GDR de Physique Quantique Mésoscopique

Réunion plénière

27-30 Nov 2023

Centre Paul Langevin, Aussois

Organizers

Audrey Bienfait, Landry Bretheau, Marie-france Mariotto

Schedule

Monday, November 27

14:10 Welcome

<u>**Session 2D materials**, chair : Everton Arrighi</u>

14:20 **Vanishing bulk heat flow in the $\nu = 0$ quantum Hall ferromagnet in monolayer graphene** - François Parmentier - CEA-Saclay

14:55 **Magnetic Field Driven Quantum Phases in Magic-angle Twisted Bilayer Graphene** - Ipsita Das - LMU Munich

15:30 **Electron collisions in a Graphene Interferometer** - Leo Pugliese - CEA-Saclay

16:00 **Electron-photon Chern number in cavity-embedded 2D moiré materials** - Danh Phuong Nguyen - MPQ Paris

16:30 Pause café

<u>**Session semi-superconductors**, chair : Caglar Girit</u>

17:00 **Extended Bose-Hubbard model with dipolar excitons** - Camille Lagoin - CRHEA Nice

17:35 **Calorimetry of a phase slip in a Josephson junction** - Efe Gumus - Institut Néel Grenoble, now at Alice&Bob

18:10 **Near-power-law temperature dependence of the superfluid stiffness in strongly disordered superconductors** - Anton Khvalyuk - LPMMC Grenoble

19:00 Diner

20:30 Session Poster

Tuesday, November 28

Session Anyons I, chair : Hadrien Duprez

08:45 **Tutoriel - Anyonic exchange on the edge of a fractional quantum Hall state** - Gwendal Fève - LPENS Paris & Christophe Mora - MPQ Paris

10:00 **Signature of anyonic statistics in the integer quantum Hall regime** - Anne Anthore - C2N, Palaiseau

5mm] 10:30 Pause café

Session Anyons II, chair : Giacomo Rebora

11:00 **Time-domain braiding of anyons** - Mélanie Ruelle - LPENS, Paris

11:30 **Anyonic Braiding and Andreev-like Processes in the Fractional Quantum Hall effect** - Kishore Iyer - Centre de Physique Théorique Marseille

12:00 **Tunable Edge Magnetoplasmon Resonator** - Elric Frigerio - LPENS, Paris

12:30 Déjeuner

Session Mesoscopic Superconductivity I, chair : Clemens Winkelmann

14:00 **Floquet-Andreev resonances in hybrid superconducting systems** - Andriani Keliri - LPTHE, Paris

14:35 **Non-local Josephson effect in carbon nanotubes** - Samy Annabi - LPMC, Palaiseau

15:05 **Tunable charge-4e supercurrent in germanium based JoFET** - Axel Leblanc - PHELIQS, Grenoble

15:35 **Microwave Photon to Electron Conversion Using a High Impedance Quantum Circuit** - Ognjen Stanisavljevic - LPS, Orsay

16:05 Pause café

Session Mesoscopic Superconductivity II, chair : Olesia Dmytruk

16:25 **Josephson diode effect in Andreev molecules** - Jean-Damien Pillet - LPMC, Palaiseau

17:10 **Interaction-driven quantum phase transition of a single magnetic impurity in Fe(Se,Te)** - Mateo Uldemolins - LPS, Orsay

17:40 **Poor man's Majorana states in coupled quantum dots** - Guanzhong Wang - TU Delft

18:05 **Superconductivity and the normal state's quantum geometry: a conflicting influence** - Florian Simon - LPS, Orsay

19:00 Dîner

20:30 Session Posters

Wednesday, November 29

<u>**Session High-impedance cQED**, chair : Cécile Naud</u>

08:40 **Tutoriel : Novel manifestations of the Josephson effect in a high-impedance environment** - Vladimir Manucharyan - EPFL, Lausanne

09:35 **Exact reduced density matrix of a Resistively Shunted Josephson junction** - Philippe Joyez - SPEC, CEA Saclay

10:05 **Circuit QED theory of dual Shapiro steps for a Josephson junction coupled to a high-impedance transmission line resonator** - Federico Borletto - MPQ, Paris

10:35 Pause café

<u>**Session Superconducting circuits**, chair : Danijela Markovic</u>

11:00 **Long-lived quantum memories using 3D niobium cavities** - Fabien Lafont - Weizmann Institute

11:35 **Transmon qubit readout using a nonlinear cross-Kerr interaction: QNDness versus readout photon number** - Cyril Mori - Institut Néel, Grenoble

12:05 **Landau-Zener-Stückelberg-Majorana interferometry without two-level systems** - Léo Peyruchat - EPFL, Lausanne

12:35 Déjeuner

14:00 Temps libre

<u>**Session Topology**, chair : Alexandru Petrescu</u>

16:00 **Fragility of spectral flow for topological phases in non-Wigner-Dyson classes** - Luka Trifunovic - LPT Toulouse

16:35 **Topological and non-topological degeneracies in string-net models** - Jean-Noël Fuchs - LPTMC, Paris

17:05 **Revealing topological hinge states in the second order topological insulator Bi4Br4** - Jules Lefeuvre - LPS Orsay

17:35 **Room-temperature anomalous planar Hall effect from topological nodal-lines in PtBi2** - Arthur Veyrat - LPS Orsay

18:05 **Discussion GDR** - Guillaume Weick

18:20 **In memoriam - Laurent Saminadayar** - David Carpentier

19:00 Dîner

Thursday, November 30

Session Quantum states manipulation I, chair : Carles Altimiras

08:40 Tutoriel: **Skyrmion-Based Quantum Computing: Challenges For Future Applications** - Christina Psaroudaki - LPENS, Paris

09:35 Reconstructing the potential configuration in a high-mobility semiconductor heterostructure with scanning gate microscopy - Dietmar Weinmann - IPCMS, Strasbourg

10:05 Pause café

Session Quantum states manipulation II, chair : Emmanuel Flurin

10:25 **Surface Acoustic Wave phonons, mediator of quantum interactions** - Etienne Dumur - PHELIQS, Grenoble

11:00 **Nonclassical mechanical states in cavity optomechanics in the strong coupling regime** - Jonathan Wise - LOMA Bordeaux

11:30 **Coherent hole spin qubit shuttling in germanium: quantum links and high-fidelity quantum logic** - Corentin Déprez - TU Delft

12:00 Déjeuner - Panier repas et départ des bus à 13h

Liste des participants

A

Allard Thomas

Altimiras Carles

Aluffi Matteo

Annabi Samy

Anthore Anne

Arrighi Everton

Ayache Raphaël

B

Bard Matthieu

Basset Julien

Bernabeu Lou

Bienfait Audrey

Bocquet Adrien

Borici Dalin

Borletto Federico

Bretheau Landry

Bugaud Lucas

Buisson Olivier

C

Caceres Ramirez Joan Joel

Calmels Brian

Calvo Florent

Carles Baptiste

Carpentier David

D

Cécile Naud

D'antuono Maria

Das Ipsita

Datta Anushree

Deblock Richard

Demazure Noé

Déprez Corentin

Desort Thibaut

Dmytruk Olesia

Dubovitskii Kirill

Dudas Julien

Dumur Étienne

Duprez Hadrien

F

Ferrier Meydi

Fève Gwendal

Flurin Emmanuel

Frigerio Elric

Fuchs Jean-Noël

G

Gabelli Julien

Gallego Lacey Oliver Nicholas

Gennser Ulf

Ghazouani Gharbi Oussama

Giacomelli Luca

Girit Çağlar

Goerbig Mark Oliver

Goffman Marcelo

Gorini Cosimo

Groth Christoph

Gueron Sophie

Gumus Efe

H

Hantute Maxime

Höfer Johannes

Houzet Manuel

J

Joyez Philippe

K

Iyer Kishore

Keliri Andriani

Khvalyuk Anton

Kumar Prasoon

L

Lafont Fabien

Lagoin Camille

Le Sueur Hélène

Leblanc Axel

Lefeuvre Jules

Lefloch François

Lorriaux Tristan

Loucif Sara

M

Maillet Olivier

Manucharyan Vladimir

Marganska Magdalena

Marguerite Arthur

Mariotto Marie-France

Markovic Danijela

May Alexandre S.

Mazzella Lucas

Meidan Dganit

Meyer Julia

Mohapatra Sambit

Montambaux Gilles

Mora Christophe

Mori Cyril

Morin Romy

Moulinas Adrien

N

Nabil Reda

Nguyen Danh Phuong

O

Orignac Edmond

Ouacel Mohamed Seddik

P

Parmentier François

Petrescu Alexandru

Peyruchat Léo

Piéchon Frédéric

Pillet Jean-Damien

Pothier Hugues

Pradas Sergi

Psaroudaki Christina

Pugliese Leo

R

Rebora Giacomo

Rech Jérôme

Renard Julien

Riechert Hannes

Roche Patrice

Ronetti Flavio

Rospars Adria

Roverc'h Erwan

Ruelle Mélanie

S

Safi Inès

Seyve Lilian

Shaju Jashwanth

Simon Florian

Stanisavljevic Ognjen

T

Trifunovic Luka

U

Uldemolins Mateo

V

Vakhtel Tereza

Vasselon Thomas

Veillon Alexandre

Veyrat Arthur

W

Wagner Alexander

Waintal Xavier

Wang Guanzhong

Weick Guillaume

Weinmann Dietmar

Winkelmann Clemens

Wise Jonathan

Wolff Joanna

Z

Zhang Aifei

Abstracts

Entropy measurement of a few carriers in a bilayer graphene quantum dot

Christoph Adam [1], Hadrien Duprez * [1,2], Solenn Cances [1], Antoni Iglesias [1], Natalie Lehmann [1], Takashi Taniguchi [3], Kenji Watanabe [3], Klaus Ensslin [1], Thomas Ihn [1]

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The entropy of a non-interacting system directly reflects its number of accessible micro-states. Using an entropy to charge conversion scheme, that hinges on one of the Maxwell relations, it is possible to experimentally access the entropy of an electronic system possessing a large charging energy. We directly measured the entropy of the ground state of one and two charge carriers in an electro-statically defined quantum dot in bilayer graphene, where the valley degree of freedom plays an important role. We also studied the perpendicular magnetic field dependence of the measured entropy and supported it with excited states spectroscopy measurements.

*Speaker

Multiple polaritonic edge states in a dimerized chain of dipoles strongly coupled to a multimode cavity

Thomas Allard * [1]

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A key challenge in the growing field of topological photonics is to understand the interplay between the physics of topological phases of matter, such as the remarkable presence of topological edge states robust against perturbations, and the one of strong light-matter coupling, which has been shown to significantly modify materials properties (1).

To this end, in this work, we study a dimerized chain of oscillating dipoles strongly coupled to a multimode optical waveguide cavity (2). By integrating out the photonic degrees of freedom of the cavity, the system is recast in a two-band model with an effective longer range coupling, so that it mimicks a variation of the paradigmatic Su-Schrieffer-Heeger model, which features a nontrivial topological phase and hosts topological edge states.

In the strong coupling regime, the cavity photons hybridize the bright, upper, dipolar bulk band into a polaritonic one, renormalizing the eigenspectrum and strongly breaking the chiral symmetry. This leads to a formal loss of the mid-gap edge states present in the topological phase, with their merging into the polaritonic bulk band. Interestingly, however, we find that bulk polaritons entering in resonance with the edge states inherit part of their localization properties, so that multiple polaritonic edge states are observed. Although these states are not fully localized on the edges, they present unusual properties. In particular, due to their polaritonic nature, such edge states exhibit efficient edge-to-edge transport characteristics. Instead of being degenerate, polaritonic edge states occupy a large portion of the spectrum, allowing one to probe them in a wide driving frequency range. Moreover, being reminiscent of symmetry protected edge states, they feature a strong tolerance to positional disorder.

(1) F. J Garcia-Vidal, C. Ciuti, and T. W. Ebbesen, Manipulating matter by strong coupling to vacuum fields, Science 373, eabd0336 (2021)

(2) C. A. Downing, T. J. Sturges, G. Weick, M. Stobinska, and L. Martin-Moreno, Topological phases of polaritons in a cavity waveguide, Phys. Rev. Lett. 123, 217401 (2019).

*Speaker

Ultrashort electron wavepackets via frequency-comb synthesis

Matteo Aluffi * [1], Thomas Vasselon [1], Mohamed Seddik Ouacel [1], Hermann Edlbauer [1], Clément Geffroy [1], Preden Roulleau [2], Christian Glattli [2], Giorgos Georgiou [3], Christopher Bauerle [1]

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Single-electron sources play a crucial role in modern nanoelectronic devices, enabling a new area of research known as electron quantum optics. A promising possibility to implement a single-electron source is to use a single-charge Leviton, obtained by applying a Lorentzian voltage pulse to the Fermi sea of a quantum conductor (1). For electron quantum optics applications, voltage pulses with widths in the range of picoseconds are necessary. However, current arbitrary waveform generators are not yet capable of generating such pulses. In this work, we introduce a novel signal generator based on Fourier synthesis, which can produce Lorentzian voltage pulses with a width down to 25 ps. We demonstrate the capabilities of our device by using it to generate an electron wavepacket in the 2-dimensional electron gas (2DEG) of an electronic Mach-Zehnder interferometer (MZI). We employ pump and probe techniques to characterize the wavepacket in a timeresolved manner as it propagates through the Fermi sea of our quantum device. We report on the detection of a 27 ps Lorentzian wavepacket, the shortest reported to date (2), paving the way for future application as a single-electron source for flying-electron qubits (3,4).

(1) J. Dubois et al., Nature 502, 659 (2013).

(2) M. Aluffi et al., Phys. Rev. Appl. 20 056 503 (2023).

(3) C. Bäuerle et al., Rep. Prog. Phys. 81 056503 (2018).
(4) H. Edlbauer et al., EPJ Quantum Technol. 9, 21 (2022).

*Speaker

Non-local Josephson effect in carbon nanotubes

Samy Annabi * [1], Hannes Riechert , Everton Arrighi , Joël Griesmar , Landry Bretheau† , Jean-Damien Pillet‡

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Andreev bound states (ABS) are fermionic states localized at the weak link of a Josephson junction. They carry a supercurrent that flows coherently through the device with an amplitude depending on the superconducting phase difference δ across the junction: it's the Josephson effect. When two Josephson junctions are sufficiently close to each other compared to the superconducting coherence length, the ABS wavefunctions hybridize forming an Andreev molecule and the Josephson effect becomes non-local: the supercurrent flowing through one junction not only depends on the phase difference across this junction, but also on the phase difference across the other junction. We present here the experimental observation of such an effect in carbon nanotube-based Josephson junctions. The device was fabricated using a novel assembly technique involving carbon nanotube pick-up with hexagonal boron nitride, yielding remarkably clean samples.

*Speaker

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Signature of anyonic statistics in the integer quantum Hall regime

Anne Anthore * [1], Pierre Glidic , Colin Piquard , Ivana Petkovic , Abdel Aassime , Ulf Gennser , Frédéric Pierre

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Anyons are exotic low-dimensional quasiparticles whose unconventional quantum statistics, different from bosons and fermions, is predicted to unlock topologically protected quantum computing. The fractional quantum Hall regime provides a natural host, with first convincing anyon signatures recently observed experimentally through interferometry and cross-correlations of colliding beams. However, the fractional regime is fraught with experimental complications, such as an anomalous tunneling density of states, which hamper the manipulation of anyons. In this talk, I will show that the canonical integer quantum Hall regime can provide a robust anyon platform. Due to the Coulomb interaction between two co-propagating quantum Hall channels, when an electron tunnels into one channel, it generates two wave-packets behaving as fractional anyons. Their unconventional anyonic statistics is revealed by negative cross-correlations between diluted beams.

*Speaker

Superconducting weak link frequency multiplication : a fingerprint of the current-phase relationship

Lou Bernabeu * [1]

[1] Quantronics group, CEA Saclay – Service de Physique de l'Etat Condensé (SPEC) - IRAMIS – France

Superconducting weak links are components corresponding of two weakly coupled superconducting leads. Such weak links function as nonlinear inductive elements ; their behavior is determined by their current-phase relationship (CPR) that links Cooper pair flow through the element to the phase difference between the leads' superconducting condensates. Determining the CPR of a weak link gives a full characterization its behavior, giving acces to the number of conduction channels and their transmission. Most in situ characterization methods use DC quantities and phenomena, such as Andreev reflections, to determine the number of channels and their transmission in a weak link.
Due to their non-linearity, weak links driven by a monochromatic sine wave voltage emit harmonics of the microwave tone, whose amplitude depends on the weak link's CPR as well as the incoming microwave tone. By studying the amplitude of a single emitted harmonic, we determine that it contains a complete and retrievable fingerprint of the CPR in the form of its Fourier coefficients. We also notice that the emission of even-order vs. odd-order harmonics is dictated by a constant phase offset factor that may develop naturally at the weak link. we also propose two ways to retrieve the weak CPR's Fourier coefficient by measuring the emission of a single harmonic of the drive tone. One involves taking an appropriate transform of emission as a function of input power; the other one adjusts the constat phase offset by a flux bias and uses flux traces. **These characterization methods would use no DC contacts, leaving a clean low-frequency RF environment**. Design and fabrication of samples to test the methods are underway.

*Speaker

Circuit QED theory of dual Shapiro steps for a Josephson junction coupled to a high-impedance transmission line resonator

Federico Borletto *† [1], Luca Giacomelli [1], Cristiano Ciuti [1]

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We present a theory (1) describing the direct and dual Shapiro steps of a Josephson junction coupled to a multi-mode transmission line resonator. In particular, our theoretical framework is based on a multi-band mean-field treatment of the Josephson Bloch-like dynamics in the presence of both ac and dc driving fields. We show how the metrological quality of the dual Shapiro step quantization depends on the relevant physical parameters of the Josephson junction (capacitive and inductive energies) and of the transmission line (impedance, free spectral range,..), as well as of the driving fields and temperature.

(1) F. Borletto, L. Giacomelli, C. Ciuti, in preparation

*Speaker

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Realizing an universal electron spin resonance spectrometer using superconducting microwave resonators

Matteo Boselli , Benjamin Huard , Audrey Bienfait * [1]

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Electron paramagnetic resonance (EPR) is an exquisite tool to analyze and characterize unpaired electrons in a substance. Its wide application in chemistry and pharmaceutical research, biology and physics boosts an active field of research in EPR development. The implementation of superconducting quantum circuits to measure the EPR response has shown to enhance the spin detection sensitivity down to a few spins (_˜20) on a nanoscale volume _˜100fL – a gain of five orders of magnitude compared to the state-of-the-art. The unprecedented sensitivity originates from small mode-volume and narrow line-width detection resonators, millikelvin temperatures and amplification of the spin microwave signals using quantum-limit amplifiers. These circuits are however intrinsically characterized by a long ring-down time, making them ill-suited for probing spin species with low coherence times. We propose a dynamical bandwidth tuning of the EPR resonator to lift the constraints on the ring-down time while keeping the benefits offered by superconducting circuits in detection. We are working with Niobium-Titanium-Nitride (NbTiN) alloy and exploiting the kinetic inductance of such magnetic-resilient superconductor to implement the tunability scheme using a varying DC current. This would allow us to perform pulsed-EPR sequences on a large scope of spin species in micron-sized samples adding a tool for new research paths as detection of unpaired electron in single cells or measurement of both inorganic and organic micro-crystal.

*Speaker

WTe2-based Josephson junctions: searching for signatures of helical states

Lucas Bugaud * [1], Xavier Ballu† [1]

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WTe2, a transition metal dichalcogenide with large spin-orbit interactions, is predicted to have striking topological properties that combine type II Weyl semimetal character with second-order 3D topological insulator (SOTI) character. SOTIs are characterized by topologically protected (insensitive to disorder) helical 1D states at their hinges. 1D states located at certain edges of multilayer WTe2 have indeed been demonstrated in Josephson interferometry experiments. However, their ballistic nature was not tested. We have designed WTe2-based Superconducting Quantum Interference Devices (SQUIDs) in which the supercurrent through the junction close to one edge of the crystal interferes with the supercurrent far from the edge.. Depending on the geometry of the junction along the edge, the SQUID oscillations are dominated by the contributions of either the bulk states or the edge states. In the case where a large number of bulk states are contacted by superconducting electrodes in both junctions, we observe sinusoidal SQUID-like oscillations whose amplitude is modulated by orbital interferences between diffusive trajectories delocalised in the whole bulk of the junctions. This interference pattern has been investigated in the three magnetic field directions. On the special case where only few edge states are contacted in the junction along the edge, the strongly asymmetric SQUID pattern is dominated by the contribution of the current-phase relation of those edge states and exhibits a sawtooth shape. This shape is a tell-tale sign that the supercurrent through the edge flows ballistically over 600 nm (which is ten times the estimated normal state mean free path) and is due to the SOTI character of WTe2.

*Speaker

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Transmon qubit readout using in-situ bifurcation amplification in the mesoscopic regime

Olivier Buisson * [1], Rémy Dassonneville [2], Tomás Ramos [3], Cyril Mori , Vladimir Milchakov , Luca Planat , Cécile Naud , Wiebke Guichard , Juan-José Garcia Ripoll , Nicolas Roch

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Qubit state readout is a mandatory step in quantum information processing. We demonstrate a transmon qubit readout based on the nonlinear response to a drive of polaritonic meters in-situ coupled to the qubit (1). Inside a 3D readout cavity, we place a transmon molecule sample consisting of a transmon qubit and an ancilla mode interacting via a non-perturbative cross-Kerr coupling (2). The meter, resulting from a strong hybridization of the ancilla and the cavity modes, shows a high qubit-dependent displacement that can be used for readout without causing Purcell decay. The meter is also anharmonic and dissipative, as it inherits a self-Kerr nonlinearity U from the ancilla mode and an effective decay from the open cavity. From its nonlinearity, the meter presents bistability, and bifurcation behavior when the probing power increases. In this work, we focus on the bifurcation at low power in the few-photon regime, called the mesoscopic regime, which is accessible when the self-Kerr and decay rates of the meter are similar U $\sim$. Capitalizing on a latching mechanism by bifurcation, we thus report a single-shot fidelity of 98.6 % while having an integration time of 500 ns and no requirement for an external quantum-limited amplifier.

(1) R. Dassonneville et al, Phys. Rev. Applied 20, 044050 (2023).
(2) R. Dassonneville et al, Phys. Rev. X 10, 011045 (2020).

*Speaker

Quantum reservoir computing with a superconducting resonator in the semi-classical regime

Baptiste Carles * [1], Julien Dudas [1], Hannes Riechert [2], Ambroise Peugeot [2], Everton Arrighi [2], Jean-Damien Pillet [2], Landry Bretheau [2], Julie Grollier [1], Danijela Markovic [1]

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Quantum reservoir computing is a promising approach to quantum neural networks capable of solving hard learning tasks on both classical and quantum input data (1). Multiple implementation schemes were proposed, using basis states of a qubit system (2), basis states of a system of coupled quantum oscillators (3), or field-quadratures of a system of parametrically coupled quantum oscillateurs (4) as reservoir neurons. However, experimental realizations were lacking. Here we implement experimentally reservoir computing on a quantum oscillator in the semi-classical regime. We use the fundamental mode of a superconducting resonator as a quantum oscillator, and its field quadratures as reservoir neurons. We sample the two quadratures multiple times for the same input data point in order to increase the number of effective neurons. We encode the input data in the amplitude of the resonant drive, and we set the amplitude range in the Kerr regime, in order to obtain the nonlinearity that is essential for data processing. We test the performance of the superconducting reservoir on a simple benchmark task for reservoir computing, that is sine and square waveform classification. This task specifically tests the memory of the neural network and thus its capacity to process temporal data series. We demodulate each pair of output neurons from a 20 ns oscillator emission. Using 8 samples per data point and thus 16 effective neurons, we obtain $>$ 99% accuracy on this task. This is an improvement in terms of the number of necessary neurons compared to reservoir computing with classical oscillators : with a single spintronic nano-oscillator, this task requires 24 effective neurons (5).
This is the first experimental implementation of reservoir computing with superconducting circuits and an important step towards the experimental realization of quantum reservoir computing with the basis states of coupled quantum oscillators that will fully exploit the quantum nature of this system.
(1) S. Ghosh, A. Opala, M. Matuszewski, T. Paterek, and T. C. H. Liew, "Quantum reservoir processing", npj Quantum Information 5, 35 (2019)

(2) K. Fujii and K. Nakajima, "Harnessing Disordered-Ensemble Quantum Dynamics for Machine Learning", Physical Review Applied 8, 024030 (2017)

*Speaker

(3) Julien Dudas, Baptiste Carles, Erwan Plouet, Alice Mizrahi, Julie Grollier, and Danijela Markovic, "Quantum reservoir computing implementation on coherently coupled quantum oscillators" npj Quantum Inf 9, 64 (2023).

(4) G. Angelatos, S. Khan, and H. E. Türeci, "Reservoir Computing Approach to Quantum State Measurement Gerasimos", Physical Review X, 11, 041062 (2021)
(5) M. Riou, F. A. Araujo, J. Torrejon, S. Tsunegi, G. Khalsa, D. Querlioz, P. Bortolotti, V. Cros, K. Yakushiji, A. Fukushima, H. Kubota, S. Yuasa, M. D. Stiles, and J. Grollier, "Neuromorphic Computing through Time-Multiplexing with a Spin-Torque Nano-Oscillator", IEEE Trans Electron Devices (2017)

Characterization of Josephson junction array superinductances

Joan Joel Caceres Ramirez * [1], Marcelo Goffman [1], Hugues Pothier [1], Cristian Urbina† [1], Emmanuel Flurin‡ [1]

[1] Service de physique de l'état condensé – Commissariat à l'énergie atomique et aux énergies alternatives, Université Paris-Saclay, Centre National de la Recherche Scientifique – SPEC - UMR3680 CEA-CNRS(ex-URA 2464), CEA/Saclay, Orme des Merisiers, F-91191 GIF SUR YVETTE CEDEX, France

One method to obtain an intrinsically noise-protected qubit is to reduce the overlap of the wavefunctions associated with the qubit states and to delocalize the wavefunctions. This can be obtained in a qubit based on the hybridization of Andreev states with the electromagnetic modes of the circuit in which it is embedded. The wavefunction delocalization is achieved with a superinductance in parallel with the weak link.

I will present experimental characterization of superinductances based on Josephson junction arrays by microwave reflectometry measurements.

*Speaker

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Magnetic Field Driven Quantum Phases in Magic-angle Twisted Bilayer Graphene

Ipsita Das *† 1

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The recent discovery of magic angle twisted bilayer graphene (MATBG), in which two sheets of monolayer
graphene are precisely stacked to a specific angle, has opened a plethora of grand new opportunities in the
field of topology, superconductivity, and other strongly correlated effect. In twisted van der Waals materials,
lattice mismatch can generate moiré patterns, which act as an additional periodicity that has a length scale
order of magnitude larger than the underlying atomic lattice scale. For MATBG with a small twist angle
close to

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Higher Chern number ideal bands of helical trilayer graphene in magnetic fields

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Helical trilayer graphene (HTG), characterized by three layers of graphene with same successive twists, is an unique tunable platform for realizing a variety of correlated and topological phases. It exhibits a supermoire with domains centered around stacking points ABA or BAB, where two well separated low energy bands appear with Chern numbers +/-(2, -1) forming a Chern mosaic. When the twists are tuned to a 'magic-angle', these bands flatten perfectly at the chiral limit, with large degeneracies at the zero energy. We demonstrate that HTG retains such precise flatness of the low energy bands in the chiral limit even when a perpendicular magnetic field is applied. By a mapping of the zero-energy wavefunctions with those of the lowest Landau level, we identify the analytical forms of the zero-modes at finite magnetic fields. Furthermore, we find topological phase transitions involving gap closings and openings, at fields corresponding to unit and half-flux per unit cell, leading to higher Chern number bands. Such transitions happen at the supermoire scale which alter with each other when the direction of the field is reversed. Due to large moire length scale, these transitions at strong flux limit can become experimentally accessible.

*Speaker

Theory of quasiparticle-induced errors in Schroedinger cat qubits

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Understanding mechanisms of qubit decoherence is a crucial prerequisite for improving the qubit performance. The conventional theory of superconducting qubit decoherence by residual Bogoliubov quasiparticles (1,2) was constructed for qubits in equilibrium. However, the novel cat qubits of dissipative and Kerr types (3,4) are operated under non-equilibrium conditions. Namely, an external microwave drive is needed to stabilize the so-called "cat states", given by superpositions of coherent degenerate eigenstates of the effective stationary Lindbladian in the rotating frame. We quantify the effect of the quasiparticles on such driven-dissipative qubits by introducing additional dissipators which act on the density matrix of the cat qubit. We also account for the effect of the external drive on the quasiparticles along the lines of Ref. (5).
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Learning with coherently coupled quantum oscillators

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Authors : Dudas.J, Carles.B, Plouet.E, Mizrahi.F, Grollier.J, Gouzien.E, Marković.D

Implementing neural networks on quantum systems allows for the use of their quantum properties and dynamics for computing. Compared to qubits, coupled quantum oscillators offer larger Hilbert space for encoding neurons, and can be parametrically coupled, thus providing trainable parameters - weights of the neural network.

We first show that coupled quantum oscillators can transform the input data in a nonlinear manner, and thus allow for its classification, using a simple neural network architecture called quantum reservoir. We investigate the performance of such a network for different variables used as network outputs, i.e., field quadratures (1) and occupation probabilities (2), as well as the performance scaling with the size and parameters of the system.

Learning of the coupling parameters requires to repeatedly simulate quantum system for new parameter values, estimate the gradients of the outputs with respect to parameters and update parameters using this gradient until convergence. This procedure calls for efficient simulation method, and Linblad master equation with Shrödinger representation used in the previous works is not adequate for it. To go towards learning, we have developed a new simulation method, that relies on the Heisenberg representation and analytical expressions for gaussian boson sampling probabilities, to reduce computation time by orders of magnitude.

The model that we have developed can be used for hybrid training of a physical neural network (3), as well for assessing the limits of classically simulable quantum systems, essential for demonstration of quantum advantage of quantum neural networks.

(1) Gerasimos Angelatos, Saeed A. Khan, and Hakan E. Türeci, Phys. Rev. X 11, 041062
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*Speaker

Surface Acoustic Wave phonons, mediator of quantum interactions

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Phonons are of particular interest because mechanical deformations can mediate coherent interactions with a wide range of different quantum systems, including solid-state defects, superconducting qubits, and optical photons. Phonons thus hold promise for quantum-focused applications as diverse as sensing, information processing, and communication. In this talk, we will describe our journey in hybrid experiments involving superconducting qubits and surface acoustic waves (SAW) phonons.
We will present our initial experiment where we demonstrated the quantum control of a single confined SAW mode by a superconducting qubit(1). Such control over the phonon-photon interaction paved the way towards a phononic quantum state transfer via a multi-mode Fabry-Pérot SAW resonator(2).

From that point, we freed ourselves from SAW resonators and truly explore quantum optics like experiments with itinerant SAW phonons(3). Recently, such itinerant SAW phonon where used in a Hong-Ou-Mandel type experiment(4).

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*Speaker

Coherent hole spin qubit shuttling in germanium: quantum links and high-fidelity quantum logic

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The coupling of distant qubits or quantum processors presents clear advantages for the implementation of modular, fault-tolerant and large-scale quantum computers. In semiconductor spin qubits, such long-distance coupling can be implemented by shuttling coherently spins between neighbouring quantum dots. Long distance and coherent electron spin state transports via shuttling have been demonstrated in GaAs (1-4) and in silicon (5,6) enabling the implementation of quantum operations between distant spin qubits (7).
In this work, we investigate the coherent shuttling of hole spin qubits in germanium quantum dot arrays. We demonstrate the coherent transfer of single hole spin qubits through the quantum dots of a 2x2 germanium quantum processor (8). Transferring spin basis states in few nanoseconds, we observe coherent oscillations which witness significant changes in the direction of the quantization axes of neighboring quantum dots. They arise from the strong spin-orbit interaction and lead to rotations of the qubit state during the shuttling. Mitigating their effects, we demonstrate that hole spin qubits can be shuttled coherently up to few hundreds of times between quantum dots. Alternatively, we show that these rotations can also be harvested to perform high-fidelity single qubit operations based only on shuttling thus without the need of microwave signals.

Our work evidences the potential and the versatility of coherent shuttling for the operation of hole spin qubit processors in germanium. It opens new perspectives for the development of scalable architectures and distributed quantum computing on-chip.

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(2) H. Flentje et al., *Nature Communications*, **8**, 501 (2017)
(3) P.-A. Mortemousque et al., *PRX Quantum*, **2**, 030331 (2021)
(4) B. Jadot et al., *Nature Nanotechnology*, **16**, 570-575 (2021)
(5) J. Yoneda et al., *Nature Communications*, **12**, 4114 (2021)
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Tunable Edge Magnetoplasmon Resonator

Elric Frigerio *† [1], Mélanie Ruelle , Giacomo Rebora , Yong Jin , Ulf Gennser , Antonella Cavanna , Jean-Marc Berroir , Plaçais Bernard , Pascal Degiovanni , Gwendal Fève , Gerbold Ménard‡

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Edge magnetoplasmons (EMPs) are the low-energy excitations of a 2DEG in the Quantum Hall regime. These chiral collective excitations propagate along the electrostatic edge of the 2DEG at a velocity v fixed by the magnetic field B: v α 1/B (1). In an isolated Hall island, these trajectories are closed loops, making it possible to create a resonant cavity for EMPs. Such resonance depends on both the velocity v of the EMPs and the perimeter L of the cavity through the relation f=v/L.

Since the EMPs propagate along the edge of the Hall Island, it is possible to tune the resonant frequency by changing the perimeter of the resonator. Varying the perimeter is made possible by a set of QPCs and top gates deposited on the sample. Applying a strong enough potential on a top gate changes locally the electronic density of the 2DEG and a new edge arises at the interface. With a few top gates, it is possible to design various cavities in the same sample, thus changing the resonance frequency.

The cavity must be isolated for the resonance to happen: there must be no ohmic contact to the rest of the 2DEG. This isolation forbids any ohmic contact between the resonator and the rest of the environment: the 2DEG must thus be excited capacitively (via a top gate). In this work we present our results on tunable micrometer-sized resonators with resonances in the GHz range. We show that the size of the cavity can be modulated and that we can achieve a multi-modes regime.

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Emergent quantum phase transition of a Josephson junction in a high-impedance a multimode resonator

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Understanding phase transitions of quantum systems non-perturbatively coupled to reservoirs is challenging. In particular, the physics of a single Josephson junction coupled to a resistive environment is a long-standing fundamental problem at the center of an intense debate, strongly revived by the advent of superconducting platforms with high-impedance multi-mode resonators. In the present work (1) we investigate the emergent criticality of a junction coupled to a multimode resonator when the number of modes is increased. We demonstrate analytically how the multi-mode environment renormalizes the Josephson and capacitive energies of the junction: for a homogeneous transmission line, in the thermodynamic limit the ratio between the renormalized Josephson and capacitive energies diverges when the impedance is smaller than the resistance quantum and vanishes otherwise. The critical behavior is shown not to depend on the extended or compact nature of the Josephson junction phase. Via exact diagonalization, we find that the transition surprisingly stems from a level anticrossing involving not the ground state, but the first excited state, whose energy gap vanishes in the thermodynamic limit. We show that at the transition point the spectrum displays universality not only at low frequencies. In agreement with recent experiments, we reveal striking spectral signatures of the phase transition. (1) L. Giacomelli, C. Ciuti, arXiv:2307.06383

*Speaker

The Fermio-bosonic qubit

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We propose a novel superconducting circuit aiming at more robust quantum states, and featuring two distinct quantum degrees of freedom. It consists in the parallel combination of a large inductance, a capacitor and a quasi-ballistic single-channel weak link. The large inductance results in large fluctuations of the phase across the weak link. The weak link implements a Josephson coupling that depends on an internal fermionic degree of freedom associated with the Andreev level. The electromagnetic modes of the circuit depend on the fermionic occupation, leading to a "fermio-bosonic" qubit. We present preliminary calculations of the wave functions, the relaxation and dephasing rates due to noise in the external flux and weak link channel reflectivity. We find that in addition to having little dispersion and disjoint supports, the small energy difference between the states leads to a reduced effect of ohmic bathes on the relaxation indicating very promising coherent properties.

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Calorimetry of a phase slip in a Josephson junction

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Josephson junctions are a central element in superconducting quantum technology; in these devices, irreversibility arises from abrupt slips of the quantum phase difference across the junction. This phase slip is often visualized as the tunnelling of a flux quantum in the transverse direction to the superconducting weak link, which produces dissipation. Here we detect the instantaneous heat release caused by a phase slip in a Josephson junction, signalled by an abrupt increase in the local electronic temperature in the weak link and subsequent relaxation back to equilibrium. Beyond the advance in experimental quantum thermodynamics of observing heat in an elementary quantum process, our approach could allow experimentally investigating the ubiquity of dissipation in quantum devices, particularly in superconducting quantum sensors and qubits.

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Microwave spectroscopy of Schmid transition

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In 1983, Schmid predicted that a shunted Josephson junction displays a quantum phase transition, and becomes insulating, upon the shunt impedance reaching a critical value. So far, the experimental observation of the Schmid transition remained elusive. Modern attempts to find Schmid transition rely on finite-frequency measurements of a superconducting quantum circuit. As it is typical for a quantum impurity problem, at finite frequencies the transition is broadened to a crossover. We develop the theory of the finite-frequency response functions needed for the interpretation of experimental data. The universal scaling that we unveil will contribute to identifying the Schmid transition unambiguously.

*Speaker

Optimization of nano-calorimeters for the detection of dissipation in quantum devices

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We present a detailed study of voltage-biased ultrasmall tunnel junctions between a superconductor and a proximitized normal metal. Such junctions exhibit a zero-bias anomaly where the conductance has a strong dependence on the electron temperature in the normal metal. In addition, we find a qualitatively similar behaviour of the junctions' reactance by measuring the in-phase and quadrature components of a radio-frequency probing signal. Taking both conductance and reactance into account, we evaluate the responsivity of the zero-bias signal with respect to temperature. Leveraging both contributions could allow for faster and more sensitive calorimeters that are easily coupled to quantum devices, rendering them a broadly applicable tool for the study of dissipation at the nano-scale.

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Anyonic Braiding and Andreev-like Processes in the Fractional Quantum Hall effect

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Edges of the fractional quantum Hall (FQH) host anyonic quasiparticles, having a charge e* which is a fraction of the electron charge (e.g. e*=e/3), and a fractional or "anyonic" braiding statistics, which is intermediate between bosons and fermions. In this talk I will theoretically describe two consequences of these properties, recently observed in experiment.

The first is due to the mismatch between the fractional charge e* of the excitations in the system, and the electron charge e tunneling between two distinct FQH droplets. This results in a process similar to the Andreev reflection occurring between a normal metal and a superconductor. I find our theoretical results (1) to match well that of the recent experiments (2).

Secondly, I consider anyonic statistics through the anyon collider experiment, where the noise created at a quantum point contact by two incoming streams of anyonic quasiparticles allows to measure the anyonic statistics (3, 4). Here, I will show that taking into account the finite extension of the anyonic quasiparticles is crucial to have a correct description of the anyonic braiding. Importantly, this leads to results in agreement with the experimental observations for composite fractions of the FQHE, like = 2/5 (5).

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in the = 1/3 fractional quantum hall regime. *Nature Communications, 14(1):514, Jan 2023.*
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(5) K. Iyer, F. Ronetti, B. Grémaud, T. Martin, J. Rech, and T. Jonckheere. Finite width of anyons changes braiding signatures. In preparation, planned submission on arXiv and Phys. Rev. Lett. before the meeting.

Exact reduced density matrix of a Resistively Shunted Josephson junction

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I will show that the reduced density matrix of a resistively shunted Josephson junction (RSJ) can be obtained using the stochastic Liouville equation method in imaginary time – an exact numerical scheme based on the Feynman-Vernon influence functional. In this approach, the resistance-induced modifications of the junction's equilibrium state are expected to be perturbative in the large R limit. Indeed, in this limit, numerical results recover the results of the well-known Cooper pair box (CPB) family of qbits. For all parameters looked at, the shunted junction is found more superconducting than in the unshunted CPB, with no trace of the dissipative quantum phase transition long believed to occur in the RSJ. This work brings a theoretical confirmation to a similar conclusion previously drawn by Murani et al., based on experimental observations. It also explains precisely how the phase of a Josephson junction decompactifies in presence of an environment.

*Speaker

Floquet-Andreev resonances in hybrid superconducting systems

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An interesting class of periodically driven condensed matter systems is obtained by coupling one or several quantum dots to a finite number of superconducting reservoirs. A unique feature of such systems is that time-periodicity can be realized by purely dc-voltage biasing of the reservoirs. As a result of the periodic driving, the equilibrium Andreev bound states, localized on the dot, turn into non-equilibrium Floquet-Andreev resonances. The resonances have a finite lifetime due to multiple Andreev reflection (MAR) processes.
We focus on the S-QD-S-QD-S bijunction, also known as the "Andreev molecule". We consider two observables: the MAR current and the time-averaged spectral function, which can be probed by tunneling spectroscopy (1). We then consider the bijunction away from the molecular regime. We find that periodic driving induces a long-range coupling between the dots, resulting in interferometric behavior (2).

(1) A. Keliri and B. Douçot, "Driven Andreev molecule", Phys. Rev. B 107, 094505 (2023)
(2) A. Keliri and B. Douçot, "Long-range coupling between superconducting dots induced by periodic driving, arXiv: 2304.05987 (2023)

*Speaker

Near-power-law temperature dependence of the superfluid stiffness in strongly disordered superconductors

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We present results of experimental and theoretical studies on the temperature dependence of superfluid stiffness
Θ (T) in strongly disordered pseudo-gaped superconductors. Experimentally, it is demonstrated that temperature-
dependent suppression of superfluid density in strongly disordered InOx films follows at T Tc a power-law
behavior $\delta\Theta$ (T) T^b, with b slightly less than 2. Theoretically, by combining analytical and numerical methods
to a model of a disordered superconductor with a pseudogap, we found qualitatively similar low-temperature
behavior with exponent b $\sim 2 - 3$ being disorder-dependent. Broad distribution of supercon-ducting order
parameter known to exist in such superconductors (1, 2) even moderately far from the superconductor-insulator
transition, is important for this result. The obtained results are relevant for the search of su-perconducting
superinductors – devices much wanted for several fields of modern quantum technology.

*Speaker

Long-lived quantum memories using 3D niobium cavities

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Long-lived memory qubits can significantly reduce error correction overheads in future quantum processors. Superconducting cavities, capable of reaching quality factors well beyond one billion, are promising candidates for such quantum memories. However, these high-Q cavities are yet to be leveraged to achieve extended coherence times due to their coupling to noisy ancilla qubits.

We introduce a quantum memory using a novel niobium cavity controlled by a weakly-coupled transmon ancilla. We show that a single-photon qubit encoded in the cavity achieves lifetimes an order of magnitude beyond the current state of the art (1). (1) O. Milul, B. Guttel et al., PRX Quantum 4, 030336 (2023).

*Speaker

Extended Bose-Hubbard model with dipolar excitons

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The Bose-Hubbard (BH) model quantifies the quantum matter phases accessible to strongly correlated
bosons confined in lattice potentials. In its elementary form the BH Hamiltonian is restricted to on-site
interactions and quantifies the transition from superfluid to Mott insulating phases. Extending the BH model
to additional degrees of freedom naturally provides a route to broaden the range of accessible quantum matter
states. In this presentation we introduce a new platform to experimentally emulate the Bose-Hubbard model
extended by nearest neighbour interactions. In particular, we emphasise dipolar excitons of GaAs bilayers,
confined in electrostatic lattice potentials. They realise first a Mott insulating phase at unitary lattice filling,
and a second quantum insulator at half lattice filling that exhibits the signatures of a checker-board solid (1).

(1) C. Lagoin et al., Nature 609, 485 (2022)

*Speaker

Tunable charge-4e supercurrent in germanium based JoFET

Axel Leblanc *† [1], Chotivut Tangchingchai , Elyjah Kiyooka , Jean Michel Hartmann , Boris Brun , Vivien Schmitt , Simon Zihlmann , Romain Maurand , Étienne Dumur , Silvano De Franceschi , François Lefloch‡

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Parity-protected superconducting qubits, in which the quantum information is encoded in wave-
functions with disjoint support, have recently emerged as promising candidates to enhance the lifetime
of quantum states. This innovative approach leverages $\cos(2\phi)$ Josephson elements dominated by charge-4e supercurrent – the coherent transfer of pairs of Cooper pairs.
In this work, we investigate highly transparent superconductor-semiconductor-superconductor Joseph-
son field effect transistor (JoFET) fabricated from SiGe/Ge/SiGe heterostructures. First, employing a SQUID featuring a wide and a narrow JoFET, we explore the current phase relation (CPR).
It exhibits gate-tunable higher order harmonics, revealing both charge-2e and charge-4e dissipationless transport, a finding confirmed by Shapiro steps measurements. Second, by harnessing the
superconducting diode effect within a SQUID made of two similar JoFETs, we identify the regime of
perfect critical current symmetry. In this configuration, Shapiro steps measurements at half flux quantum bias exhibit a pronounced reduction in the first harmonic, thereby realizing a $\cos(2\phi)$ Josephson element.
These results pave the way for the realization of Ge-based parity-protected qubits using CMOS compatible processes.

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Revealing topological hinge states in the second order topological insulator Bi4Br4

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Topological Insulators (TIs) hold great promise for making novel electronic devices, thanks to the existence at their boundaries of topologically protected conduction channels. Unfortunately, the expected protection has turned out to be less robust than anticipated, notably due to inelastic processes involving bulk excitations. This complicates the fundamental study of the edge states, and motivates the search for different TIs with a reduced contribution of the non-topological bulk states. Among newly discovered TIs, Bi4Br4 appears to be a very promising material, with a large bulk gap (_˜ 230 meV), and experimental indications of a Second Order Topological Insulator (SOTI) character. SOTIs are topological insulators with (d-2)-dimensional topological states, d being the dimension of the bulk. Indeed, 1D states were evidenced by ARPES and visualized by STM at the hinges of a Bi4Br4 crystal, persisting up to 300K. Our work has been focused on evidencing these hinge states in low-temperature transport experiments by investigating the modulation of quantum interferences with magnetic field and gate voltage. We have found signatures of phase coherence in μm-sized samples with surprisingly large characteristic fields, and a strongly anisotropic behavior. These results suggest that transport in the Bi4Br4 flakes is mediated by 1D ballistic channels, which scatter only in the region under the metallic electrodes. STEM/EDX experiments on FIB lamellae are underway, and should shed light on the morphology of the contact/Bi4Br4 interface. To better evidence the topological 1D edge states, we turned to superconducting contacts. Indeed, because they are ballistic, topological states can carry large supercurrents when proximitized with superconducting electrodes, hence magnifying their signatures in transport. We find sizeable supercurrents in S-Bi4Br4-S Josephson junctions that persist up to extremely high fields (several Teslas), and switching histograms with strong dynamical effects. Our results thus support the SOTI nature of Bi4Br4.

*Speaker

A catch-and-release type protocol for a quantum memory out of eletronic-spin ensemble at unit cooperativity

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Superconducting qubits are strong candidates for quantum information processing, yet their scalability is a current challenge.
Multimode quantum memories have been proposed to alleviate the resource requirement of quantum architectures. They require high storage density, long-coherence time and the ability to write and read on-demand an arbitrary register. Electronic spin-ensemble are good candidates meeting these requirements, especially when operated at a clock transition. Backing the processing power of qubits using spin-based quantum memories operating on echo-silencing protocols at microwave frequency would combine the best performances of each platform in a hybrid architecture. These protocols require among other considerations to control the microwave absorption and emission from the spin ensemble. We use here a hybrid architecture composed of a frequency and bandwidth-tunable superconducting resonator coupled to a quantum memory based on bismuth dopant ensembles in silicon which allows to efficiently and coherently swap quanta of microwave energy between the two systems. This new design tackles several issues commonly encountered in such hybrid systems. By exploiting a kinetic inductive non-linearity, we can active a parametric process to dynamically control the virtual bandwidth of the resonator. We propose a catch-and-release type protocol with at unit cooperativity. The protocol efficiency is characterized using numerical simulations of the hybrid device using various theoretical models.

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TUNNELING SPECTROSCPY OF FEW LAYER SUPERCONDUCTING NbSe2

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Few- and monolayer NbSe2 exhibits high in-plane critical magnetic fields, attributed to Ising supercon-
ductivity. The in-plane field H is also predicted to induce unconventional superconductivity. (1) Among
the possibilities are an odd-parity equal-spin triplet order parameter coupled by H to the con- ventional
singlet order parameter. Tunneling spectroscopy measurements previously carried out by the NS2 group
on bilayer NbSe2 at high H give (H) consistent with this scenario.(1) Here is the superconduct- ing
energy gap. The triplet order parameter is also predicted to give rise to a mirage gap in the density of
states, higher in energy than the superconducting gap.(2) Recently, angle-dependent quantum transport
measurements have been interpreted as evidence transitions to orbital Fulde-Furrell-Larkin-Ovchinnikov
(FFLO), nodal, nematic or topological superconducting phases.(3, 4, 5) In addition, a phase density wave
has been predicted. (6, 7) Further tunnel spectroscopy measurements would be helpful to dis- tinguish
between these possibilities, which are not necessarily mutually exclusive. We have fabricated NIS and
S'IS tunnel devices based on few-monolayer NbSe2 flakes and measured their density of states. We have
not seen the mirage gap. We do see some magnetic field-dependent states in the superconducting gap,
which are possibly due to magnetic defects.(8)

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Advances in Single Microwave Photon Detection

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Circuit Quantum Electrodynamics (CQED) has not only been at the forefront of quantum computing but also shows promise for quantum sensing applications. Specifically, the Single Microwave Photon Detector (SMPD) leverages the transformation of a traveling photon state into a qubit excitation via a 4-wave mixing parametric process. This technique marked a milestone by enabling the detection of individual electron spins and achieved a sensitivity as high as 10^{-22} W/$\sqrt{\{Hz\}}$[?]$Ref1\}$.

$Inthispresentation, weintroduceanenhancedSMPDarchitecturethatpromisesasignificantreductioninthedet$

$\{Ref1\}L.Balembois, etal.PracticalSingleMicrowavePhotonCounterwith10\$\{-22\}\$W/\$\sqrt{\{\{Hz\}\}}\$sensitiv$

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Anyon braiding and quasiparticle Andreev scattering in a mesoscopic "collider"

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We report noise investigations of anyon physics with a mesoscopic collider implemented in the nu=1/3 FQH state of a Ga(Al)As 2D electron gas. Sourcing e/3 Laughlin quasiparticles with weakly back-scattering QPCs and setting a central beam splitter QPC to allow e/3 tunneling charges, we first reproduce and consolidate the negative cross-correlations previously observed (1), indicative of a non-trivial anyon braid phase (2). Then, we explore the opposite tuning of 1 e tunneling charges across the central beam splitter while keeping e/3 charges impinging on it: here, the braid phase is predicted to be trivial. Our observation of negative cross-correlations in this " charge mismatch " limit then points rather on the emergence of a different scattering mechanism akin to Andreev reflection encountered at Normal/Superconductor interfaces (3). In this Andreev process, suggested by Kane and Fisher (4) an impinging e/3 quasiparticle results in the transmission of an electron of charge e together with the reflection of a hole of charge -2e/3. In light of recent theoretical developments on the description of scattering of dilute Laughlin quasiparticle beams by a QPC (5,6,7), we discuss issues raised to the finite experimental temperature.

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*Speaker

Novel manifestations of the Josephson effect in a high-impedance environment

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Dynamics of Josephson junctions can be heavily influenced by the properties of the embedding electrical circuit. In particular, a low-impedance circuit would favor small fluctuations of the superconducting phase-difference variable, leading to semi-classical dynamics. A high-impedance case is more intriguing, as it is required to observe deviations from the semi-classical dynamics. We introduce two recently studied cases, a junction shunted by a (very) high inductance and a junction embedded into an ideal Ohmic environment of a high wave impedance transmission line. The former circuit is known as Blochnium (quasicharge qubit), a dual of transmon qubit, the low-energy spectrum of which can be understood by replacing the Josephson element with a non-linear (periodic in charge) capacitance. The latter circuit generally belongs to a class of many-body problems and cannot be readily simulated on a computer. We show that the junction scatters microwaves in a high-impedance transmission line elastically and inelastically. The sign of the elastic phase-shift changes as the line's wave impedance crosses resistance quantum for Cooper pairs (6.5 kOhm), that is to say the junction changes from inductance to capacitance. This behavior is in agreement with a dissipative localization quantum phase transition (Schmid transition), predicted for a particle in a periodic potential with friction three decades ago. Inelastic scattering is a more subtle effect, which has never been encountered in circuit QED. It makes the junction act as an ideal resistor at the critical wave impedance, a property required to continuously transform an inductance into a capacitance at any finite frequency.

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Electronic interactions and superconductivity with fragmented Fermi surface

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It has long been known that the superconducting pairing does not necessarily have to arise from an attractive interaction - starting from the Kohn-Luttinger proposal, through the high-Tc superconductors, up to the recent studies of superconducting pairing in the van der Waals material NbSe2 arising from the competition between repulsive Coulomb processes at different ranges (1,2). The Fermi surface in this material is split into three pockets, around the Gamma, K and K' points. The presence of different pockets separates the Coulomb processes with different scattering ranges. This processes compete and can result in the formation of Cooper pairs, provided that the short-range repulsion is stronger than the long-range one.
Depending on which of the interaction ranges is dominant, we find that the material can support several superconducting gaps with different symmetries, both in the s and in the f pairing channel. We analyze the dI/dV characteristics of recently performed STM experiments on NbSe2 (3) and find that while they are consistent with both one and two gaps, the agreement is better when two gaps are considered.
In order to gauge the strength of the interaction at different ranges we have calculated the screened Coulomb potential in this material, using the tight-binding model and the RPA approximation. We find that the dominant interaction is one that induces the predominantly s-wave gaps, two of them forming at the K/K' pockets and nearly degenerate, with the third one, around the Gamma pocket considerably larger. Far from being a spectator, the third Fermi pocket can be a powerful player, even to the point of changing the symmetry of the gaps in the K/K' valleys.

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Fractional quantum Hall state preserving gates

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Metallic (Schottky) gates are widely used to tune the carrier density in mesoscopic and nanoelectronic AlGaAs/GaAs two-dimensional electron gas (2DEG) based devices. However, such gates have detrimental effects on the fractional quantum Hall states. In this work we try to find the origin of this annihilation of the fractional states, and thus find a recipe for gates that preserves them. Studying a series of gated Hallbar devices made from high mobility 2DEG with varying thicknesses of the gate metal layer in Schottky gates and of the dielectric layer (HfO2) in metal-insulator (MI) gates, we find a reduction of the low temperature carrier mobility for increasing gate metal thickness and / or increasing dielectric thickness. Furthermore, the MI gate devices show several fractional Hall states, suggesting a strain-related increase of the disorder in the 2DEG leading to the destruction of the fractional quantum Hall states. To further investigate this, we implement a novel periodic gate structure which, via the study of commensurability oscillations, allows us to verify the presence of the strain and evaluate its role.

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Anyonic exchange on the edge of a fractional quantum Hall state

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Under strong magnetic fields, electrons that are confined to two spatial dimensions can exhibit a fractional quantum Hall state where the elementary particles carry only a fraction of the electron charge. These exotic excitations, called anyons, moreover behave under the interchange of two individuals neither as fermions nor as bosons but are characterized instead by a non-trivial exchange phase. The experimental proof of these anyons and their exchange phase was performed only recently, in 2020. Recent experiments have notably demonstrated that a quantum point contact on the edge channels of a fractional quantum Hall (Laughlin) state is able to reveal the anyonic phase from noise measurements.
This lecture will present an introduction to anyons within the fractional quantum Hall effect, exploring their imprint along the edge of the system. Using quantum constrictions called quantum point contacts (QPC), anyons can be randomly transferred between two edges of a fractional quantum Hall conductor. This lecture will focus on the use of current noise measurements to characterize the exotic properties of anyons. The anyon fractional charge was extracted over twenty years ago from noise measurements implemented in sample geometry comprising a single QPC. Recent experiments performed in more complex geometries where several QPCs are used as anyon sources and anyon beam-splitters have revealed the anyon fractional statistics. In these geometries, we will present how anyon tunneling at a QPC can be understood as a 1+1 space-time braiding mechanism between anyons. This mechanism mirrors the conventional anyonic braiding observed when a quasiparticle adiabatically encircles another.

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Transmon qubit readout using a nonlinear cross-Kerr interaction: QNDness versus readout photon number

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In the standard transmon readout scheme, the qubit is coupled directly to a microwave resonator through a transverse coupling. It has been observed that the qubit fidelity and readout QNDness deteriorate even under moderate drive powers and the qubit suffers from Purcell decay. To address these issues, our experiment relies on a multimodal circuit called the transmon molecule, consisting of a qubit mode and an ancilla mode, with a non-perturbative cross-Kerr interaction between them (1,2). The circuit is placed inside a 3D readout cavity such that the qubit mode (resp. the ancilla mode) is uncoupled (resp. coupled) to the cavity field. The ancilla-cavity coupling leads to two hybridized polaritonic meters which also inherit the cross-Kerr coupling to the qubit. This results in a large qubit-dependent displacement of the meters that can be read out without causing Purcell decay. The talk will present this alternative readout scheme and discuss the impact of increasing readout power on the readout fidelity and QNDness.

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Electron-photon Chern number in cavity-embedded 2D moiré materials

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We explore theoretically how the topological properties of 2D materials can be manipulated by cavity quantum electromagnetic fields for both resonant and off-resonant electron-photon coupling, with a focus on van der Waals moiré superlattices. We investigate an electron-photon topological Chern number for the cavity-dressed energy minibands that is well defined for any degree of hybridization of the electron and photon states. While an off-resonant cavity mode can renormalize electronic topological phases that exist without cavity coupling, we show that when the cavity mode is resonant to electronic miniband transitions, new and higher electron-photon Chern numbers can emerge.

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A large, unusual insulating state at finite magnetic field in hBN / graphene moiré heterostructures?

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Graphene van der Waals heterostructures, notably moiré systems, provide a great platform for various exotic physics. In a close to zero degree aligned hBN / graphene moiré system, one observes the emergence of the so called satellite peaks in resistance due to the modification to its band structure. Applying a strong perpendicular magnetic field yields the famous Hofstadter's butterfly, a fractal energy spectrum due to the matching between the size of moiré lattice and the magnetic length.

We have measured high-field and low temperature electron magnetotransport in hBN / graphene moiré heterostructures where the graphene flake is encapsulated between two hBN crystals, aligned respectively at about 0◦ and 30◦ with the graphene flake. While we observed in one device the usual transport signatures of Hofstadter's butterfly, the other device showed a very pronounced, fully insulating state replacing the usual quantized states of the quantum Hall effect at low to moderate carrier densities. To our knowledge, such a robust insulating state, still present above 10 K, has not been reported before. We are currently investigating the origins of this insulating behaviour.

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Vanishing bulk heat flow in the nu=0 quantum Hall ferromagnet in monolayer graphene

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Under high perpendicular magnetic field and at low temperatures, graphene develops an insulating state at the charge neutrality point. This state, dubbed nu=0, is due to the interplay between electronic interactions and the four-fold spin and valley degeneracies in the flat band formed by the n=0 Landau level. Determining the ground state of nu=0, including its spin and valley polarization, has been a theoretical and experimental undertaking for almost two decades. Here, we present experiments probing the bulk thermal transport properties of monolayer graphene at nu=0, which directly probe its ground state and collective excitations. We observe a vanishing bulk thermal transport, in contradiction with the expected ground state, predicted to have a finite thermal conductance even at very low temperature. Our result highlight the need for further investigations on the nature of nu=0.

*Speaker

Reconstructing the potential configuration in a high-mobility semiconductor heterostructure with scanning gate microscopy

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The weak disorder potential seen by the electrons of a two-dimensional electron gas in high-mobility semiconductor heterostructures leads to fluctuations in the physical properties and can be an issue for nanodevices. We show that a scanning gate microscopy (SGM) image contains information about the disorder potential, and that a machine learning approach based on SGM data can be used to determine the disorder. We reconstruct the electric potential of a sample from its experimental SGM data and validate the result through an estimate of its accuracy. (1) (1) G. J. Percebois, A. Lacerda-Santos, B. Brun, B. Hackens, X. Waintal, D. Weinmann, arXiv:2308.13372 (2023)

*Speaker

Landau-Zener-Stückelberg-Majorana interferometry without two-level systems

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The non-adiabatic transition of a quantum system across an avoided level crossing is known as a Landau-Zener-Stückelberg-Majorana (LZSM) transition. Under periodic driving, the accumulation of phase during repeated passages gives rise to LZSM interferences (1). The precise understanding of LZSM transitions in quantum systems enabled the implementation of fast quantum protocols and the characterization of the system's decoherence properties (2,3).
In this work, we explore the emergence of LZSM interferences in nonlinear superconducting resonators made of flux-tunable Josephson junction arrays. By tailoring the nonlinearity over several order of magnitudes, we study the physics of the model as a function of the ratio between the Kerr nonlinearity and the photon loss rate.
We demonstrate that at low readout power, the same interference pattern can be observed independently of the nonlinearity. Increasing the readout power, we then investigate the simultaneous competition between nonlinearity and interference pattern. In weakly nonlinear resonators, we observe the deformation and merging of classical Duffing oscillator instabilities. Within a different circuit where the nonlinearity exceeds the photon loss rate, we demonstrate a regime in which the quantized nature of the photonic field competes with the non-adiabatic nature of the modulation to form a novel interference pattern.

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Josephson diode effect in Andreev molecules

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We propose a platform for observing the Josephson diode effect: the Andreev molecule (1). This nonlocal electronic state is hosted in circuits made of two closely spaced Josephson junctions, through the hybridization of the Andreev states. The Josephson diode effect occurs at the level of one individual junction while the other one generates the required time-reversal and spatial-inversion symmetry breaking. We present a microscopic description of this phenomenon based on fermionic Andreev states, focusing on single channels in the short limit, and we compute both supercurrent and energy spectra. We demonstrate that the diode efficiency can be tuned by magnetic flux and the junctions' transmissions and can reach 45%. Going further, by analyzing the Andreev spectra, we demonstrate the key role played by the continuum, which consists of leaky Andreev states and is largely responsible for the critical current asymmetry. On top of proposing an experimentally accessible platform, this work elucidates the microscopic origin of the Josephson diode effect at the level of the fermionic Andreev states.
The first part of this presentation will be dedicated to a general and pedagogical introduction to the Josephson diode effect, and in particular its link with symmetry breaking.
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Skyrmion-Based Quantum Computing: Challenges For Future Applications

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Magnetic nano-skyrmions develop quantized helicity excitations, and the quantum tunneling between nano-skyrmions possessing distinct helicities is indicative of the quantum nature of these particles. Experimental methods capable of non-destructively resolving the quantum aspects of topological spin textures, their local dynamical response, and their functionality now promise practical device architectures for quantum operations. With abilities to measure, engineer, and control matter at the atomic level, nano-skyrmions present opportunities to translate ideas into solid-state technologies. This talk aims to discuss the basic concept of a magnetic skyrmion qubit, its advantages, and challenges in this new research avenue in quantum magnetism and quantum information.

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Electron collisions in a Graphene Interferometer

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Collisions of electronic excitations at an electronic beamsplitter provide an essential way of studying their coherence and indistinguishability. Their realization requires the generation of on-demand single electron excitations, their synchronization and the subsequent detection of the collision. We demonstrate coherent collisions of single electron excitations, generated by periodic voltage sine pulses, at a graphene Mach-Zehnder interferometer. Measuring and analyzing the shot noise of electrical current provides us with a complete view of the manipulated states' coherence structure : by tuning the time delay between the two injected excitations, we observe fermionic Hong-Ou-Mandel effect, whose visibility is a witness to the two-particle coherence, while the visibility of the Mach-Zehnder's interference pattern gives us access to single-particle coherence. The excellent visibilities enable comprehensive quantum state reconstruction, exemplified by the tomography of a Leviton state.The possibility of coherent operations involving flying qubits for entanglement is now within reach in graphene.

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Theoretical model for a gate tunable edge magnetoplasmon resonator

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In this poster, we present our capacity to precisely control the properties of a recently experimentally realized tunable radiofrequency magnetoplasmonic resonator. The resonance frequency of this system is regulated by a set of electrostatic gates that enable the adjustment of the resonant cavity's dimensions and the electronic density of the two-dimensional electron gas. This work is motivated by a theoretical proposal to use an edgemagnetoplasmon resonator as the basis for an interferometric device aimed at testing the properties of fractional quantum Hall states. Notably, Quantum Hall systems can be used as a testbed to explore the topological properties and non-trivial statistics of quasiparticles, including anyonic statistics.

*Speaker

Towards a carbon nanotube-based gate-controlled transmon qubit

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The standard transmon qubit may be modified by using a Josephson junction with few well-transmitted channels. Via a gate the junction's transmission and thus qubit properties become tunable. Previous works have shown coherent measurements in these devices with nanowire or graphene-based junctions. We present a qubit design using single carbon nanotubes as junction material. Measurements of the resonance frequency show signatures of Coulomb blockade in the quantum dot formed by the carbon nanotube. While currently the life time is probably design limited, the ultraclean manufacturing of nanotubes and their intrinsic low-dimensionality promise long coherence times.

*Speaker

Topological and non-topological degeneracies in string-net models

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String-nets were introduced by Levin and Wen as exactly solvable models of topological order with all kinds of anyons. The energy spectrum of these models is trivial but the degeneracies are not. We will show how to compute these degeneracies and obtain the exact partition function of these models opening the way to their study at finite temperature. https://arxiv.org/abs/2309.00343

*Speaker

Cross-Resonance Readout of a Fluxonium Qubit

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Having a fast and efficient quantum non-demolition (QND) readout scheme is instrumental for many quantum protocols and in particular for quantum error correction. A usual QND readout scheme is the dispersive readout, for which a qubit is off-resonantly coupled to a readout cavity, and the frequency response of the cavity depends on the state of the qubit. This readout can in principle be sped up by increasing the amplitude of the readout pulse. However, above a certain power, the qubit leaks out into higher excited states. We propose an alternative readout scheme -inspired by the cross-resonance gate on two fluxonium qubits-, where instead of sending the signal directly to the cavity, we will send the signal at the cavity frequency through the qubit. Depending on its state, the qubit will filter the drive on the cavity. Fluxonium qubits are well suited for this readout scheme because of their widely different transition frequencies and charge matrix elements. We will show theoretically and numerically that this readout should outperform the dispersive readout in the limits of small or large dispersive shifts.

*Speaker

Time-domain braiding of anyons

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Experimental evidence of anyon fractional statistics has been so far exclusively obtained in the DC regime, without possibility of a time-domain study. We demonstrate here the on-demand generation of subnanosecond single anyon current pulses. These pulses are artificial anyons whose fractional statistics can be continuously tuned by varying the fractional charge carried by each pulse (1,2,3). In this work, we use artificial anyons as a probe to study the dynamics of the tunneling of bulk topological anyons in the time domain.
We implement a Hong-Ou-Mandel (HOM) experiment between two artificial anyons at a quantum point contact (QPC) in a fractional quantum Hall fluid at filling factor nu=1/3. The incoming artificial anyons and the tunneling topological anyons braid at the QPC, thus effectively probing the role of anyon braiding on the characteristic timescale of anyon tunneling. We measure as proposed in (3) a HOM dip in the current noise at the outputs of the QPC, which width depends on the characteristic timescale for tunneling. By comparing integer and fractionally charged pulses, we observe that anyon dynamics is controlled by the scaling dimension, contrasting with the electron case where without braiding, the timescale for tunneling is set by the temporal width of the current pulses.

This experiment provides a new route for studying the role of braiding on the dynamics and temporal correlations of topological excitations. It also opens the way to a new generation of experiments where anyons are emitted on-demand in a circuit.

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Synchronized collision of flying electrons at a beam splitter

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Semiconductor quantum dots in 2D electron systems can be used to encode and process quantum information on individual electrons. Current implementations are mostly based on the electron spin which benefits from a long coherence time in purified semiconductors. Alternatively, one may think of encoding the quantum information in the orbital part of the electron wave function, when delocalized over two spatially separated quantum rails. This novel approach would enable us to perform quantum operations on the flight, in a network of quantum rails with similar architecture as photonic quantum circuits. Individual flying electrons in quantum rails can be obtained with surface acoustic waves creating a confining potential by piezo electric effect, thereby realizing a moving quantum dot in a depleted 1D channel. After our first demonstration of the triggered injection of a single electron in a well-defined moving dot and its partitioning by a tunneling beam splitter (1), we investigated the interaction of two flying electrons transported in adjacent quantum rails, by performing a collision experiment (2). We evidenced a clear antibunching effect in the probability distribution, that could be quantitatively attributed to Coulomb repulsion, opening the way to two-qubit operations. Here, we focus on our latest experiments where we increase the number of electrons up to 5, and evidence a strong antibunching effect in all cases. We interpret quantitatively the partitioning probabilities in terms of mutual Coulomb interactions between the multiple electrons, thanks to a theoretical modelling using mean field theory.

*Speaker

Superconductivity and the normal state's quantum geometry: a conflicting influence

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Superconductivity has, since 1911, become a pillar and a flagship of condensed matter physics. The main paradigm is given by BCS theory which, in its standard form, consists of quasiparticles in a single, partially filled band, pairing and thus condensating in a collective dissipationless state. This single band approximation has its limits. Indeed, since the 1980s, physicists have come to realize that in a multiband setting, even adiabatic, each band will carry an influence of the other bands in the form of two geometric quantities, namely the Berry curvature and the quantum metric. These quantities form what we call band/quantum geometry, and they are consequences of the "quasi" in quasiparticles. In the context of superconductivity, this means that even if a single band is involved in the Cooper pairing, it can carry a quantum geometry if the normal state has more than one band. The influence of this normal state's quantum geometry on the superconducting state is the subject of this talk. On one side, we study the influence of the normal state's Berry curvature on BCS theory in the context of two-dimensional massive Dirac fermions. We find that it generally lowers the critical temperature, in a quantifiable way. On another side, we consider the two-dimensional (111) ${LaAlO}_3/{SrTiO}_3$ interface. Our results suggest that the quantum metric has a sizeable role in the appearance of superconducting domes in this interface, as a function of gate voltage. This positive influence of the normal state quantum metric points towards a conflicting relationship between quantum geometry and superconductivity.
Associated works:

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Microwave Photon to Electron Conversion Using a High Impedance Quantum Circuit

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We realize a microwave photon to electron converter in which a superconducting tunnel junction acts as a voltage tuneable quantum absorber through the photon-assisted tunneling of quasiparticles. We use granular aluminium to build a high impedance microwave Fabry-Pérot cavity strongly coupled to a superconducting tunnel junction. The engineered cavity mode has properties set by the finite impedance mismatch between a transmission line and the cavity on one side and by the tunnel junction on the other. By adjusting the dc-voltage applied to the junction, we tune the photon-assisted quantum tunnelling conversion rate to the microwave coupling rate of the resonator on the other side. At this critical coupling, microwave photons are efficiently harvested and continuously converted into a flow of electrons across the junction. The quantum efficiency estimated from the measured photo-assisted current approaches unity. Such experimental development paves the way towards high efficiency single microwave photon detection using charge detection techniques.

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Fragility of spectral flow for topological phases in non-Wigner-Dyson classes

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Topological insulators and superconductors support extended surface states protected against the otherwise localizing effects of static disorder. Specifically, in the Wigner-Dyson insulators belonging to the symmetry classes A, AI, and AII, a band of extended surface states is continuously connected to a likewise extended set of bulk states forming a "bridge" between different surfaces via the mechanism of spectral flow. In this work we show that this principle becomes {fragile} in the majority of non-Wigner-Dyson topological superconductors and chiral topological insulators. In these systems, there is precisely one point with granted extended states, the center of the band, E=0. Away from it, states are spatially localized, or can be made so by the addition of spatially local potentials. Considering the three-dimensional insulator in class AIII and winding number =1 as a paradigmatic case study, we discuss the physical principles behind this phenomenon, and its methodological and applied consequences. In particular, we show that low-energy Dirac approximations in the description of surface states can be treacherous in that they tend to conceal the localizability phenomenon. We also identify markers defined in terms of Berry curvature as measures for the degree of state localization in lattice models, and back our analytical predictions by extensive numerical simulations. A main conclusion of this work is that the surface phenomenology of non-Wigner-Dyson topological insulators is a lot richer than that of their Wigner-Dyson siblings, extreme limits being spectrum wide quantum critical delocalization of all states vs. full localization except at the E=0 critical point. As part of our study we identify possible experimental signatures distinguishing between these different alternatives in transport or tunnel spectroscopy.

*Speaker

Interaction-driven quantum phase transition of a single magnetic impurity in Fe(Se,Te)

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Understanding the interplay between individual magnetic impurities and superconductivity is crucial for bottom-up construction of novel phases of matter, as well as to exploit the local response as a probing tool. For decades, the description by Yu, Shiba and Rusinov (YSR) of single spins in a superconductor and its extension to include quantum effects has proven highly successful: the pair-breaking potential of the spin generates sub-gap electron- and hole excitations that are energetically equidistant from zero. By tuning the energy of the sub-gap states through zero, the impurity screening by the superconductor makes the ground state gain or lose an electron, signalling a parity breaking quantum phase transition.

Here, we present a set of scanning tunneling microscopy (STM) measurements that explicitely invalidate the classical YSR paradigm, and we propose an interpretation in terms of a multi-orbital Anderson impurity model (1). In particular, we show that in multi-orbital impurities, electronic correlations can lead to a quantum phase transition where the impurity's mean occupation changes dramatically, without significant role of the screening by the superconductor. This finding implies that the YSR treatment is not always valid, and that intra-atomic interactions, particularly Hund's coupling that favours high-spin configurations, are an essential ingredient for understanding the sub-gap states. Our study belongs to a renewed effort to characterize the quantum behavior of magnetic impurities in superconductors by employing toy-models that incorporate many-body correlations (2,3) and draw inspiration from previous works on mesoscopic superconductors.

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Tunneling of fluxons via a Josephson resonant level

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Fluxons in a superconducting loop can be coherently coupled by quantum phase slips occurring at a weak link such as a Josephson junction. If Cooper pair tunneling at the junction occurs through a resonant level, 2π quantum phase slips are suppressed, and fluxons are predominantly coupled by 4π quantum phase slips. We analyze this scenario by computing the coupling between fluxons as the level is brought into resonance with the superconducting condensate. The results indicate that the 4π-dominated regime can be observed directly in the transition spectrum for circuit parameters typical of a fluxonium qubit. We also show that, if the inductive energy of the loop is much smaller than the plasma frequency of the junction, the low-energy Hamiltonian of the circuit is dual to that of a topological superconducting island. These findings can inform experiments on bifluxon qubits as well as the design of novel types of protected qubits.

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Observing the unconventional scaling dimension of fractional quantum Hall anyons

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Unconventional quasiparticles emerge in the fractional quantum Hall regime, the challenge being to observe their exotic properties unambiguously. Although the fractional charge of quasiparticles has been demonstrated for more than three decades (1,2), the first convincing evidence of their anyonic quantum statistics has only recently been obtained (3,4,5) and, so far, the predicted scaling dimension that determines quasiparticles' dynamics has not been observed (6). In particular, while the non-linearity of the tunneling quasiparticle current should reveal their scaling dimension, the measurements do not match the theory, possibly due to real device complications.
Here we experimentally obtain the scaling dimension from the thermal to shot noise cross-over, and observe remarkable agreement with predictions for quasiparticles emerging at fractional filling factor = 1/3, 2/5 and 2/3. Measurements are fitted to predictions involving both the quasiparticles' scaling dimension and charge (7), in contrast to previous works using a free fermion phenomenological expression.

This establishes a central property of fractional quantum Hall anyons and demonstrates a powerful and complementary window on exotic quasiparticles.

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Room-temperature anomalous planar Hall effect from topological nodal-lines in PtBi2

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Geometric phase effects are at the origin of some of the most striking macroscopic signatures of
quantum effects. They are also deeply related to the classification of topological phases, which are
difficult to evidence experimentally at three dimensions as they coexist with trivial bulk states. Here we report a new mechanism to induce strong non-compensated Berry curvature in Dirac-nodal-line semimetals under infinitesimal external magnetic fields. We experimentally observe a manifestation of this mechanism in the Weyl semimetal PtBi2, which was recently reported to host
intrinsically superconducting Fermi arcs. We observe a strong dissipative planar Hall effect and, importantly, a non-dissipative anomalous planar Hall effect in PtBi2 nanostructures directly associ-
ated with non-compensated Berry curvature due to bulk Dirac nodal lines above the Fermi en-
ergy.
This effect is visible at magnetic fields as low as 3T and is robust up to room temperature. Our work
opens a new route to engineer strong Berry curvature in the large family of Dirac nodal line systems
and paves the way to find new materials coupling strong topological features to superconduc-
tivity.

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Poor man's Majorana 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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Nonclassical mechanical states in cavity optomechanics in the strong coupling regime

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Introducing a controlled and strong anharmonicity in mechanical systems is a present challenge of nanomechanics, since the anharmonicity may be exploited to generate nonclassical states of motion. Such states could not only be exploited to investigate the fundamental physics of macroscopic quantum mechanics, but also allow the development of novel quantum technologies. We present a protocol for the generation of such nonclassical mechanical states in the context of cavity optomechanics, where the intrinsic nonlinear interaction between cavity and oscillator provides an ideal platform for manipulating the mechanical state. While most previous works have focused on the steady state solution, we propose here a simple method for generating nonclassical mechanical states in the transient dynamics via driving of the optical cavity. A perturbative analytical treatment for weak drive explains well the physics of these states, which resemble quantum superpositions of coherent states of different amplitude. The strong nonclassicality of the oscillator state is manifested in its Wigner function and is shown via numerical simulation to be robust against weak dissipation.

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Optomechanics of suspended magnetic van der Waals materials

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The persistence of a magnetic order in a monolayer of van der Waals magnetic material has been established
in 2016, offering the perspective to embed a magnetic degree of freedom in heterostructures made of other
bidimensional materials such as graphene or light-emitting transition metal dichalcogenides. The physical properties
of van der Waals materials can be easily tuned by perturbations like strain or doping, inviting to the
exploration of magnetism in two dimensions and its exploitation in novel ultrathin devices (1). Our approach is to
suspend these magnetic materials forming drum-like resonators in order to investigate the influence of the strain
on their magnetic order. We probe magnetic phase transitions in homo- and heterostructures
based on FePS3 and NiPS3, two materials from the transition metal thiophosphates family displaying a
zigzag antiferromagnetic order, combining nano-optomechanics to optical spectroscopies. The tuning by
strain of their light emission and magnetic properties is also investigated, in particular the photoluminescence
of NiPS3 (2). This work opens to the study of proximity effects in van der Waals magnetic heterostructures and
their control by strain.

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*Speaker

Zero bias anomaly in graphene

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In quantum Hall regime, a two dimensional electron gas will form conducting edge channels and the bulk remains insulating, the conductance in each edge channel is quantized to conductance quantum $G_0 = \frac{e^2}{h}$. However the robustness of these quantum Hall plateaus are menaced when an external energy source is provided, for instance a temperature increase or a DC bias. It is then intriguing to study how a well formed plateau is destroyed by such energy injection. In this experiment we fabricate a hBN encapsulated graphene Corbino sample and inject a DC current into the central contact, we observe the breakdown of quantum Hall plateaus as well as the so called zero current anomaly (ZCA), where the conductance at the transition between plateaus also varies with the DC bias. We try to understand its evolution with bias voltage and eventually with temperature in the frame of variable range hopping.

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