mathrm{SU}(n)^{\times r}} F(x), \quad F : \mathrm{SU}(n)^{\times r} \to \mathbb{R} \text{ non-convex},$$

$$dZ_t = -grad F(Z_t)\, dt + \sqrt{\frac{2}{\beta}}\, dW_t.$$

Figure 2: Langevin Dynamics proposed to find the minimum of *F*.

Photon counting statistics in NV centers

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Abstract

We model and experimentally benchmark the full counting statistics of photons emitted by a single nitrogen vacancy center in diamond within the context of a quantum jump formalism. This formulation allows for the study of fluorescence under non-resonant laser excitation and resonant micro-wave (MW) control. We build a phenomenological framework which relates the relevant physical parameters with the detected photon counts. Furthermore, we can investigate the time correlations of the emitted photons and elaborate detection protocols to optimize the energy and time resources while maximizing the system sensitivity of magnetic-field measurements.

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Figures

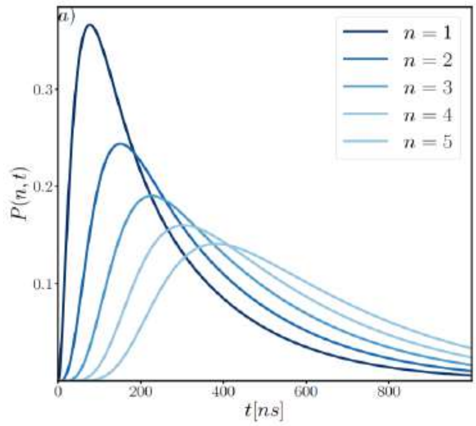

Figure 1: Probability P(n,t) of emitting n photons by an NV excited by a green laser as a function of time.

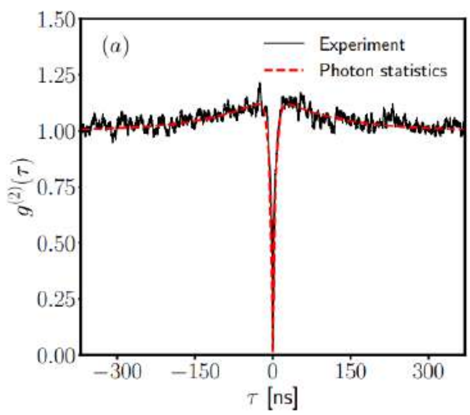

Figure 2: Measured autocorrelation function (black) for an NV centre and the photon statistics prediction (red).

Geometry and Faddeev-Jackiw quantization of electrical networks

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Abstract: In lumped-element electrical circuit theory, the problem of solving Maxwell's equations in the presence of media is reduced to two sets of equations. Those addressing the local dynamics of a confined energy density, the constitutive equations, encapsulating local geometry and dynamics, and those that enforce the conservation of charge and energy in a larger scale that we express topologically, the Kirchhoff equations. Following a consistent geometrical description, we develop a new and systematic way to write the dynamics of general lumped-element electrical circuits as first order differential equations derivable from a Lagrangian and a Rayleigh dissipation function. Combining this construction with the Faddeev-Jackiw[1] method, we are able to identify and classify all singularities that arise in the search for Hamiltonian descriptions of general networks. Furthermore, we provide systematics to solve those singularities, which is a key problem in the context of canonical quantization of superconducting circuits[2,3]. The core of our solution relies on the correct identification of the reduced manifold in which the circuit state is expressible, e.g., a mix of flux and charge degrees of freedom, including the presence of compact ones. We apply the fully programmable method to obtain (canonically quantizable) Hamiltonian descriptions of nonlinear and nonreciprocal circuits which would be cumbersome/singular if pure node-flux or loop-charge variables are used as a starting configuration space. Generalizations beyond the lumped-element approximation as continuous limits thereof, and a rigorous quantum description of dissipation are discussed. This work unifies diverse existent geometrical pictures of electrical network theory, and will prove useful, for instance, to automatize the obtention of exact Hamiltonian descriptions of superconducting quantum chips.

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Figures

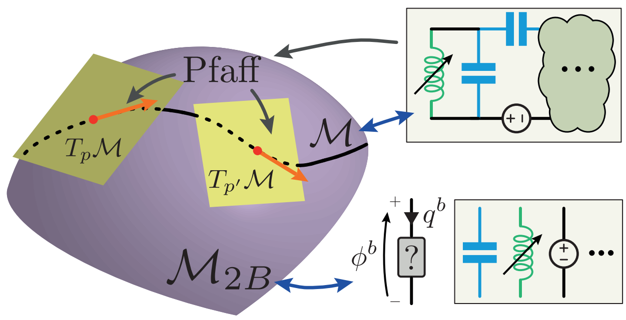

Figure 1: Artistic geometrical picture of the state of a collection of lumped elements. There are two variables per branch (flux ϕ^b and charge q^b) that span the manifold $\mathcal{M}_{2B}$. Connecting the branches in a circuit gives rise to constraints, collected in a Pfaff system that fixes the possible directions at each point on $\mathcal{M}_{2B}$. The integration of those directions results in the integral (reduced) manifold $\mathcal{M}$ that describes the constrained physics.

Towards quantum control of an ultracoherent mechanical resonator with a fluxonium qubit

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Superconducting quantum circuits are one of the most promising platforms for the realization of a scalable quantum computer. On the other hand, owing to recent advances in phononic engineering, chip-scale mechanical resonators with lifetimes in excess of 100 s have been recently demonstrated [1]. These macroscopic mechanical systems, typically vibrating at MHz frequencies have a coherence time in the second range in a thermal environment at 10 mK. Interfacing an ultra-coherent macroscopic mechanical resonator with a superconducting qubit would be a remarkable breakthrough: from the point-of-view of quantum computing, such a hybrid platform would enable a 3-orders of magnitude boost in coherence time. Furthermore, mechanical resonators could play an important role as quantum transducers, connecting superconducting circuits and optical photons [2]. On a more fundamental perspective, such a hybrid platform would be ideal to test gravitational collapse models in an unprecedented regime [3]. One of the biggest challenges consists in bridging the frequency gap between these resonators that typically oscillate below 10 MHz, and superconducting qubits in the GHz domain. Our approach is to overcome the frequency gap between this mechanical object and superconducting quantum circuits by coupling the former to a cutting-edge superconducting circuit: the fluxonium qubit [4]. This highly non-linear circuit is composed of a Josephson junction shunted by a large inductance in the high-impedance regime and has recently outperformed the transmon architecture, which constitutes the current quantum computing standard. Opportunely, the frequency of the qubit manifold in the heavy fluxonium regime naturally matches the mechanical resonance frequency of the ultracoherent mechanical membranes envisioned in this project. Furthermore, the large capacitive shunt of the heavy fluxonium is also ideally suited for a capacitive coupling scheme to the mechanical system.

In this talk, I will present results obtained on phononic crystal membrane resonators and the fluxonium qubit, and the flip chip assembly which is required to couple the two systems.

Figures

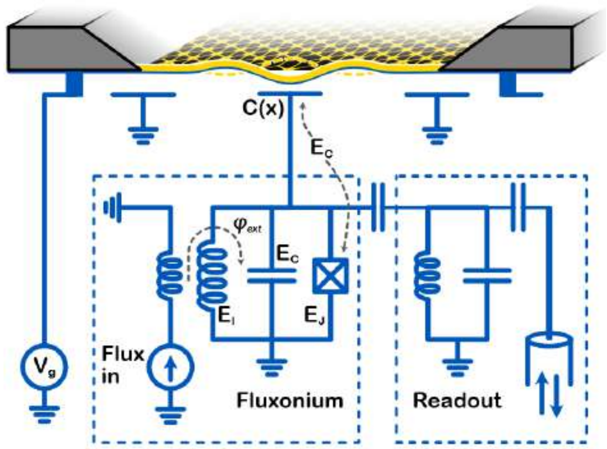

Figure 1: Flip chip assembly with the aim to capacitively couple the mechanical membrane with the fluxonium qubit.

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Theory of Caroli-de Gennes-Matricon analogs in full-shell hybrid nanowires

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We show that full-shell hybrid nanowires can host subgap states similar to teh Caroli-de Gennes- Matricon (CdGM) states in vortices, which are shell-induced Van Hove singularities in propagating core subbands.The CdGM analgos exhbit a characteritic skewness towards higher flux values inside non-zero Little-Parks (LP) lobes, resulting from the interplay of three ingredients: orbital copuling to the field, coalescence into degeneracy points, and the average radii of all CdGM analog wavefunctions inside the core. An approximation to realistic parameters is controlled by the electrostatic band bending at the core/shell interface. The analysis provides a transparent interpretation of the nanowire spectrum and allows for the extraction of microscopic information by measuring the number and skewness of CdGM analogs. Moreover, it allows for the derivation of an efficient Hamiltonian of the full-shell nanowire in terms of a modified hollow-core at the average radius of the CdGM wave functions.

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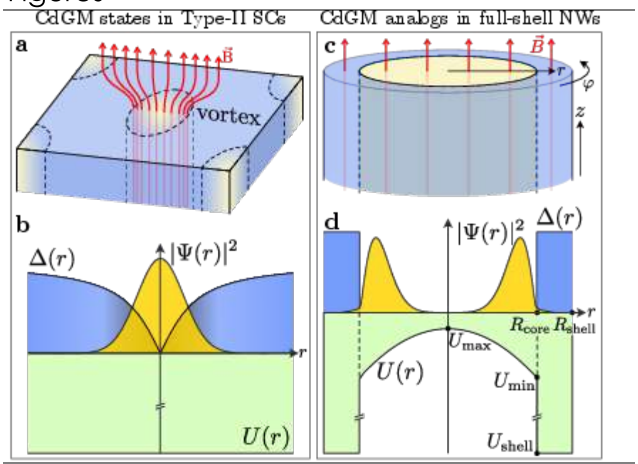

Figure 1: (a,c) Schematics of CdGM in Abrikosov vortices vs. full-shell hybrid nanowires. (b,d) Comparison of their radial wave functions.

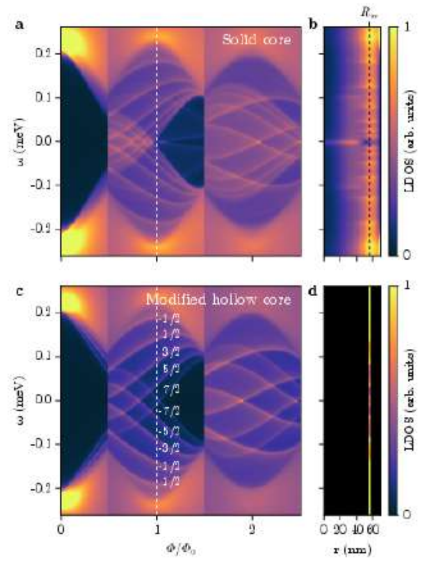

Figure 2: (a, b) Full microscopic simulation of the LDOS vs. magnetic flux and position at the end of the semi-infinite nanowire. (c,d) Same as (a,b) but using our effective 1D model.

Revolutionizing Problem-Solving: The Power of Distributed Quantum Simulation

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Quantum computing is a rapidly growing field that holds enormous promise for solving complex problems in areas such as cryptography, chemistry, and finance. The simulation of quantum algorithms is a crucial aspect of quantum computing, as it allows researchers to study and test these algorithms before they are run on actual quantum hardware. However, conventional simulation methods can be limited by the size of the system being simulated and are often unable to provide an accurate representation of large-scale quantum systems.

Distributed quantum simulation, on the other hand, offers a powerful solution to this problem. By breaking down the simulation into smaller, manageable parts and running each part on separate computational nodes, researchers can simulate much larger quantum systems. This approach also offers many benefits in terms of scalability, as it allows for the simulation of quantum systems that are too large to be run on a single computer. Additionally, it provides a way for researchers to collaborate on the simulation of quantum algorithms, allowing for a more comprehensive and efficient exploration of the field.

Considering these benefits, it is crucial that organizations and researchers in the quantum computing field consider the potential of distributed quantum simulation. By investing in this technology, they can help to advance the field and bring new, powerful quantum algorithms to fruition. Furthermore, distributed quantum simulation will play a key role in the development of quantum-based technologies, such as quantum cryptography and quantum sensors, which have the potential to revolutionize many aspects of our daily lives.

In conclusion, the potential benefits of distributed quantum simulation are clear and compelling. By embracing this technology, organizations can position themselves at the forefront of the quantum computing revolution and help to drive the development of this exciting field.

Figures

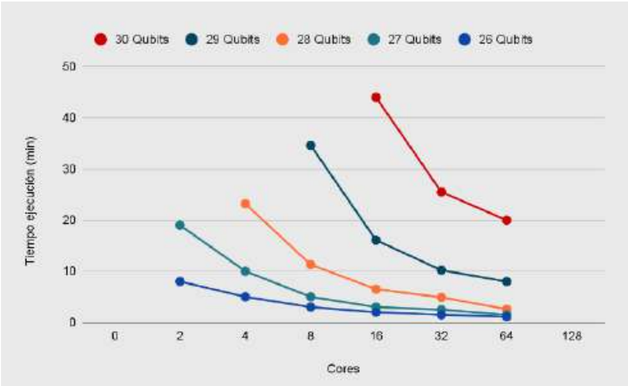

Figure 1: Simulation times with different core and qubits number for Grover´s algorithm.

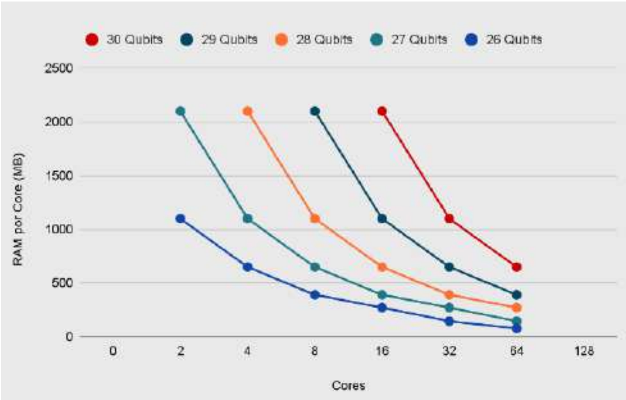

Figure 2: RAM usage per core with multiple simulations on Grover´s algorithm.

Reduce-and-chop: Shallow circuits for deeper problems

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The performance of state-of-the-art quantum computers is significantly restricted by number of qubits and coherence time, among others. While numerous techniques have been invented to make the most out of fewer-qubit devices [1, 2], analogous schemes for depth-limited computations are less explored.

This work investigates to what extent we can mimic the performance of a deeper quantum computation by using a shallower device repeatedly. We propose a method for this inspired by the Feynman quantum circuit simulation approach. The circuit is cut in halves. First half is executed and the most relevant outcomes are calculated. Then, the second half is run based on the outcomes. See Fig. 1 for a schematic description.

If the method is applied naively, it is inefficient due to the exponential number of possible outcomes. This is called the computational-basis (CB) rank. We propose to mitigate this using a shallow variational circuit, the reducer R , and whose purpose is to maintain the CB rank within pre-defined low limits. We identify the bottlenecks arising during the quest for R and provide a tailored optimisation method to find it.

We support the reduce-and-chop method with numerical experiments inspired in the Transverse-Field-Ising-Model (TFIM). Within this framework, we lowered the depth requirements of a quantum computer from 40 to 24 layers within controlled error levels. See Fig. 2.

Although the method as presented likely will not immediately lead to new uses of large currently available quantum computers due to practical bottlenecks, we believe it may stimulate new research towards exploiting the potential of shallow quantum computers.

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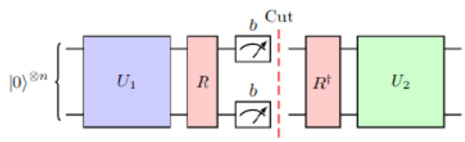

Figure 1: Schematic description of the reduce-and-chop algorithm

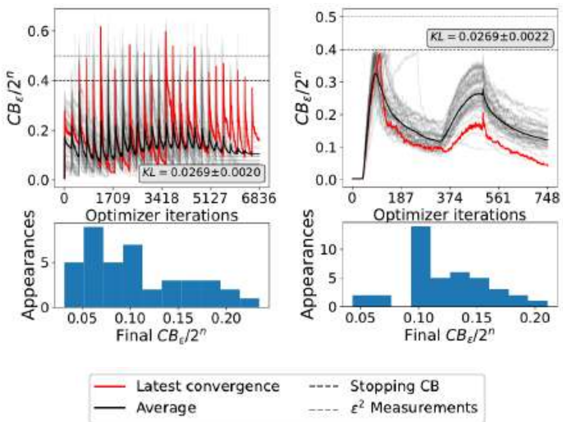

Figure 2: Two different optimization paths for the reduce-and-chop algorithm applied to a TFIM-inspired quantum circuit. This circuit has 40 layers, and is reduced to halves of 20 layers, plus a 4-layers reducer R.

Controlling ultra-high-quality microwave cavities using noisy auxiliary qubits

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Three-dimensional microwave cavity resonators can reach lifetimes of the order of a second [1,2,3]. Such cavities represent an ideal platform for quantum computing with bosonic qubits. The effective control of such qubits remains a problem since the large mode volume results in inefficient coupling to nonlinear elements used for their control. Moreover, this coupling introduces additional cavity decay via the inverse Purcell effect which can easily destroy the advantage of long intrinsic lifetime. Here, we discuss conditions and protocols for efficient control of these ultra-high-quality microwave cavities using conventional nonlinear circuits. We show different effective interaction terms between the auxiliary qubit and the storage cavity that can be used to achieve a control rate exceeding the decay rate of the auxiliary. We will explore the necessary trade-offs between increasing the control rate and increasing cavity decay (inverse Purcell effect) associated with increased auxiliary qubit-cavity coupling. Our work explores a potentially viable roadmap towards using ultra-high-quality microwave cavity resonators for storing and processing information encoded in bosonic qubits.

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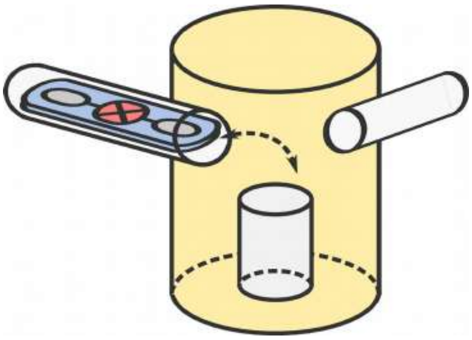

Figure 1: Schematic presentation of the cavity memory and its control.

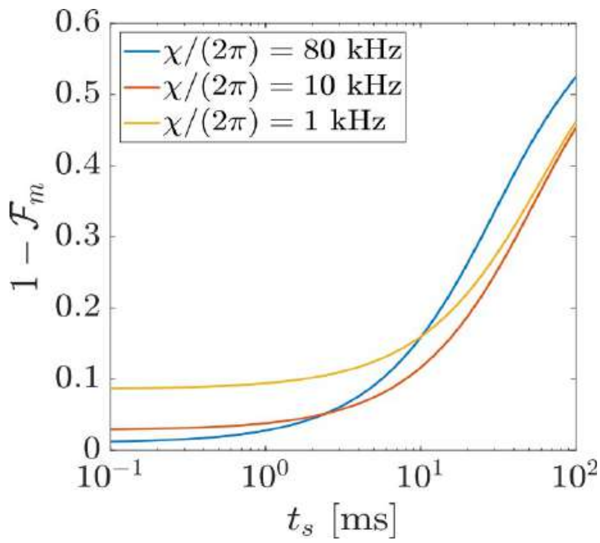

Figure 2: Cat state memory fidelity with different coupling strengths.

Minimal Kitaev-transmon qubit based on double quantum dots

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We propose a theoretical model of a superconducting qubit based on a Josephson junction between two double quantum dots. Such double quantum dot platform is the minimal realization of a 4π-Josephson Kitaev junction with four Majorana bound states. We show that the the presence of Majoranas in the junction results in distinct spectroscopic features in the microwave (MW) spectra of such hybrid qubit. This occurs as different parameters of the junction, such as double quantum dot level detunings, are varied.

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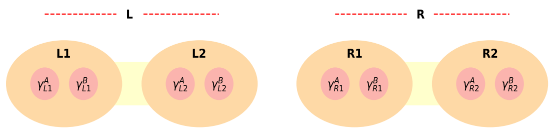

Figure 1: *Schematic illustration of the device. Each chain (α = L,R) is made of two quantum dots (β = 1,2) connected by a superconductor-semiconductor hybrid nanowire*. The two chains are coupled to each other through a tunneling junction.

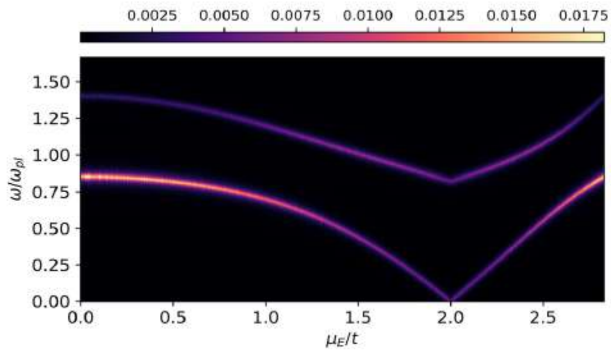

Figure 2: Microwave absorption spectrum of the hybrid qubit as a function of external chemical potentials ($\mu_{L1} = \mu_{R2} = \mu_E$), calculated at $n_g(2e)$ = *0.25* and $E_J/E_C = 0.9$.

Quantum Secure Multiparty Computation to Support Genomic Medicine

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Data mining and analysis over large Genomic databases promise major advances in medicine. Protecting the privacy of the data owners demands the use of adequate and sophisticated cryptographic primitives and protocols [1]. Nevertheless, to make the genomic data useful we must ensure large-scale interaction between data owners that do not trust each other. This trade-off between data privacy and data mining can be reached by implementing secure multiparty computation (SMC) functionalities [1]. The cryptographic primitive oblivious transfer (OT) plays a central role since it allows for the implementation of any SMC functionality [2]. However, classical implementations of OT are computationally very demanding, requiring a strong relaxation in the security. To overcome these constraints, we design, test, and implement in a real quantum network, a SMC service capable of compute a public phylogenetic tree from private genomic database. To implement that functionality, we develop a quantum oblivious key distribution (QOKD) protocol from which we generate OTs [2].

In this work we present recent results of the implementation of a SMC service involving three private genome databases. We test our SMC in the Madrid quantum network, see Figure 1. The three nodes ran a quantum-enabled SMC procedure to jointly compute the matrix distance of the genome sequences. This without revealing their private genome sequences. Each node pair consumed oblivious keys, generated through the implementation of a QOKD protocol, as well quantum key distribution protocol. The final output, shared by the three nodes, was the phylogenetic tree corresponding to the genome sequences belonging to the three private genome databases.

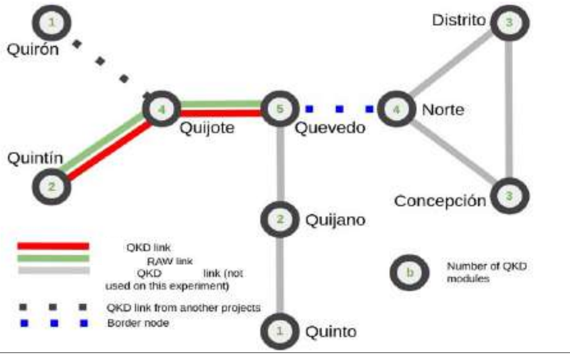

Figure 1: Madrid quantum network.

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Acknowledgements

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Noise reduction in FFTs through machine learning algorithms for the study of Ge-based quantum computing devices

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Ge quantum devices have become increasingly relevant and widely studied in recent years due to their applications in quantum computation. One of the most effective techniques for characterizing these materials and studying their physical properties is High Angle Annular Dark Field imaging in a Scanning Transmission Electron Microscope (HAADF-STEM). This technique allows researchers to study the crystallography of the material and determine its composition and the presence of defects.

A commonly used methodology for studying these materials involves calculating the Fast Fourier Transform (FFT) spectrum from various regions of interest in the device. These spectra provide information about the crystal phase and orientation of the region. By applying a mask to different frequencies, researchers can visualize the different crystallographic planes and possible defects in the material. However, FFT spectra often have noise that can impede the study of these materials.

To address this issue, in this work, we used a Convolutional Neural Network (CNN) to denoise FFT spectra. The CNN was trained on over 5000 simulated spectra from various materials, typically used in quantum devices, and in different orientations. Denoising the FFTs facilitated a more thorough study of these spectra, allowing us to conduct a comprehensive study of these Ge devices. Furthermore, this CNN model may become a key and common step in the analytical workflow towards cleaner microscopy data analysing quantum devices and beyond.

Figures

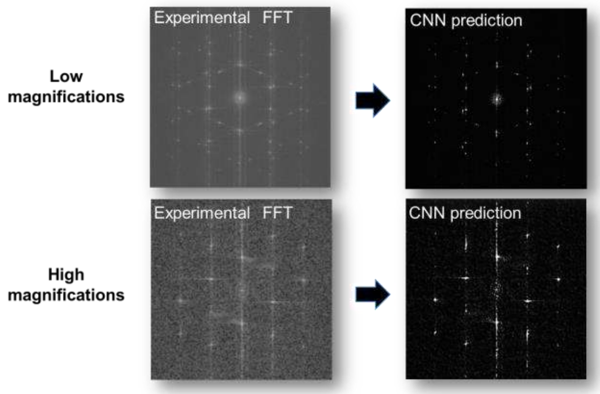

Figure 1: CNN results of the FFT denoising applied to low and high magnification spectra.

Gravitational Wave Data Analysis on a Quantum Computer

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Abstract

Classical data analysis requires computational efforts that become intractable in the age of Big Data [1]. An essential task in time series analysis is the extraction of physically meaningful information from a noisy time series. One algorithm devised for this very purpose is singular spectrum decomposition (SSD), an adaptive method that allows for the extraction of narrow-banded components from non-stationary and non-linear time series [2]. The main computational bottleneck of this algorithm is the singular value decomposition (SVD). Quantum computing could facilitate a speedup in this domain through superior scaling laws [3]. We propose quantum SSD by assigning the SVD subroutine to a quantum computer. The viability for implementation and performance of this hybrid algorithm on a near term hybrid quantum computer are investigated. In this work we show that by employing randomised SVD, we can impose a qubit limit on one of the circuits to improve scalability. Using this, we perform quantum SSD on GW150914, the first detected gravitational wave event.

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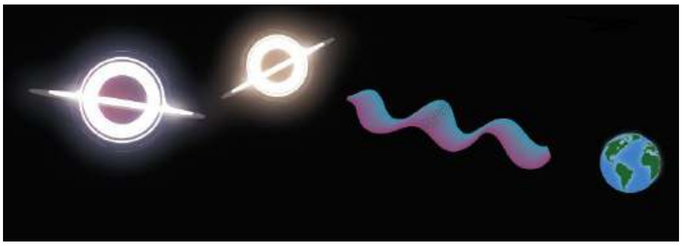

Figure 1: Black hole binaries are a source for gravitational waves, which can be measured on Earth with high sensitivity detectors such as LIGO-Virgo. Analysis of such signals yields great insight into gravitational physics.

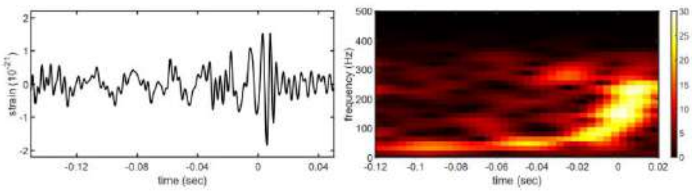

Figure 2: Gravitational wave GW150914, with its associated spectrogram, after being filtering through quantum singular spectrum decomposition. A waveform is obtained that has favourable properties for data analysis purposes.

Improved implementation of the Quantum Self-Consistent Equation-of-Motion (Q-SC-EOM) method in INQUANTO

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Abstract

The Quantum Self-Consistent Equation-of-Motion (Q-SC-EOM) method for the calculation of excitation energies has been recently published by Asthana, Kumar *et al.* [1] We have now built upon the original method with an implementation in INQUANTO[2] that employs an alternative state preparation procedure for the linear combination of states, by using the method based on Givens rotations.[3] We benchmark our implementation against classical calculations for small systems such as H_2, LiH and H_3^+, and discuss the required circuit depths for different parts of the implementation. In addition, we further improve our implementation by using symmetry filtering, in order to avoid the calculation of redundant elements, which facilitates the study of larger systems. We show here the results for H_4, H_2O, as well as a challenging case of scanning the potential energy surface of ethylene (using minimum active space) along its torsion angle rotation coordinate.

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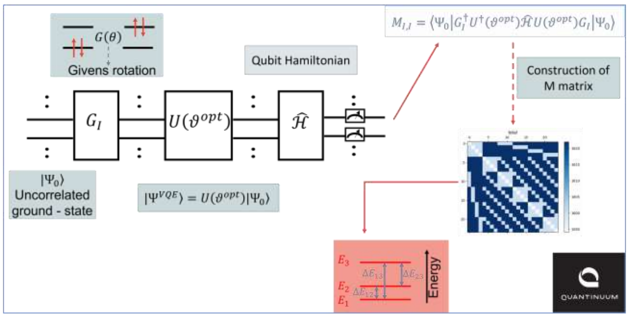

Figure 1: Schematic picture of the implementation of the Q-SC-EOM method in INQUANTO

Origin of the heavy-hole in-plane g-factor in individual annealed InGaAs/GaAs quantum dots

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Self-assembled InGaAs/GaAs quantum dots (QDs) are of unique importance to photonic quantum computing as platforms for entangled spin qubits [1], quantum receivers [2] and spin-photon cluster states [3]. Some of these quantum protocols and notably deterministic cluster state generation for measurement-based quantum computing rely on the optical selection rules under a transverse magnetic field, which are related to the actual spin eigenstates (Fig.1b). Notably, the linear polarization axes of the optical transitions for a given in-plane magnetic field orientation are determined by the g-factor of the QD valence band ground state - a so-called heavy-hole - which in general must be represented by a second order tensor. It has been recently reported that for an ensemble of annealed QDs, the components of this tensor are dominated by a confinement-renormalized Luttinger parameter *q*, associated to *valence band warping* [4], rather than to the *valence band mixing* induced by the QD structural anisotropy [5]. Using polarization-resolved photoluminescence (PL) measurements of *individual* QDs for different angles of the applied magnetic field, we assess the respective contribution of the valence band warping and mixing to the heavy-hole in-plane g-factor tensor.

Under a strong transverse magnetic field (B = 5T), we excite individual QDs off-resonantly and find that the linear polarization of the four Zeeman-split PL lines, remain essentially parallel to the directions <110> of the crystal (Fig.1-a), regardless of the in-plane field angle. We also observed a significant anisotropy in PL intensity, with eigenaxes along the same directions <110>, and essentially independent of the magnetic field strength (Fig. 1-c) and direction (not shown). Both observations point to a valence band mixing as the origin of the heavy-hole in-plane g-factor despite annealed (hence likely less anisotropic) QDs. For a more quantitative analysis, we also performed simulations with a simple spin model including both valence band mixing and warping. With respect to Ref. [4], our results point to the criticality of the annealing procedure to control the effective heavy-hole in-plane g-factor tensor in such QDs.

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Figure 1

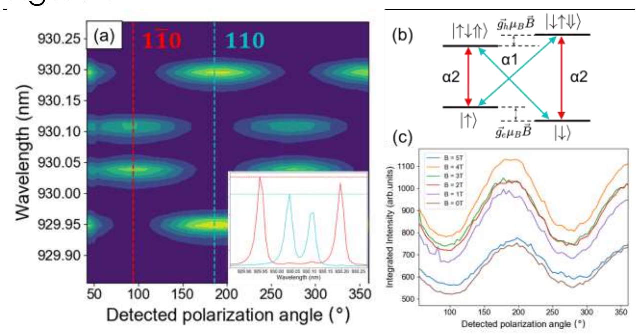

Figure 1: a) Contour plot PL intensity as a function of emitted light polarization and wavelength at B = 5 T. Inset shows spectra associated to <110> directions. b) Energy level diagram of the system. c) Integrated PL intensity vs emitted light polarization at varying magnetic field strength

Quantum machine learning algorithms and its implementation in molecular qudits

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Quantum machine learning (QML) is recently gaining interest in both theory and experiment thanks to variational circuits implemented in the noisy intermediate-scale quantum computers (NISQs) [1]. Since we are in such an era, algorithms capable of being implemented in small circuits are of great interest. In pursuit of this objective, we explore QML algorithms that are implementable in circuits involving a single qudit, a system with d > 2 levels, instead of the traditional qubit (d = 2). Molecules with large electronic and/or nuclear spins provide a natural platform with multiple operational levels [2], being a suitable choice for implementing our qudits. Operations are driven by electromagnetic pulses resonant with the allowed transitions, which can be realized with EPR techniques or by coupling them to superconducting circuits [3]. It has been shown that this type of control in a single qudit is sufficient to implement any d-dimensional unitary operation [4], thus being an universal quantum processing unit. Specifically, we explore supervised learning [5] and classification problems of databases comprising more classes than levels are accessible in our qudit, forcing the development of tools to find maximally orthogonal states [6].

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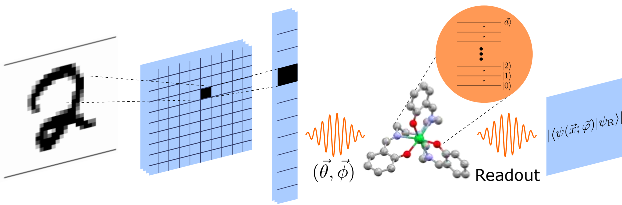

Figure 1: Sketch of a hybrid neural network combining the classical capabilities for pre-processing and optimization with the generation of quantum states in molecular qudits.

Break-even point of quantum repetition code[1]

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Enhancing the lifetime of qubits with quantum code-based memories on different quantum hardware is a significant step towards fault-tolerant quantum computing. We theoretically show that the break-even point, i.e., preserving arbitrary quantum information longer than the lifetime of a single idle qubit, can be beaten even with the quantum phase-flip repetition code in a dephasing-time-limited system. Applying circuit-based analytical calculation, we determine the efficiency of the phase-flip code as a quantum memory in the presence of relaxation, dephasing, and faulty quantum gates. Considering current platforms for quantum computing, we identify the gate error probabilities and optimal repetition number of quantum error correction cycles to reach the break-even point.

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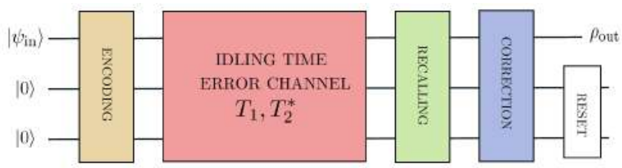

Figure 1: The schematic draw of a quantum code-based memory. In the decoding step, the initial state is entangled with a few ancillary qubits initialized in the ground state. During the idling time, every qubit is affected by the noise sources, e.g., dephasing and relaxation. After the correction, the state is recalled to one of the physical qubits. A reset of the ancilla qubits is necessary if we want to repeat this process. In many applications, the order of the recalling and correction processes is reversed.

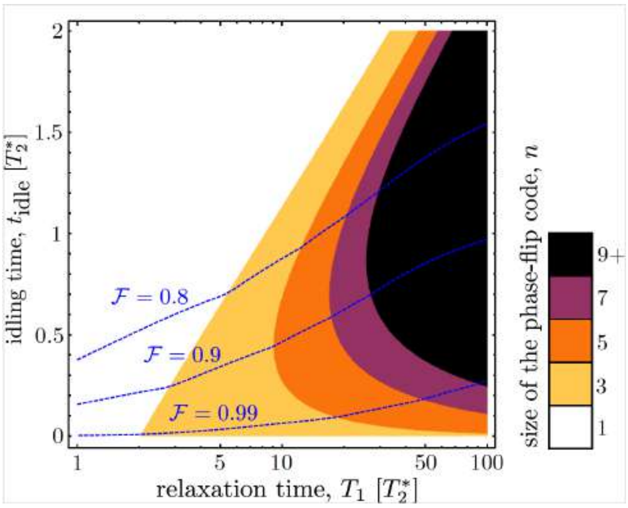

Figure 2: The size of the phase-flip repetition code giving the largest fidelity after one cycle of error correction as well as three iso-fidelity contours as a function of relaxation and idling times in units of T_2*. Gate errors are neglected. For n=1 (white region) the idle qubit gives better fidelity than a quantum code. In a dephasing-time limited system ($T_1 > 2T_2$*) if the idling time is shorter than a threshold value (colourful region) then the break-even point is beaten.

Periodically driven chiral engine beyond the Carnot limit

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Classically, the power generated by an ideal thermal machine cannot be larger than the Carnot limit. This profound result is rooted in the second law of thermodynamics. Whether this bound is still valid for microengines operating far from equilibrium is an open question in quantum thermodynamics. Here, we demonstrate [1] that a quantum chiral conductor driven by AC voltage can indeed work with efficiencies much larger than the Carnot bound. Our pump engine [see Fig. 1(a)] consists of a scatterer of arbitrary energy-dependent transmission tunnel coupled to electronic hot and cold reservoirs in the presence of an external AC bias voltage. An AC driving typically generates a finite input power that diminishes the efficiency. Our key idea to overcome this difficulty is to selectively apply an AC external field to the electrons depending on the direction, which can be implemented using a chiral conductor such as those created in two-dimensional systems (topological or quantum Hall conductors) [see Fig. 1(b)]. This completely avoids any AC input power, allowing a high efficiency of the quantum engine, in contrast to nonchiral cases. Nonetheless, entropy production is always positive when using the proper definition for AC driven conductors beyond weak coupling [2] and the second law is preserved. The role of the AC driving can be interpreted as a nonequilibrium demon [3] as the driving induces additional entropy production by rearranging the electron energy distribution in a more uncertain way, while injecting zero net energy. Our results are relevant in view of recent developments that use small conductors to test the fundamental limits of thermodynamic engines.

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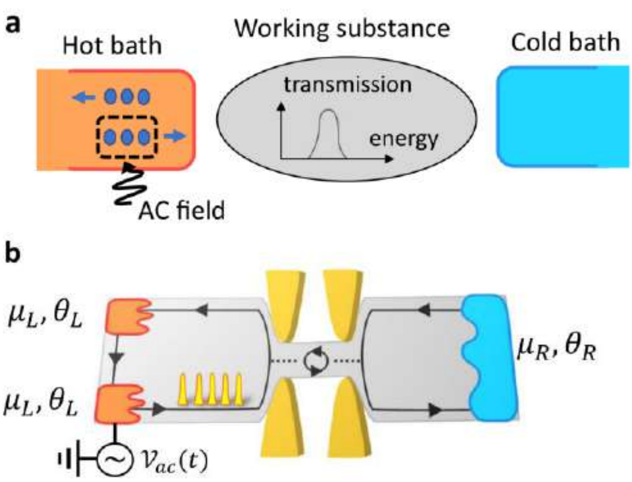

Figure 1: (a) Schematic of periodically driven chiral engine. (b) An implementation using a chiral conductor. $\mu_{L(R)}$ and $\theta_{L(R)}$ are chemical potential and temperature of left (right) reservoir.

Qubit readout with a non-linear cavity coupled to a transmon qubit via direct cross-Kerr coupling

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The multimodal circuit nicknamed Quantromon has two orthogonal modes: a transmon qubit and a linear oscillator coupled to each other via direct cross-Kerr coupling. An integrated qubit-cavity system is realized using these modes with the linear oscillator playing the role of the readout cavity. We previously demonstrated a high measurement fidelity of 97.6% without using the Josephson parametric amplifier due to the possibility of using higher photon numbers in the Quantromon. In this work, we replace the linear oscillator mode with a non-linear Josephson junction based oscillator. This enables the possibility of accessing the parametric amplification and bifurcation regime of the non-linear oscillator for integrated amplification in the measurement cavity. Previous experiments have explored integrated amplification using non-linear readout cavity e.g. the quantronium qubit in the charging regime [1] and a transmon qubit coupled transversely to a non-linear oscillator [2]. More recently, a transmon qubit readout using in-situ bifurcation of a nonlinear dissipative polariton has been demonstrated [3]. We will discuss the different operating regimes of our device and present experimental data demonstrating qubit measurement. We will also compare our technique and results with the others mentioned above and discuss key similarities and differences.

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Nonlocal heat engines with hybrid quantum dot systems

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The energy absorbed by a conductor from a non-equilibrium environment can be rectified to generate finite electrical power. Typically, this depends on tiny energy-dependent asymmetries of the device, formed by e.g. a quantum dot [1]. We show that larger currents are expected in hybrid systems, where a superconductor hybridizes the even-parity states in the quantum dot. We consider the environment to consist on a quantum dot Coulomb-coupled to the conductor one and tunnel-coupled to a hot reservoir. Two main mechanisms contribute to the generation of power. On one hand, the non-equilibrium charge fluctuations in the second dot correlate with the Andreev processes hence injecting Cooper pairs in the superconductor. This provides the necessary symmetry breaking energy transfer. On the other hand, this mechanism competes with quasiparticle contributions, which benefit from the sharp features of the superconducting density of states, and is able to increase the engine performance [3].

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Haiku graphene nanoribbons with tunable topology: emergence of localized magnetic moments

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Abstract

Recent advances on surface-assisted synthesis open the door to engineering topological phases in atomically precise graphene nanoribbons (GNRs). However, to fully exploit their potential, a rational design is needed to achieve GNRs with optimal properties for spintronics or quantum computing applications.

Here we explore a novel family of armchair GNRs, which we name haiku-AGNRs, consisting of 5- and 7-atom wide segments. Based on ab initio simulations, we predict a tunable topological phase dependent on the density of the 7-atom wide segments, with the concomitant emergence or quenching of topological end and interface states [1]. Moreover, we derive a generalized Su-Schrieffer-Heeger (SSH) model that allows to treat haiku-AGNRs of technologically relevant lengths, thus providing valuable information for the devise of future experiments. Finally, we also present some results for B-doped periodic haiku-AGNRs in comparison with experiments performed at Prof. Pascual's lab in nanoGUNE, San Sebastian (Spain) [2].

We acknowledge financial support from Grant PID2019-107338RB-C66 funded by MCIN/AEI/10.13039/501100011033, the European Union (EU) H2020 program through the FET Open project SPRING (Grant Agreement No. 863098) and the IKUR Strategy under the collaboration agreement between Ikerbasque Foundation and DIPC on behalf of the Dep. of Education of the Basque Government.

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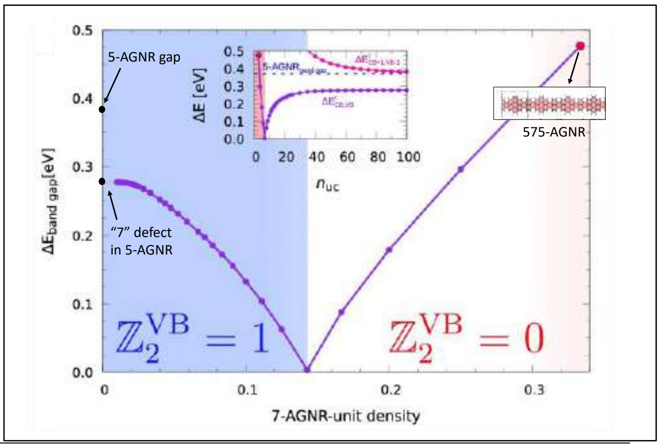

Figure 1: DFT-SIESTA band gap of 7-(5-AGNR)nuc as a function of the density (1/n_{UC}) of 7 widenings for periodic haiku ribbons with supercells containing n_{UC} 5-AGNR unit cells. The band gap closes separating the topological and the trivial phases. The inset highlights the presence of a defect level localized around isolated 7-widenings for very dilute systems. Notice that the labels 575-AGNR and 7-(5-AGNR)$_3$ denote the same system.

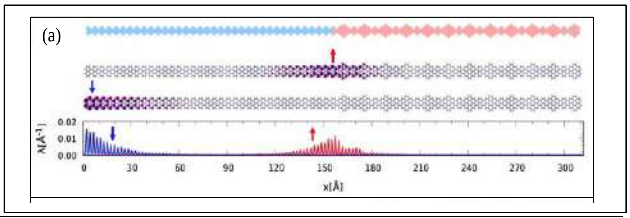

Figure 2: DFT-SIESTA calculation of the spin polarized end states appearing at the boundaries of the 5-AGNR portion of a mixed 5-AGNR/575-AGNR long ribbon.

Squeezing and Quantum Approximate Optimization

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Abstract:

Variational quantum algorithms offer fascinating prospects for the solution of combinatorial optimization problems using digital quantum computers. However, the achievable performance in such algorithms and the role of quantum correlations therein remain unclear. Here, we shed light on this open issue by establishing a tight connection to the seemingly unrelated field of quantum metrology: Metrological applications employ quantum states of spin-ensembles with a reduced variance to achieve an increased sensitivity, and we cast the generation of such squeezed states in the form of finding optimal solutions to combinatorial problems (e.g., MaxCut) with increased precision. On the one hand, by solving this optimization problem with a quantum approximate optimization algorithm (QAOA), we show numerically as well as on an IBM quantum chip, how highly squeezed states are generated in a systematic procedure that can be adapted to a wide variety of quantum machines. On the other hand, squeezing tailored for the QAOA of the MaxCut relates to quantum correlation in the form of entanglement, it permits us to propose a figure of merit for future hardware benchmarks, and it can resource-effectively boost the averaged final energy of QAOA optimization obtained in MaxCut of random graph instances. Further exploitation of this connection between metrology and optimization may uncover solutions to prevailing problems and push the scope of precision in both fields.

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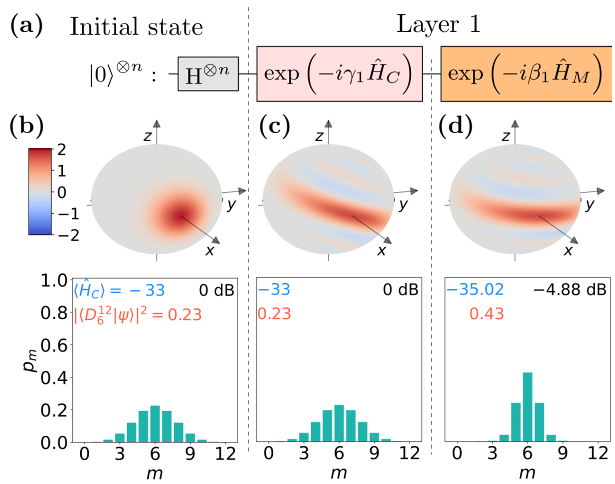

Figure 1: Squeezing generated by QAOA: (a) Circuit representation of QAOA with alternating application of cost-function and mixer Hamiltonian. Wigner quasi-probability distribution on the Bloch spheres (above row) and histograms (below row) from (b) to (d) show the state after the corresponding gate in the optimized QAOA circuit. Negativity in the Wigner distribution indicates that the states are non-Gaussian. The squeezing (in dB, black), energy expectation $\langle H_c \rangle$ (in blue) and overlap probability density with the target Dicke state $|\langle D_6^{12}|\psi\rangle|^2$ (in orange) are shown inside each histograms.

Topological superconductivity in a Josephson junction mediated by magnetic domains

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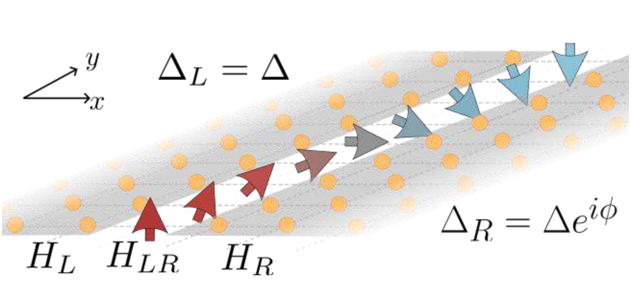

Figure 1: Superconductors L and R are separated by a ferromagnetic insulator barrier, so that the hopping between them is spin dependent. The magnetization direction of the insulating barrier changes in space, as depicted by the arrows, akin to a magnetic domain wall.

Topological superconductors are appealing building blocks for robust and reliable quantum information processing [1]. Most platforms for engineering topological superconductivity rely on a combination of materials with intrinsic spin-orbit coupling and external magnetic fields, which are usually challenging to manipulate [2]. We propose and describe a setup (Fig. 1) without spin-orbit or magnetic fields where a conventional Josephson junction is linked by a narrow ferromagnetic insulator barrier with multi-domain structure [3]. Sequences of magnetic domains that preserve the net magnetization's rotation direction are sufficient for generating topological superconductivity in a wide range of parameters and degrees of disorder. The topological phase transition depends on the magnitude and rotation period of the net magnetization. Interestingly, a phase bias ϕ across the junction can control the localization of a pair of Majorana zero-energy modes (MZMs) at the edges of the junction interface, with an observable effect on the current-phase relation (Fig. 2).

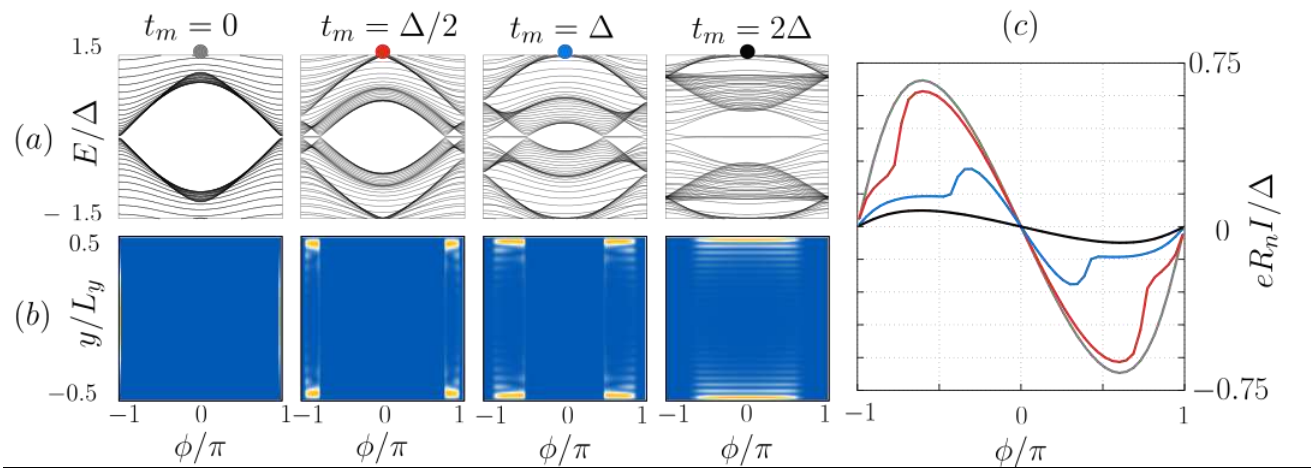

Figure 2: Localizing edge modes by phase biasing the junction. (a) Energy bands showing the gap reopening and MZMs at finite ϕ. (b) Local density of states (a.u.) at E = 0 vs junction width, showing the localization of a pair of topological edge states. (c) Current-phase relation for the parameters used on the left. Increasing the magnetization strength facilitates the topological phase transition.

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Quantum-enhanced magnetic induction tomography

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Atomic magnetometry has seen significant attention in recent years, leading to various experimental approaches and applications. One prominent application of atomic magnetometers as sensors is the technique of magnetic induction tomography (MIT), a non-invasive imaging technique allowing to probe the conductive properties of a non-magnetic sample [1]. MIT exploits that an RF magnetic field induces eddy currents inside a conductive sample. These generate a response to the primary RF field, altering the total magnetic field as seen by the collective atomic spin ensemble. Monitoring the response of the collective spin continuously with a far-detuned laser allows for retrieving information about a magnetic field by monitoring the light polarization rotation using homodyne detection. Fundamentally, this measurement will be limited in sensitivity by the measurement's standard quantum limit (SQL).
To overcome the standard quantum limit governing an MIT measurement's attainable performance, quantum resources must be exploited to attain a quantum-enhanced version of the classical MIT. In our approach, we combine the well-known techniques of stroboscopic back-action evasion by probing the collective spin at twice the spins' Larmor precession with conditional spin-squeezing [2]. We exploit these for MIT to add quantum-enhanced magnetic induction tomography as a new quantum-enhanced sensing protocol. We can reduce the observed noise between unconditional and conditional measurements by 41 ± 1 % (Figure 1, blue and red error bars). Further, exploiting conditional spin-squeezing, we observe 11 ± 1 % lower noise than a back-action free measurement (green error bars). We verify the quantum enhancement by estimating the expected uncertainty for a continuous MIT compared to ours and find a noise reduction of 24 %.

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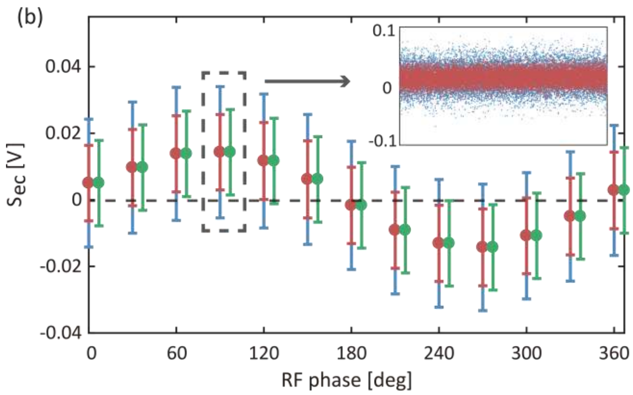

Figure 1: Recorded eddy current signals shown versus the relative RF phase. Red and blue error bars reflect conditional and unconditional measurements. Green error bars (shifted for clarity) reflect the expected noise for a back-action free measurement. Figure adapted from [3].

Majorana modes and gauge invariance of NSN junctions of magnetic topological insulators

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Magnetic topological insulators (MTIs) are outstanding candidates for the realization of topological 1D and 2D superconducting phases [1,2] with end-localized or propagating Majorana modes. However, the experimental detection of these elusive quasiparticles is still a matter of concern.
We propose to detect such topologically-protected Majorana boundary states in NSN junctions between normal and proximitized MTIs by applying asymmetric bias drops on the two leads of the device. Without Majorana modes in the superconductor, the conductance is independent of the way the total bias is split across the junction. We refer to this physical property as "gauge invariance" of the electric conductance, and we argue that such invariance is lost in presence of zero-energy Majorana modes. Indeed, an unbalanced bias leads to asymmetric currents on the two terminals of the junction and the charge conservation requires a current of Cooper pairs going to ground from the superconductor. Such electric current constitutes a characteristic signal of Majorana quasiparticles, and can be directly detected through conductance measurements in realistic devices.

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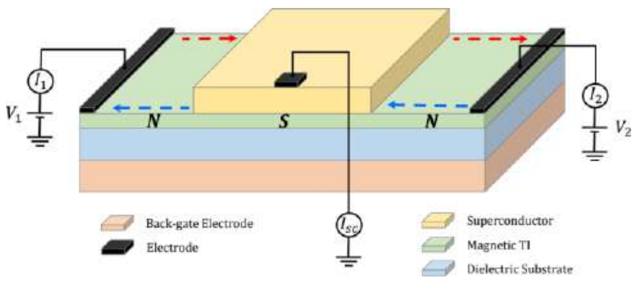

Figure 1: Proposed setup for the detection of Majorana edge modes in magnetic topological insulators.

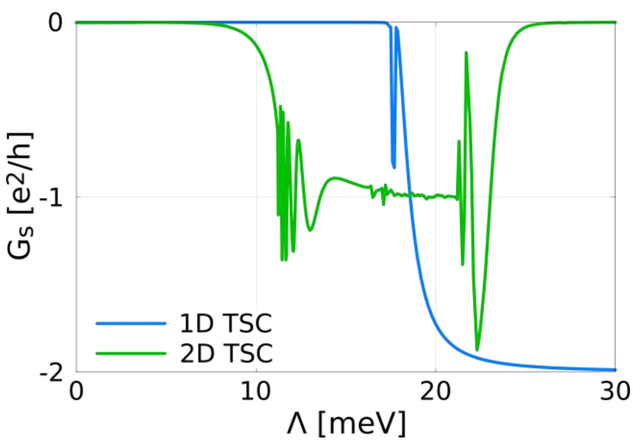

Figure 2: Conductance G_s in the superconducting lead as a function of magnetization Λ in the MTI. Conductance Plateaus $G_s = \neq 0$ are observed in presence of nontrivial Majorana modes.

Optical conductivity in the paramagnetic phases of rhombohedral trilayer graphene

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Abstract (Century Gothic 11)

Rhombohedral trilayer graphene (RTG) has been the focus of special interest in the last years, since it hosts many different interaction-driven phases, with the metallic ones yielding unconventional superconducting orders upon doping [1,2]. In this talk we present the optical conductivity (using the low-energy effective theory) for the three proposed paramagnetic metallic ground states [3]: a fully gapped valence-bond state, the bond-current state and the rotational symmetry breaking charge-density wave. We show that the optical conductivity presents specific features for each of the states and can therefore be used to distinguish between these different propose metallic ground states [4].

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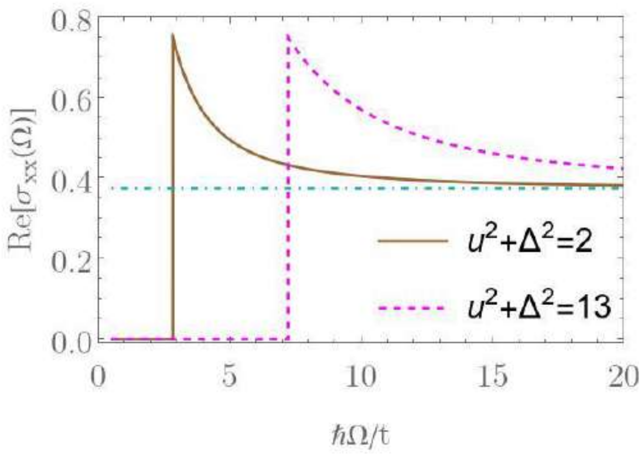

Figure 1: Real part of the optical conductivity for the VBO order.

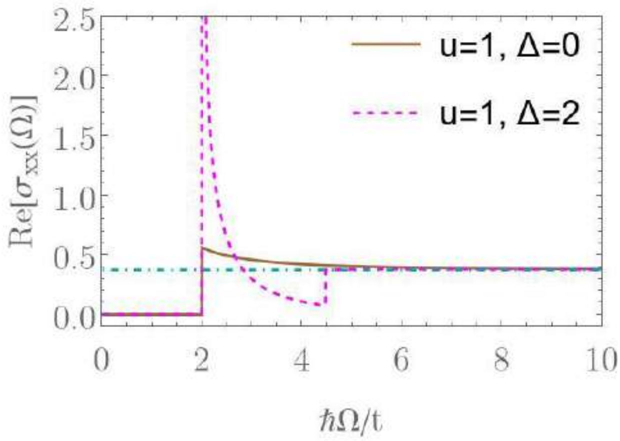

Figure 2: Real part of the optical conductivity for the BC order.

Measurement-device independent quantum tomography

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Characterization of quantum states and devices is paramount to fundamental quantum science and many applications in quantum technology. The detailed characterization often requires many individual projection measurements, such as in the case of quantum state tomography. The constituent measurements have to be perfectly under control; unfortunately, this is not the case in an experimental setting. The resulting accuracy of the quantum state characterization is ultimately limited by a mismatch between actual and assumed constituent measurements. Particularly, the mismatch yields an artificial decrease in the purity of the measured quantum state. Such artifacts can be detected by injecting a few near-pure but otherwise unknown states into the measurement device, which is perfectly feasible, particularly in photonic experiments. We show how to use the reconstruction artifacts to correct the assumption about the constituent measurements and, ultimately, reach the accurate quantum state characterization. The calibrated measurement device can be utilized for full quantum state tomography or partial characterization schemes, such as fidelity estimation and compressed sensing. We experimentally demonstrate the self-calibrating method for polarization state tomography. Furthermore, we also discuss scenarios of rotating-waveplate polarimetry and photonic path-qubit tomography on optical chips. Finally, the approach is directly applicable to multi-qubit quantum systems and quantum devices while requiring the self-calibration step solely for constituent single-qubit measurements; i.e., the approach is fully scalable. The developed measurement-device independent quantum tomography opens the way for accurate quantum state and device characterization without adverse effects of measurement imperfections.

Theory of heat transport in dirty Superconductors -Joule Spectroscopy of InAs-Al devices-

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InAs nanowires with epitaxial grown Al facets constitute a workhorse geometry for many current quantum platforms; topologically trivial as well as non-trivial. Nonetheless, effects of heating and heat dissipation are not well understood in these systems, and can be potentially detrimental, as superconductors are notorious poor thermal conductors at low temperature. In this poster I present a theoretical study of heat dissipation of Joule heating via quasiparticles in dilute superconductors, and establish how emerging excess current dips [1] can be utilised to probe superconducting properties of either leads in etched Josephson Junctions [2].

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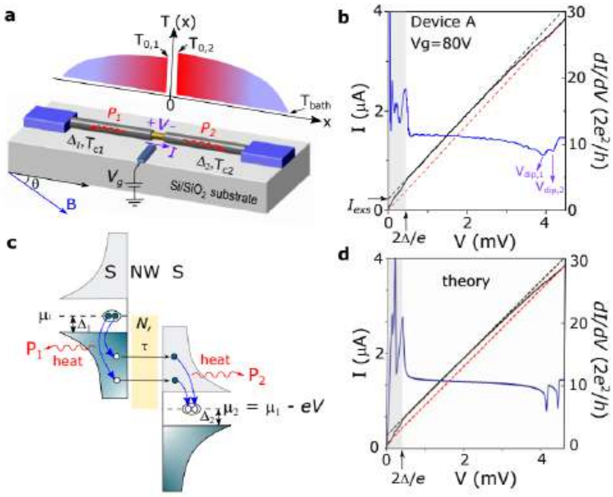

Figure 1: a Typical device geometry and illustration of temperature profiles. **b** V-I measurements showing high bias excess current dips. **c** Illustration of Joule heating in devices. **d** Theoretical calculated V-I curves showing dips.

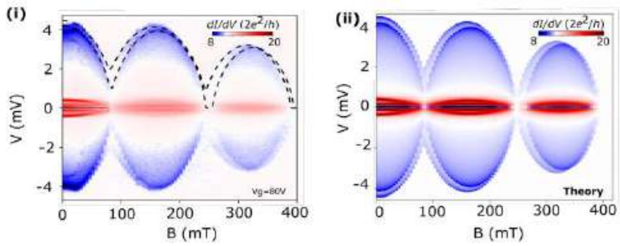

Figure 2: (i) High bias conductance measurements as a function of magnetic field. Little-Park oscillations of excess current dips are clearly visible. Dashed lines indicate fits to a simple theoretical estimate. **(ii)** Full self-consistent in temperature Keldysh-Floquet calculations of conductance.

Optical Polarization of Nuclear Spins via the negatively charged Tin-Vacancy Center in Diamond

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Optically interfaced solid-state spins are amongst the most promising approaches for quantum networking devices, combining a local quantum register of electronic and nearby nuclear spins with long-distance transmission of coherent optical photons [1]. Amongst the Group-IV color centers in diamond with their desirable optical properties [2], the negatively charged tin-vacancy center (SnV) is particularly interesting [3, 4]. Its large spin-orbit coupling offers strong protection against phonon dephasing even at 1.7 K and robust cyclicity of its optical transitions, allowing both single-shot readout and nuclear spin access via the optical transitions.
Recently, we showed multi-axis coherent control of the SnV spin qubit via an all-optical stimulated Raman drive between the ground and excited states [5]. Optically driven electronic spin resonance data shows a hyperfine-split double-peaked structure, indicating a strongly coupled nuclear spin (^{13}C). We utilize direct-driving of the forbidden zero-quantum and double-quantum transitions (Figure 1 (b)) [6].

Our gates consist of initialization of the electron, repeated drive of the nuclear spin flipping transition, reset of the electron via a single optical scattering event (optical spin-flip transition) and readout via the single-quantum transitions (Figure 1(a)). As a next step, we report on the progress of driving the optically accessed nucleus coherently and towards implementing quantum state transfer, storage and retrieval, paving the way for a local quantum memory [7].

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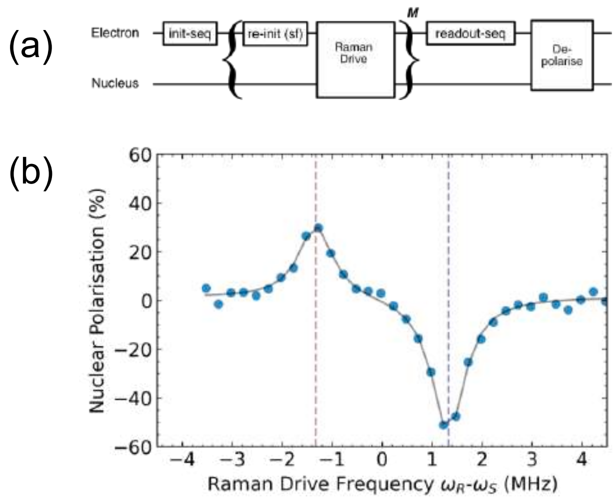

Figure 1: (a) Nuclear spin initialization gates, (b) nuclear polarization as a function of Raman drive frequency

Quantum networking with silicon-vacancy centers in diamond

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Silicon-vacancy centers in diamond (SiVs) are a promising platform for quantum information applications[1]. In particular, SiVs containing the ^{29}Si-isotope are well suited for use in quantum networks: they serve as an integrated two-qubit register with universal one- and two-qubit gates, a long-lived nuclear spin memory, and high-fidelity single-shot readout[2]. We achieve an efficient spin-photon interface by integrating SiVs into overcoupled nanophotonic cavities[3] and efficiently extracting photons with a tapered optical fiber. Here, we will discuss the operation of individual ^{29}SiV quantum memories, demonstrating heralded spin-photon gates to generate electron-photon and nuclear-photon Bell states with integrated error detection. We will then show that the platform is extensible to multi-node operation: we realize a quantum link and demonstrate entanglement between two independent nodes each containing a single SiV that are spatially separated by 20 meters. These results demonstrate the potential for large-scale quantum networking and quantum repeaters based on SiVs in diamond.

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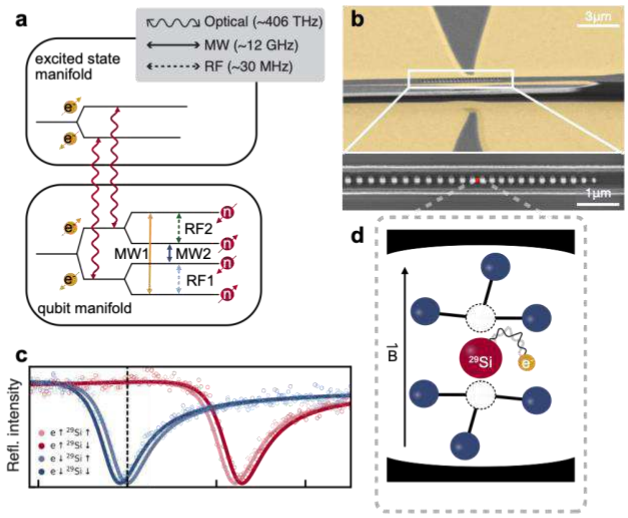

Figure 1: a) Silicon-vacancy center (SiV) energy spectrum. b) SEM micrograph of nanophotonic diamond cavity. c) Reflection spectrum of SiV-cavity system. d) Crystallographic structure of the SiV.

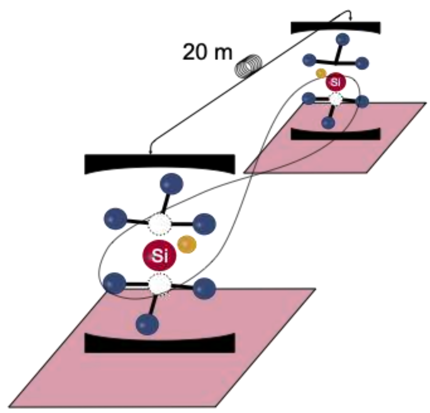

Figure 2: Schematic illustrating two-node quantum networking with silicon-vacancy centers in diamond.

Variational Waveguide-QED simulators

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Variational Quantum Algorithms (VQAs) [1] use a classical optimizer to train a parametrized quantum circuit (PQC). These have emerged as a practical way to exploit state-of-the-art quantum computers. Currently, most VQAs have been designed for fully digital approaches, in which the error ends up accumulating for circuits with many parameters. A possible way out is the use of analogue quantum simulators (AQS) instead. AQS allow a global evolution of the system and are more resilient to errors. This is why they have been recently pointed out as one of the most promising directions to achieve "practical quantum advantage" [2]. However, current proof-of-principle demonstrations with trapped ions [3] and cold atoms [4], as occurs with fully digital VQAs, are ultimately limited by the connectivities that can be achieved with these devices.

In this work we discuss a variational AQS inspired by the tunable range interactions that can be obtained in waveguide-QED platforms [5]. We show that by using the range of the interaction as a variational parameter one can design a novel class of PQCs. We compare their performance against state-of-the-art VQAs with fixed connectivities, and demonstrate that they can accurately capture the ground state of critical spin models with fewer gates and variational parameters. In summary, our results highlight the potential of variational waveguide-QED quantum simulators as a promising platform for implementing VQAs.

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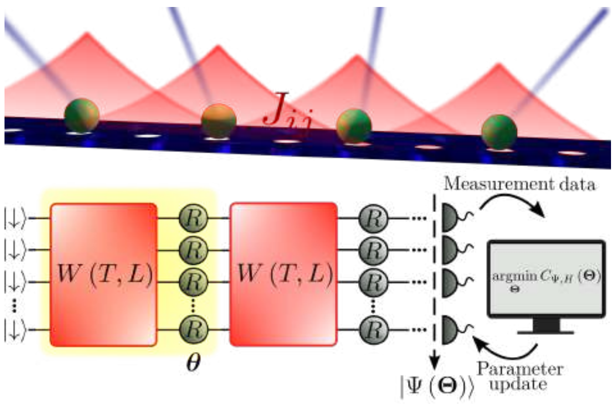

Figure 1: Top: scheme of a possible experimental setup, with quantum emitters addressed with lasers and coupled to a waveguide. Bottom: variational workflow using the analog waveguide-QED interactions.

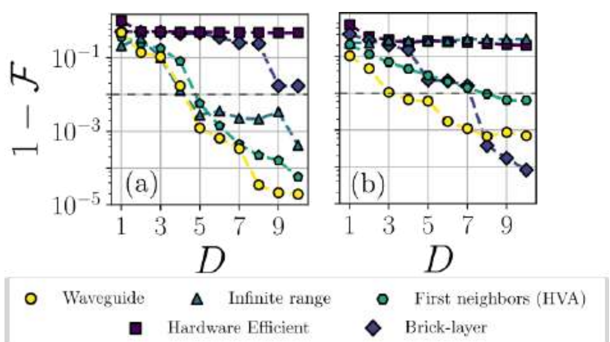

Figure 2: Infidelity between the exact ground state and the variational ones using different ansätze as a function of the layers *D* for the XXZ (a) and transverse-field Ising (b) models at critical regions of their parameter space.

Enhanced optical absorption in heterostructures formed by CdO and SnC monolayers

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Abstract

Assembling 2D materials in vertical heterostructures is one of the main techniques for enhancing electronic and optical properties. In most cases, known as van der Waals heterostructures (vdWHs), the interlayer distances are larger than typical covalent bond lengths resulting in weak interlayer interactions. It has been shown that reducing the distance between the layers can significantly alter the properties of separated layers, which is not so noticeable in vdWHs and thus creates a new platform for controlling the physical properties of 2D materials [1]. Such structures are rarely reported in the literature. Examples are borophene/ graphene [2] and ZnO/ MgO [3] heterostructures.

Motivated by the enhanced properties of 2D vertical heterostructures, we employed ab-initio calculations based on density functional theory and examined CdO/SnC systems in four different stackings. Our results reveal that despite of thermodynamic and mechanical stabilities of all considered structures, according to calculated phonon frequencies, only the structure formed by placing the Sn atom on top of the O atom and the C atom on top of the Cd atom is dynamically stable at zero Kelvin. This structure has an interlayer distance of 2.52 Å which is smaller than the interlayer distance in typical vdWHs. We also investigated the electronic and optical properties of this dynamically stable structure utilizing the GW+BSE approach. Unlike the monolayer CdO which possesses a single optical absorption peak close to the red light energy, the considered CdO/SnC structure has an optical bandgap of 1.14 eV, and it can absorb 13% of incident light in the blue light region.

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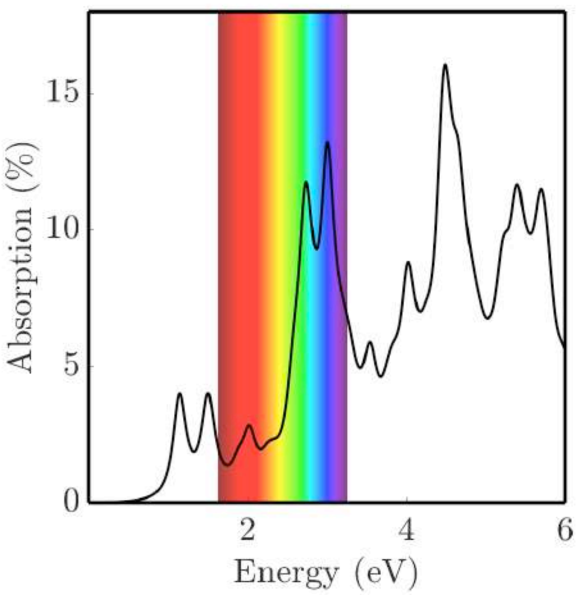

Figure 1: Optical absorption of the dynamically stable CdO/SnC heterostructure for perpendicular incident light.

Synergic generative quantum machine learning

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We present a new approach to generative quantum machine learning and describe a proof-of-principle experiment demonstrating our approach. We call our proposed approach quantum synergic generative learning because the learning process is based on the cooperation between the generators and the discriminator. The goal of the learning is for the quantum computer implementing the generative learning algorithm to learn a concept of a Bell state. After the learning process, the network is able to recognize as well as generate the entangled state. We compare our approach with the recently proposed quantum generative adversarial learning (QGAN). We present numerical proofs, obtained using quantum simulators, for single qubits as well as more qubits, and we also present experimental results obtained on a real programmable quantum computer.

The aim of QGAN which is the quantum equivalent of GAN learning, is to find a Nash equilibrium in a two player game. One player (the discriminator) generates some output, while the other player tries to determine whether the output is generated by the first player (generator) or comes from an external source. This corresponds to the min-max problem, in which the statistical distance between the outputs of generator and an external source is minimized relative to the generator strategy, while maximizing the distance between the outputs discriminator for generator and an external source relative to the discriminator strategy. It turns out that it is difficult to ensure the stability of the process in this type of optimization. In our work, we consider a conditional equilibrium state. Training such a system is based on increasing the probability of descending to the equilibrium state, which distinguishes it from learning a standard GAN, in which training is done by counting the probability of the system's exit from the equilibrium state.

We propose a new type of machine learning for quantum GANs in which a conceptually simpler problem is solved during training than in the typical QGAN approach. Our approach assumes the reversibility of the discriminator and exploits the relative entropy property and the time reversal property in unitary transformations. In the learning process, we try to minimize the cost function while making the discriminator work correctly.

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Acknowledgments

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Ministry of Education, Youth and Sports of the Czech Republic financing the infrastructure of their workplace. P.T. is supported by the Polish National Science Centre (NCN) under the Maestro Grant No. DEC-2019/34/A/ST2/00081. J.R. acknowledges the internal Palacky University grant DSGC-2021-0026.

Rydberg quantum optics in ultracold Ytterbium gases

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Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons paves the way to realize and control high optical nonlinearities at the level of single photons [1]. Demonstrations of photon-photon gates or multi-photon bound states based on this concept have so far primarily employed ultracold alkali atoms [2,3]. Two-valence electron species, such as Ytterbium, offer unique novel features namely narrow-linewidth laser-cooling, optical detection and ionization, and long-lived nuclear-spin memory states [4].

On this poster, we present our ultracold Ytterbium apparatus designed for few-photon Rydberg quantum optics experiments. The system is optimized for fast production of large, thermal ytterbium samples, to study the interactions between a large number of Rydberg polaritons simultaneously propagating through a medium with extremely high atomic density. Specifically, we discuss our two-chamber setup with 2D/3D two-color MOT configuration, and our progress towards Rydberg excitation of optically trapped Ytterbium atoms.

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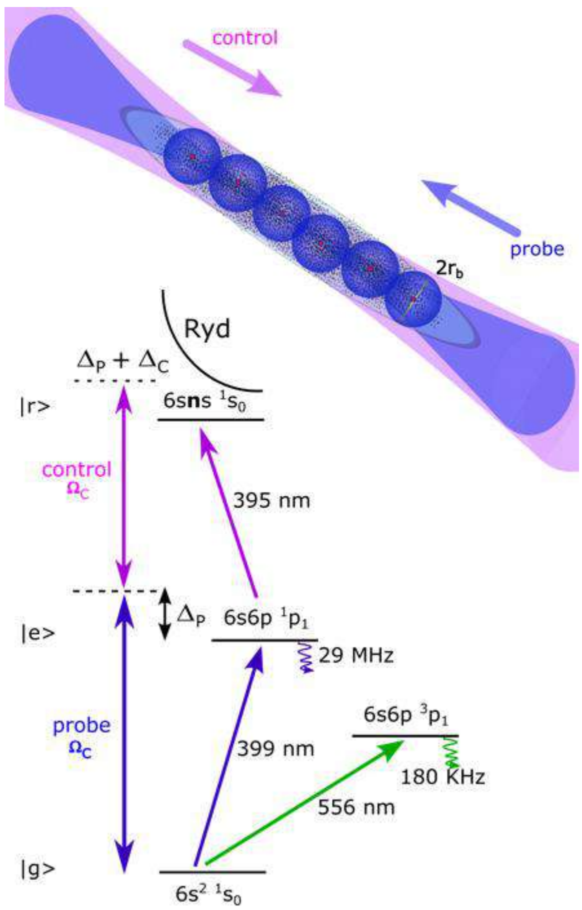

Figure 1: Experimental scheme to generate photon-photon interactions in an Ytterbium gas

Charge Sensing an Andreev Molecule

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Majorana zero modes appear at the ends of a Kitaev chain, which can be engineered by coupling quantum dots (QDs) to superconductors. A two-site Kitaev chain can hold so-called “Poor Man’s Majorana’s” at a fine-tuned spot in parameter space [1, 2]. While not being topologically protected, they do have non-Abelian properties which can be probed in an anion fusion experiment [3]. Pairwise parity readout of Majorana’s is needed to show fusion, which can be done by sensing the charge of a QD coupled to the Majoranas [4]. This requires a sensor dot being able to resolve the charge of a superconductor-semiconductor system. In this talk, we demonstrate charge sensing of an Andreev Bound State (ABS) in a hybrid semiconductor-superconductor nanowire.
First, we show that the charge sensor can detect the change of charge during the singlet-doublet transition of an ABS. Second, we resolve the continuously changing charge of an ABS which remains in the singlet state. Finally, we couple two ABSs and sense the hybridisation of charge of the combined Andreev Molecule. Our results demonstrate that QDs can be used for charge sensing Kitaev chain systems.

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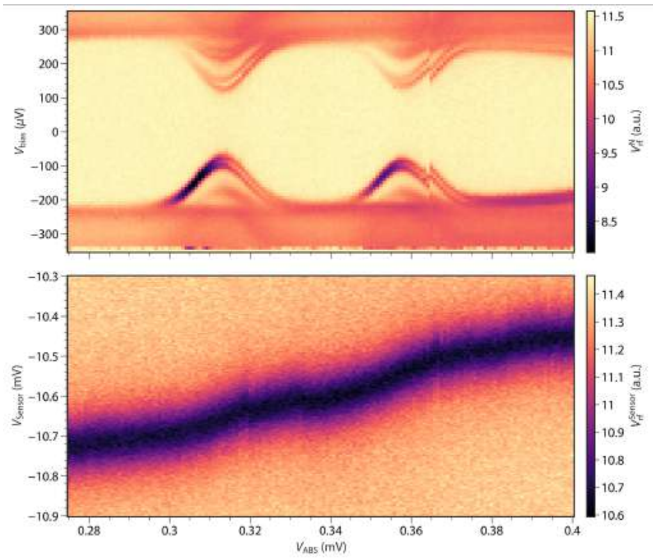

Figure 1: top. RF conductance of an ABS for varying hybrid gate and bias. **Bottom.** Charge sensor response measured simultaneously for varying hybrid gate and sensor gate.

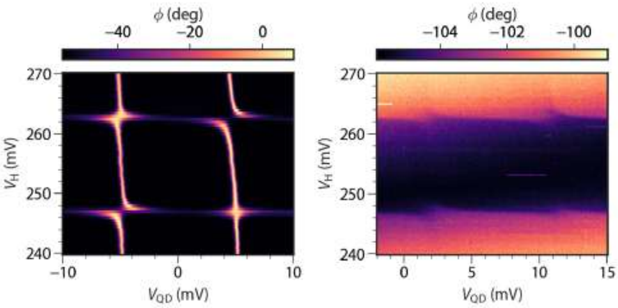

Figure 2: Left. Charge stability diagram measured in reflected phase of two coupled ABSs. **Right.** Charge sensor phase response response of the coupled ABS system.

Hybrid quantum computing with ultracold strontium atoms

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Our project has the goal of building a quantum co-processor as part of a hybrid quantum computer that will be tailored to solving problems in quantum chemistry. This will be experimentally realized by trapping strontium-88 atoms in a 2D array of optical tweezers, generated by a spatial light modulator. As qubit states we plan to use the ground $^1S_0$, and clock state $^3P_0$ of the Sr atom. Transitions between these states will be driven by a 698 nm laser and a strong magnetic field. Site selectivity will be achieved with the use of crossed acousto-optic deflectors and may in the future be expanded upon by using a fiber array for parallel qubit addressing. Global excitations to Rydberg states with a 317 nm laser will be used to generate entanglement between the qubits.

On this poster, we will report on the progress we have made so far on building the experimental setup and loading atoms in a blue and red magneto-optical trap. Further, we report on our future plans of using a pulse-based instead of gate-based approach and making our system available online on the Quantum Inspire platform

Bidirectional Quantum Control

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Quantum devices share the common aspect of being controlled by classical analog signals, related nontrivially to the device operation. The control signals need to be optimally adjusted to provide a high-fidelity operation of the device. A common approach to predicting control signals required to prepare the target quantum state, i.e., the inverse control model, minimizes an ad hoc selected distance metric in the classical control space. However, the values of control signals are given by the technical implementation and are often ambiguous. We propose and experimentally test a novel idea for constructing the inverse control model. We develop an unsupervised-like deep learning approach combining the inverse and direct control models, as depicted in the Figure. The classical control signals play the role of latent variables with no required quantification in the latent space. By minimizing the error in the space of quantum states, various models and devices, even with a different number of control signals, can be optimized and compared. We demonstrate our approach in a use case of polarization state transformation using twisted nematic liquid crystals controlled by several voltage signals. Furthermore, the method is used for local preparation and remote preparation of polarization-encoded qubits with unprecedented accuracy.

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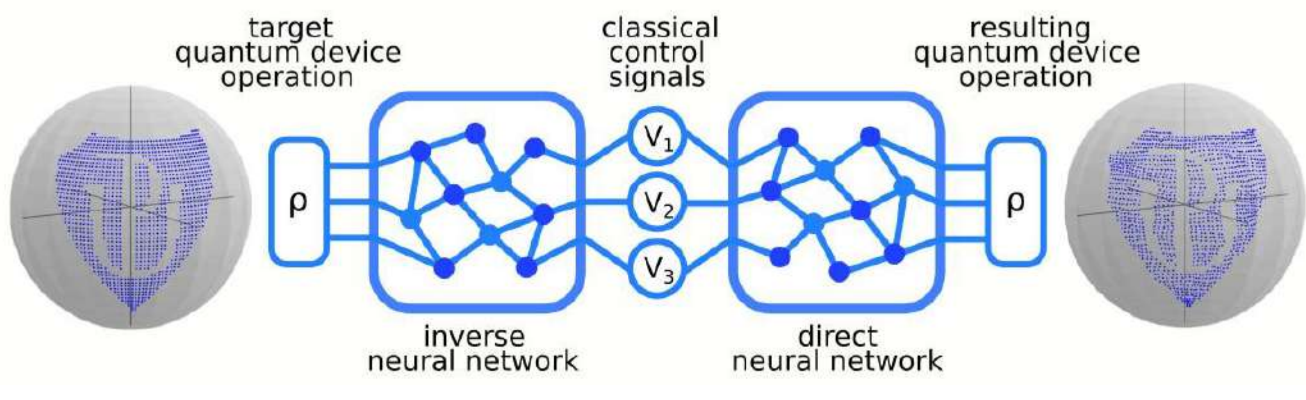

Figure: Representation of the compound neural-network model created by connecting the inverse model to the pre-trained fixed direct model. The input and output Bloch spheres depict the Palacký University logo consisting of hundreds of target and controlled quantum states of a single-photon polarization qubit, respectively.

DISCRETION: Disruptive SDN enabled by QKD for secure communications for European Defence

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In a military context, information and communications services are of central importance in different areas. These services rely on secure and reliable infrastructure. In an operational or strategic context, these networks are often static and rigid. SDN (Software-defined Networking) allows increased network flexibility, agility and manageability. These properties are very desirable on dynamical environments, and the SDN can extend their benefits to interface with SDR equipment, in tactical networks. In addition, SDN can also ensure redundancy and resilience against network failures and losses. The adoption of an SDN also opens the possibility to have a flexible QKD network [1]. QKD provides a very secure way to distribute cryptographic keys to different points. However, QKD is fairly limited in reach and flexibility, usually relying on point-to-point connections and rigid infrastructures. SDN and QKD thus provide mutual benefits in symbiotic fashion: SDN enables a flexible QKD network, with control and monitoring capabilities, and QKD enables highly secure communications within the SDN.

DISCRETION intends to develop an SDN solution integrating QKD capabilities to support optical secure communications, in a way that European Defence can benefit from these technologies to be effective not only for the network but also for the cyber situational awareness. Cipher Machines will be the components responsible for assuring data protection and network segregation in DISCRETION, enabling real-time data encryption and decryption, using key material provided by the key management system integrated with the SDN-QKD plane as well as pre-shared keys. The red-black architecture of the military networks will be considered to provide the required level of security and segregation. Mobility and tactical scenarios with SDR solutions shall be analysed and integrated into the SDN framework to cover radio network segments and support secure communication services in mobile scenarios (see **Figure 1**). The DISCRETION project, with its programmable quantum key distribution components, will facilitate the improvement of security and resilience in the exchange of information and in communication services in the miliary network.

Figures

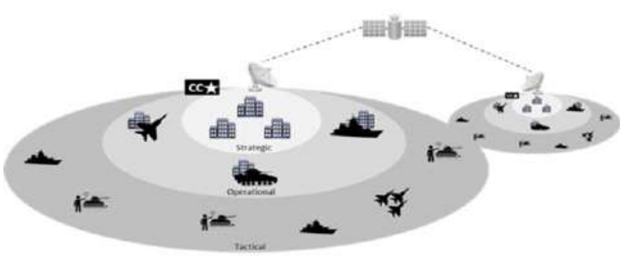

Figure 1: DISCRETION overall abstract scenarios

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A novel approach to noisy gates for simulating quantum computers

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Abstract

We present a novel method for simulating the noisy behaviour of quantum computers, which allows to efficiently incorporate environmental effects in the driven evolution implementing the gates on the qubits. We show how to modify the noiseless gate executed by the computer to include any Markovian noise, hence resulting in what we will call a noisy gate. We compare our method with the IBM Qiskit simulator, and show that it follows more closely both the analytical solution of the Lindblad equation as well as the behaviour of a real quantum computer, where we ran algorithms involving up to 18 qubits; thus, it offers a more accurate simulator for NISQ devices. The method is flexible enough to potentially describe any noise, including non-Markovian ones.

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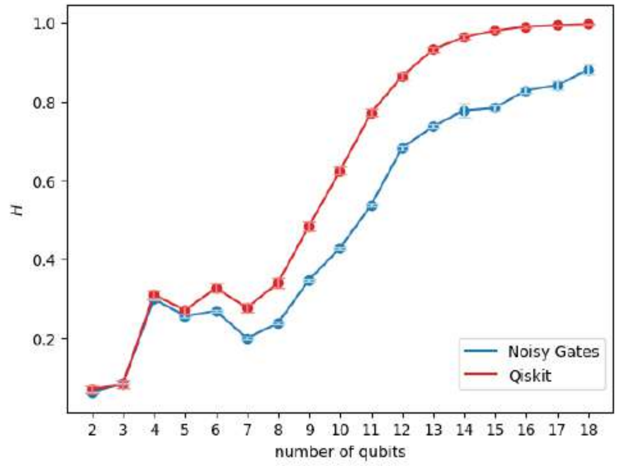

Figure 1: Hellinger Hellinger distance for the $QFT^\dagger$ algorithm for n = 2, . . . , 18 qubits. Each value is the mean of 100 independent simulations for the noisy gates, in blue, and for the Qiskit simulations, in red.

Cavity-assisted generation of steady-state entanglement between non-identical quantum emitters

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Common wisdom suggests that, in order to entangle two quantum emitters, it is desirable that these have identical natural frequencies, since this facilitates cross talk between them and enables the type of collective dynamics that leads to entanglement [1]. However, the fabrication of quantum emitters with identical properties is a significant challenge in solid state physics.

In this work, we show that the condition of identical transition frequencies can be completely relaxed and that one can achieve maximum values of steady-state entanglement between non-identical quantum emitters by driving the two-photon resonance of the composite system. When the two emitters are interacting, this driving enables coherent two-photon Rabi oscillations between the ground and the doubly-excited state; this resonance has been exploited, e.g., to estimate interaction strengths and inter-molecular distances between molecules at the nanometer scale [2]. Under a strong two-photon drive, the emitters can be dressed with photon pairs from the laser, developing a rich family of energy levels that translate into a complex structure in the spectrum of resonance fluorescence [3].

By coupling the dressed system to a cavity in the bad cavity limit, new processes among the two-photon dressed energy levels can be engineered. By placing particular dressed-state transitions in resonance with the cavity, these novel decay processes can stabilize the system into a highly entangled state. Since the energy of the dressed states can be tuned through the Rabi frequency of the drive, the system can be optically tuned in and out of these resonances, so that entanglement can be optically controlled. We also show that the stabilization of entanglement translates into particular features in the quantum optical properties of the light emitted by the system at frequencies that are well detuned from the drive, allowing to isolate the optical signatures of entanglement by simple spectral filtering.

Notably, we show that, even when the interaction between emitters is weak or non-existing, driving at the two-photon resonance can also lead to stabilization of maximally entangled state if the Purcell enhancement provided by the cavity is high enough.

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Counterdiabatic Corrections to the Quantum Approximate Optimization Algorithm

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Abstract

The Quantum Approximate Optimization Algorithm (QAOA) is a promising hybrid quantum-classical algorithm that can solve combinatorial optimization problems [1]. The quantum part of the algorithm involves using parametric unitary operations on a quantum computer to prepare a trial solution state. The parametric QAOA angles are variationally optimized minimizing a cost function using classical methods. Generalizing the results on ref. [2], we study a generalized QAOA ansatz that includes corrections to the Trotter expansion at the first and second order based on the Baker-Campbell-Hausdorff (BCH) expansion [3]. By utilizing terms in the BCH expansion as additional control unitaries, each with its own angle, we can improve convergence compared to standard QAOA (Figure 1). The additional angles are treated as independent free parameters, rather than keeping them fixed to the prescription of the BCH expansion, resulting in a cost function simpler to deal with (Figure 2).

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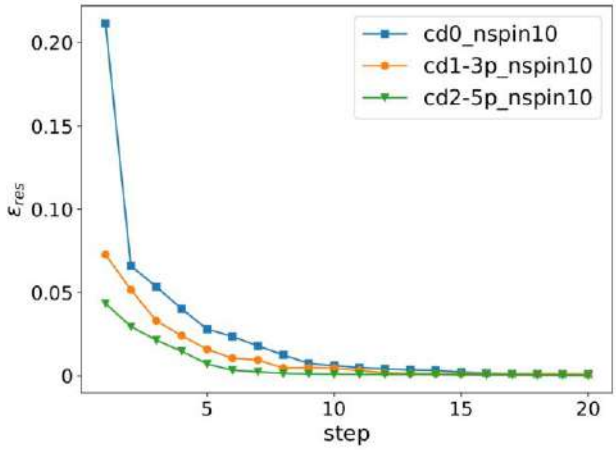

Figure 1: Residual energy (ε_{res}) for a 10-spin chain with random couplings and open boundary conditions vs number of QAOA steps. We see that, each step, the generalized QAOA ansatzes (cd1-3p and cd2-5p) yield smaller residual energies than the standard ansatz (cd0).

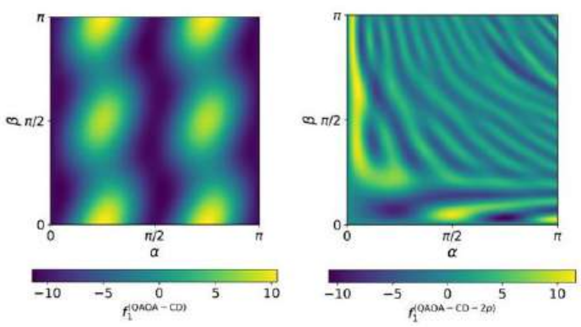

Figure 2: Cost function of the generalized QAOA ansatz including first-order BCH correction at step p = 1. Left panel: free BCH angle. Right panel: constrained BCH angle. The cost function landscape is evidently rougher in the right panel.

Fast High Fidelity Operation of Fluxonium Qubits

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Estimates for error corrected quantum computation with today's state of the art qubits indicate a two to three orders of magnitude overhead in the physical to logical qubit ratio [1]. This demand can be significantly reduced by building better underlying physical qubits. In particular, entanglement and measurement operations are currently prone to errors.
Due to its simplicity, the Transmon qubit is the widespread choice for state of the art superconducting quantum processors [2]. Nevertheless, in the last years it became clear that this simplicity comes at the expense of serious trade-offs. Thus, the community now dedicates significant efforts towards building novel circuits that promise higher fidelities on all operations.
Here we present our recent results on building Fluxonium qubits that excel in three key aspects when compared to Transmons [3]. We demonstrate the primary advantage of an increase in T_1- and T_2^*-times through a reduced transition frequency and smaller dipole matrix element. Secondly, leakage is highly supressed since the computational states are more isolated arising from to the large qubit anharmonicity above 1 GHz. This allows us to perform single qubit gates with a fidelity of 99.97%. We evaluate our gates using randomized benchmarking with a so-called restless protocol that eliminates the need for a reset and enables cycling times above 100 kHz. To significantly reduce the control line overhead in future devices we combine the flux and microwave-drive line without showing degradation in qubit gate fidelities [4].
The readout of Fluxonium qubits is performed through a mediated coupling between higher qubit states and the resonator levels. This results in a rich dispersive shift landscape that can be exploited for fast qubit readout. We discuss methods on how a flux pulse to an operating point with high dispersive shift can shorten and improve the readout fidelity. In combination with a mid-circuit active feedback, a measurement induced reset is realized. In addition, we report on our efforts to scale up the number of qubits and readout multiple qubits simultaneously.

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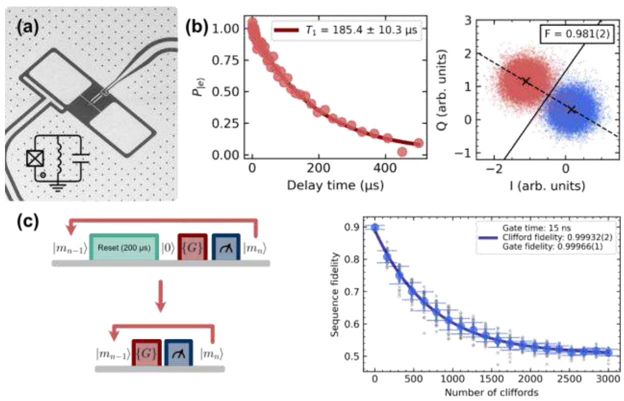

Figure 1: (a) Microscope image of Fluxonium made of Niobium sputtered on a Silicon substrate. Insert shows the Fluxonium circuit. **(b)** Measured T_1-time and readout assignment fidelity. **(c)** Comparison of standard sequence with the reset-free restless protocol. Measured randomized benchmarking for a 15 ns long single qubit gate.

Enhancing Spatial Sensitivity of Multiple NV Centers in Diamonds Using Rabi Oscillation

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Abstract (Century Gothic 11)
The Nitrogen-Vacancy (NV) center in diamonds holds great promise for quantum sensing applications. Accurately pinpointing the NV center's location within the diamond lattice is crucial for successful sensing. Traditionally, researchers usually scan and determine the location of a single NV center by measuring Photoluminescence(PL) intensity and fitting the map with a gaussian function.
In this work, we present a method for enhancing spatial sensitivity on multiple NV centers by using electron spin resonance (ESR). We measure the optically detected magnetic resonance(ODMR) at the maximal PL intensity spot of the multiple single centers to determine the resonance frequencies of the single NV centers in four orientations. Then, we scan the multiple NV centers spatially and measure Rabi oscillation with different resonance frequencies as carrier frequencies in three-dimensional space. After fitting Rabi curves with the cosine function, we get Rabi amplitudes. We build up a 3D map as the amplitude function of the space. Finally, we demonstrate the effectiveness of our method by comparing the amplitude map and the PL map.
Our results show a clear improvement in locating NV centers in different orientations, allowing us to accurately enhance the spatial resolution of the NV center in multiple NV centers. This work represents an important step towards the development of NV center-based quantum sensors with improved precision and sensitivity. By accurately determining the location of the NV center in each orientation, we can optimize NV center performance for a wide range of sensing applications.

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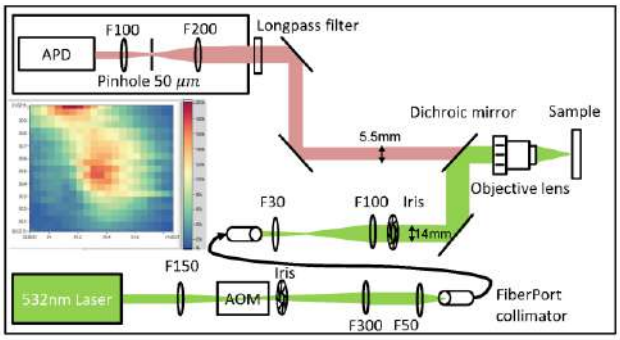

Figure 1: Schematic of the confocal microscope for initializing and detecting single NV centers. The inset shows an image of the single NV center we used in the experiment.

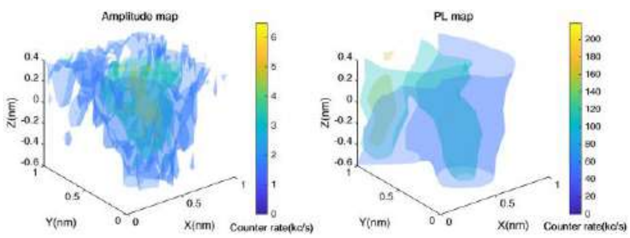

Figure 2: The amplitude and PL map with the 2792.4 MHz carrier frequency. The spatial range along x, y, and z axis are 1 mm. The increments along x, y, and z axis are 0.05, 0.05, 0.2mm.

Supercurrent-mediated coupling between two Andreev spin qubits: experimental data

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Semiconducting spin qubits are currently one of the most promising architectures for quantum computing. However, they face challenges in realizing high-fidelity quantum non-demolition readout and multi-qubit interactions over extended distances. A recent alternative, the Andreev spin qubit (ASQ), has emerged with realizations in InAs/Al hybrid nanowire Josephson junctions [1,2]. In these qubits, the spin degree of freedom is intrinsically coupled to supercurrent via the spin-orbit coupling. The spin-dependent supercurrent of ASQs facilitates qubit readout using circuit quantum electrodynamics (cQED) techniques, as recently demonstrated and can facilitate inductive multi-qubit coupling via a shared inductance [3].
Here, we investigate the supercurrent-mediated coupling between two ASQs in separate SQUID loops that share a third gate-tunable Josephson junction. To experimentally investigate the coupling between the two ASQs, we use a nanowire transmon. The transmon Josephson energy is effectively set by the state of the two ASQs in the SQUID loops which leads to a spin-state-dependent transition frequency of the transmon. By dispersively coupling the transmon to a readout resonator we can spectroscopically probe the ASQ using conventional microwave techniques developed for cQED. We explore the dependence of the ASQ-ASQ coupling strength on the gate-tunable inductance of the coupling junction and on the flux through the SQUID loops. Finally, we compare the result to the expectations from our theoretical modelling.

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Figures

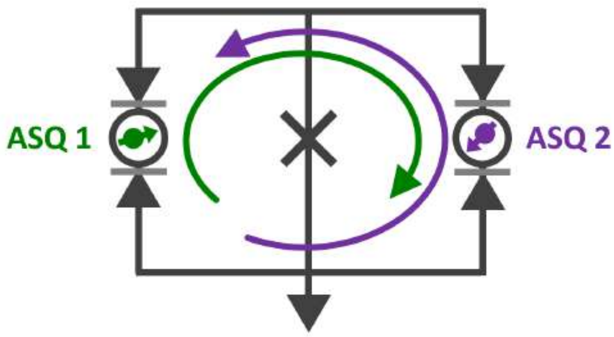

Figure 1: Circuit model of the device showing two Andreev spin qubits and a coupling Josephson junction in parallel.

Dual-type Dual-element Atom Array for Quantum Computation and Simulation

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Quantum science promises great potential to revolutionize our current technologies. The past few years have witnessed a rapid progress on using arrays of individually trapped atoms as a programmable quantum processor [1]. However, several predominant challenges remain, including reconfigurable individual addressability for qubit/spin operation and non-demolish selective detection, which lead to limited efficiency in implementing quantum algorithm, low experimental repetition rate, and preclude applications of many quantum error correction protocols. Here, we are building a novel architecture that sidesteps these challenges and enable experimental study on frontier topics in quantum information dynamics, with the long-term goal aiming for a fault-tolerant general-purpose quantum computer. This architecture combines an array of individually trapped ytterbium atoms and an array of rubidium atomic ensembles in a bilayer structure, with each layer has its own unique functionality and the interlayer interaction can be tuned with external electric field rapidly via Förster resonance. Spins/qubits are encoded with the electronic states of Yb atoms, while the Rb atomic ensembles perform ancillary operations on the nearby Yb atoms, including rapidly reconfigurable local qubit operation, and fast, non-demolish detection. With these newly developed techniques, this platform can implement previously inaccessible protocols on efficient generation of target quantum states, and is compatible with quantum error correction.

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Figure

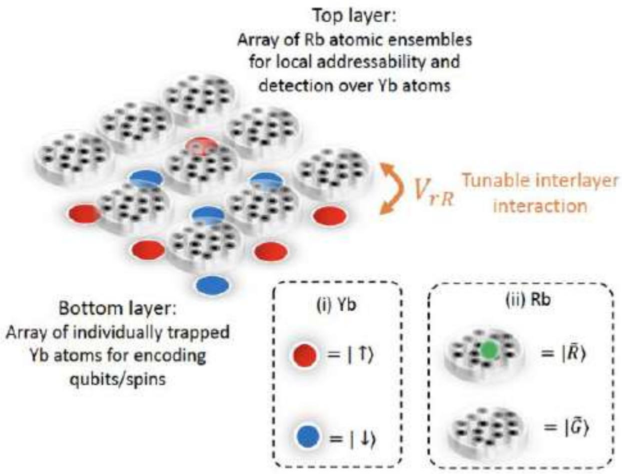

Figure: A sketch of the proposed dual-type dual-element atom array in a bilayer structure. The architecture consists of two types of arrays with different functionality: the bottom array is made with individually trapped atoms, in which the quantum information is encoded (inset (i)). The top layer is an array of small Rb atomic ensembles. Each ensemble has ~500 Rb atoms inside, with the radius of each atomic ensemble as 2um. These ensembles can facilitate local addressability over Yb atoms, and perform non-demolition, rapid readout via controllable interlayer interactions.

Atomically precise graphene nanoribbons for quantum electronics

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Atomically precise graphene nanoribbons (GNRs) have attracted much interest from researchers worldwide, as they constitute an emerging class of quantum-designed materials tailored by controlling their width and edge structure during chemical synthesis [1-3]. The major challenges toward their exploitation in electronic applications include reliable contacting, complicated by their nanometer size, and the preservation of their intrinsic physical properties upon device integration [4]. Here, we report on the device integration of armchair GNRs into various device architectures with different electrode materials [5]. First, we demonstrate an improved tunability of GNRs quantum dot (QD) behavior thanks to multiple nanometer-sized gates [6]. Second, beyond graphene-based contacts, we demonstrate the successful contacting and characterization of individual GNRs using single-walled carbon nanotubes (SWNT) electrodes and multiple gates. We observe well-defined quantum transport phenomena, including Coulomb blockade, excited states, and Franck-Condon blockade, indicating that a single GNR was contacted [7]. In addition, we demonstrate the encapsulation of GNRs in hexagonal boron-nitride and the contacting using metallic side contacts. These experimental realizations of advanced contracting and gating pave the way for the integration of GNRs in quantum devices to exploit their topologically trivial and non-trivial nature.

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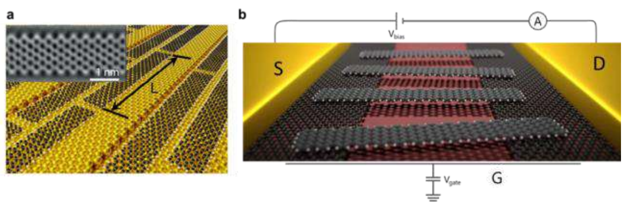

Figure 1: Atomically precise GNRs and their device integration. (a) Atomically precise GNRs illustrated by a sketch and a scanning tunneling microscopy image (inset). (b) Integration of GNRs into devices for transport measurements.

Optimization of the Experimental Generation and Measurement of High Dimensional Light States

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The engineering of high-dimensional quantum states (*qudit*) is a pivotal task in quantum information applications, since exploiting such states it is possible to increase the amount of information exchanged between parties and to enhance the security of cryptographic schemes. In photonic implementations, qudits can be encoded using the Orbital Angular Momentum (OAM) of photons. This is an internal and infinite-dimensional degree of freedom of light with several applications both in classical and quantum optics. However, to fully exploit the potential of OAM, reliable generation and measurement platforms are needed.

In our works [1,2], we present approaches for optimize the generation and for reliably detect OAM states. In both cases, we used the photonic implementation of a quantum walk (see Fig. 1) which has been proved capable of generate arbitrary OAM qudits [3].

In particular, in the generation stage [1] we adopted a black-box algorithm to optimize the production of OAM states both in classical and quantum regime, automatically accounting in this way for experimental imperfections. Instead, in the measurement phase [2], we performed a machine learning-based regression task for the reconstruction of the coefficients of the state under analysis, combining a dimensional reduction algorithm and a linear regressor. The high value of the fidelities, obtained averaging over several states, showcases the performance of both the approaches and indicates how they represent powerful tools for the implementation of quantum information protocols.

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Figures

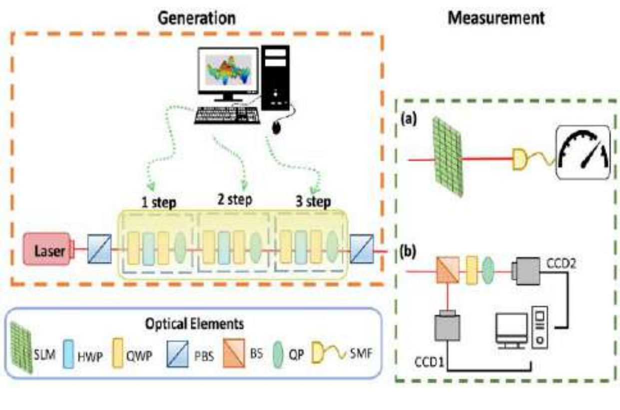

Figure 1: Experimental setup, (a) generation optimization and (b) machine learning-based measurement. SLM = Spatil Light Modulator, HWP = half-wave plate, QWP = quarter-wave plate, PBS = Polarizing Beam Splitter, BS = Beam Splitter, CCD = Charge Coupled Device, SMF = Single Mode Fiber.