EMMI workshop
"Exotic Quantum Matter: New Strategies for Measurement and Control" (EQM-MC)

Donostia / San Sebastián

Sep 30 to Oct 2, 2026

Book of Abstracts

(last updated: September 29, 2026)

organized by DIPC and EMMI

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1 Program

Wednesday, September 30, 8h30 registration, Palacio de Miramar

Wednesday, September 30, 9h00 first talk, Palacio de Miramar

Wednesday, September 30, 12h40 conference photo

Wednesday, September 30, & Thursday, October 1, 12h40 poster session, Palacio de Miramar

Thursday, October 1, 20h30 conference dinner Sidrería Txirrita

Friday, October 2, 16h00 end of the EQM-MC EMMI workshop

Wed, Thu, Fri, 18h Passion for Knowledge science festival, Victoria Eugenia theatre (optional, not part of EQM-MC)

Final Schedule for EQM-MC conference

Wed, Sep 30		Thu, Oct 1		Fri, Oct 2	
8:30-8:50	registration				
8:50-9:00	Welcome & opening				
9:00-9:35	Kouwenhoven	9:00-9:35	Ketterle	9:00-9:35	Millis
9:35-10:10	Rubio-Verdu	9:35-10:10	Yefsah	9:35-10:10	Cirac
10:10-10:30	Huang	10:10-10:30	Svendsen	10:10-10:30	Esin
10:30-11:10	coffee	10:30-11:10	coffee	10:30-11:10	coffee
11:10-11:45	Beenakker	11:10-11:45	Yelin	11:10-11:45	Sayrin
11:45-12:20	Klinovaja	11:45-12:20	Alaeian	11:45-12:20	Kraus
12:20-12:40	Bruun	12:20-12:40	Asteria	12:20-12:40	Amelio
12:40-15:10	Lunch & Posters	12:40-15:10	Lunch & Posters	12:40-14:40	lunch
				14:40-15:00	Yazici
15:10-15:45	Yacoby	15:10-15:45	Knap	15:00-15:35	Lau
15:45-16:05	Gastiasoro	15:45-16:45	Roundtable	15:35-16:10	Grushin
16:05-16:25	Morera Navarro			16:10-16:30	Julia
				16:30-16:40	conclusion
		20:30	dinner Txirrita		

2 Venue and Contact Data

Organizers: Aran Garcia-Lekue, Francesca Ferlaino, Géza Giedke, Mohammad Hafezi, Tobias Grass

Local organizers: Aran, Géza, Tobias

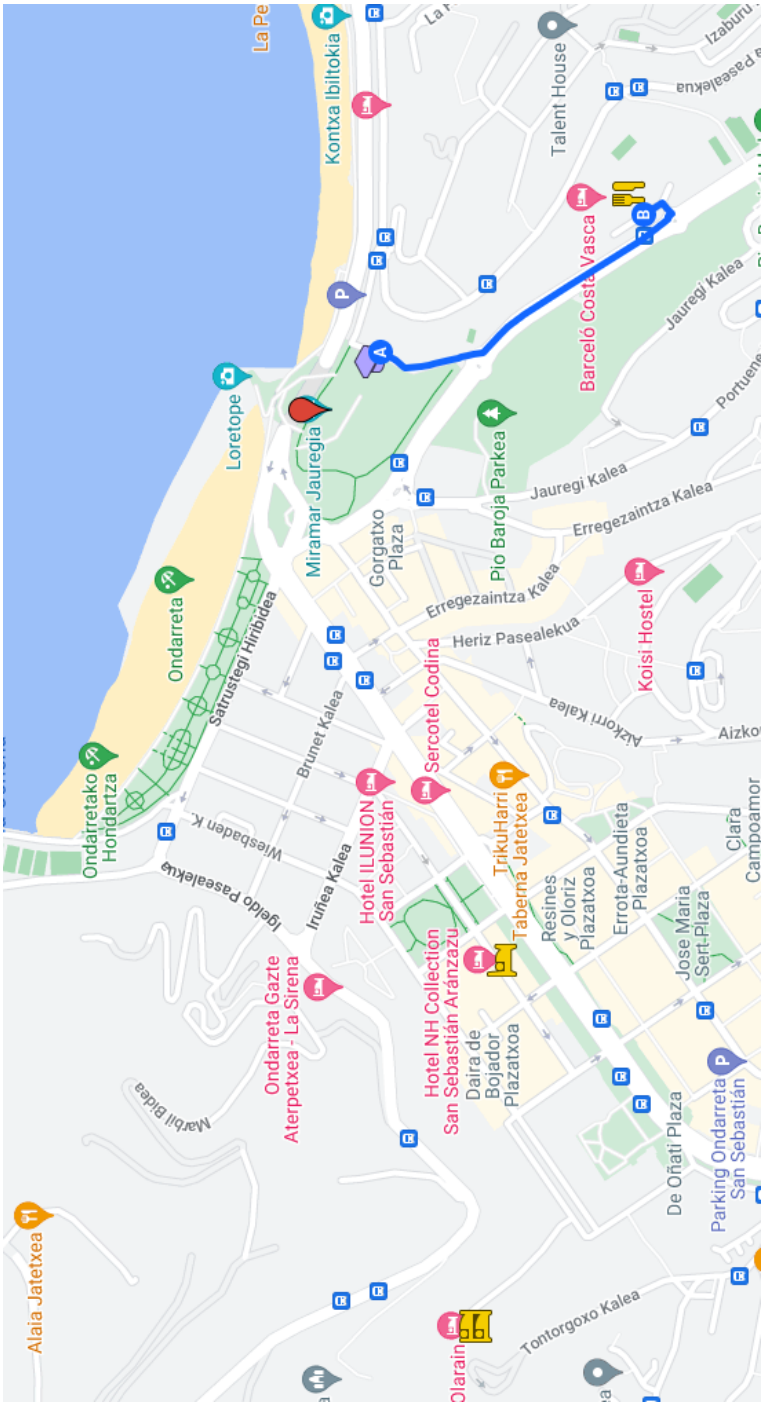
Contact:
eqm-mc-conference@dipc.org, Tel. +34 943 01 8289 (DIPC)

Website: `http://eqm-mc-conference.dipc.org/`

Venue: Palacio Miramar
Paseo de Miraconcha, 48, E-20007 Donostia-San Sebastián
Tel.: +34 943 21 9511, fax: +34 943 21 9598, email: udaikastaroak@ehu.eus
WLAN (eduroam) is available.

Lunch (Friday 13:10h): Hotel Barceló "Costa Vasca"
Avenida Pio Baroja, 15, 20008 San Sebastián
Tel: +34 94 331 79 50

School Dinner (October 1, 20:30h): Sidrería Txirrita
Calle San Bartolomé, 32, 20007 San Sebastián, Guipúzcoa
Tel. +34 943 467 638


Kontxa Ibiltokia
Talent House
Barceló Costa Vasca
Jauregi Kalea
Loretope
Miramar Jauregia
Pio Baroja Parkea
Gorgatxo Plaza
Erregezaintza Kalea
Ondarreta
Satrustegi Hiribidea
Heriz Pasealekua
Koisi Hostel
Sercotel Codina
Brunet Kalea
Ondarretako Hondartza
Hotel ILUNION San Sebastián
TrikuHarri Jatetxea
Resines y Oloriz Plazatxoa
Errota-Aundieta Plazatxoa
Iruñea Kalea
Ondarreta Gazte Aterpetxea - La Sirena
Hotel NH Collection San Sebastián Aranzazu
Daira de Bojador Plazatxoa
Jose Maria Sert Plaza
De Oñati Plaza
Parking Ondarreta San Sebastián
Alaia Jatetxea
Tontorgoxo Kalea

3 Thanks

We thank the *ExtreMe Matter Institute* (EMMI) for generous financial support of the complete EQM-MC conference.

We thank *Cursos de Verano / Uda Ikastaroak*, the summer courses of the University of the Basque Country (EHU) for hosting the conference and back-office support.

4 Invited Talks

List of Invited Talks

1. Hadiseh Alaeian (Purdue University, West Lafayette, IN): Thu, 11:45
   Criticality and nonclassical light from unconventional light–matter interactions

2. Carlo Beenakker (Universiteit Leiden): Wed, 11:10
   Lattice-simulation of interaction-induced mass generation of Dirac fermions

3. Ignacio Cirac (MPQ Garching): Fri, 9:35
   Efficient Preparation and manipulation of Tensor Network Quantum States

4. Adolfo Grushin (DIPC, San Sebastián): Fri, 15:35
   Fractons in the Fractional Quantum Hall Effect

5. Wolfgang Ketterle (MIT, Boston, MA): Thu, 09:00
   Ultracold atoms with strong magnetic interactions

6. Jelena Klinovaja (Universität Basel): Wed, 11:45
   Robust Tripartite Entanglement Generation via Correlated Noise in Spin Qubits

7. Michael Knap (TU München): Thu, 15:10
   Dynamical Signatures of Strongly Correlated Quantum States in Moiré Heterostructures

8. Leo Kouwenhoven (QuTech, Delft University of Technology): Wed, 9:00
   Qubits based on Majorana bound states in Kitaev chains

9. Barbara Kraus (TU München): Fri, 11:45
   Quantum Cooling Algorithms: State Preparation, Efficiency, and Robustness

10. Jeanie Lau (Ohio State University): Fri, 15:00
    Superconductivity and Magnetism in Flatlands

11. Andrew Millis (Columbia University, New York): Fri, 09:00
    Topological Mott Transitions: Green function zeros, chargeon edge states and superconductivity at a topological Mott transition

12. Carmen Rubio-Verdú (ICFO – The Institute of Photonic Sciences, Castelldefels): Wed, 09:35
    Two twists, twice the fun: multi-moiré graphene

13. Clément Sayrin (Laboratoire Kastler Brossel, Paris): Fri, 11:10
Hybrid Rydberg platform for the observation of long-lived spin-exchange interactions

14. Amir Yacoby (Harvard University, Cambridge, MA): Wed, 15:10
Probing and controlling isospin order with an Andreev cavity

15. Tarik Yefsah (CNRS and École Normale Supérieure, Paris): Thu, 09:35
Probing Spatial Correlations in Strongly-Interacting Fermi Gases

16. Susanne Yelin (Harvard University, Cambridge, MA): Thu, 11:10
Quantum Dynamics as a Computational Resource

Criticality and nonclassical light from unconventional light–matter interactions

Hadiseh Alaeian

Purdue University, West Lafayette, IN

Light–matter interfaces are usually described by linear single-photon coupling and local, uncorrelated dissipation. In this talk, I will show that relaxing either assumption opens qualitatively new physics. Starting from the two-photon Dicke model, where atoms exchange photons with a cavity only in pairs, I will show that engineered two-photon dissipation stabilizes the model's intrinsic instability —which single-photon loss cannot cure— producing a dissipative phase transition with superradiant states coexisting with the vacuum and spontaneous breaking of a Z_4 symmetry. The same quadratic coupling makes photon blockade collective: in a two-photon Tavis–Cummings ensemble, antibunching improves as $1/N^2$ while transmission stays near unity, enabling bright nonclassical light without single-emitter strong coupling. Finally, I will show that correlations in the environment itself can drive criticality: two remote nonlinear resonators coupled with broadband-entangled baths undergo a nonlocal quantum phase transition, breaking the symmetry of a collective mode delocalized over arbitrarily distant systems—while any local observer sees only thermal noise. These results establish nonlinear couplings and structured dissipation as genuine resources for quantum light generation and open-system criticality.

References

[1] A.J. Shah et al., Phys. Rev Lett. 135, 173602 (2025)
[2] L. Dong et al., Phys. Rev. X Quantum 7, 020349 (2026)
[3] Coppo, A. J. Shah, et al., arXiv.2606.25061 (2025)

Lattice-simulation of interaction-induced mass generation of Dirac fermions

Carlo Beenakker

Universiteit Leiden

Massless Dirac fermions, as they appear in topological insulators, are topologically protected by chiral or time-reversal symmetry at the single-particle level. This protection does not extend to strong interactions, which can produce a mass either with or without spontaneous symmetry breaking. We present lattice-fermion simulations of both scenarios, using the newly developed method of "tangent fermions" that avoids the fermion doubling obstruction which has plagued the field for decades.
Contribution based on arXiv:2601.09563, arXiv:2606.24713.

Efficient Preparation and manipulation of Tensor Network Quantum States

Ignacio Cirac

MPQ Garching

Tensor Network States, like matrix product or projected entangled pair states play an important role in both, quantum information theory and many-body physics. They offer a compact and efficient representation, enabling accelerated numerical computations and providing intuitive insights into many-body phenomena. In this talk, I will discuss how certain states can be efficiently prepared and manipulated using quantum devices, highlighting the use of local operations and classical communication.

Fractons in the Fractional Quantum Hall Effect

Adolfo Grushin

DIPC, San Sebastián

The fractional Hall effect emerges only in extremely clean samples. Extending such fractionalised phase to severely disordered systems is an open question, especially if we are after properties which have no analogue in canonical crystalline systems. In this talk, I discuss an exactly-solvable model that realises such a phase. This is done by coupling together a patchwork of Laughlin fractional Hall phases, each with a different fractionalisation. We can exactly solve this model working with the coupled-wire construction, where we can tune the topology in real space by adjusting the spatial positioning of each wire. Its ground state is an emergent gapped phase, which we call the Fractonic Fractional Quantum Hall Effect, that displays an exotic interplay of fractional quantum Hall anyons together with fractonic quasiparticle constraints and exponential ground state degeneracy. Remarkably, this phase appears to realise a gapped fractonic order in 2D, seemingly violating a prominent no-go result which prohibits such a phase emerging in fewer than three dimensions. Our method provides an analytically solvable pathway to a non-crystalline fractional quantum Hall effect and fractonic theories in two-dimensions, examples of which were lacking.

J. Schirmann*, P. D'Ornellas*, Charles Stahl, AGG, arxiv: 2503.18337

Ultracold atoms with strong magnetic interactions

Wolfgang Ketterle

MIT, Boston, MA

In this talk I will describe our current efforts to realize many-body physics with dysprosium atoms and boost magnetic interactions into the kHz regime. This requires separation between the atoms of less than 100 nm. Using tightly confined pairs of atoms in optical lattices, we have observed magnetic interaction energies of 10 kHz (500 nK) via ballistic expansion measurements and RF spectroscopy. We have also observed magnetic repulsion between pairs of atoms held in a bilayer potential with separations of 50 – 100 nm. The goal is to control many-body physics in a bilayer by varying the separation between the two layers and realize proximity effects.

Robust Tripartite Entanglement Generation via Correlated Noise in Spin Qubits

Jelena Klinovaja

Universität Basel

I will talk about the generation of genuine tripartite entanglement in a triangular spin-qubit system due to spatially correlated noise. In particular, I will cover how the formation of a highly entangled dark state—a W state—enables robust, long-lived tripartite entanglement. Surprisingly, environmentally induced coherent coupling does not play a crucial role in sustaining this entanglement. This contrasts sharply with the two-qubit case, where the induced coupling significantly influences the entanglement dynamics. Furthermore, there are two promising approaches to enhance the tripartite entanglement by steering the system towards the dark state: post-selection and coherent driving. Our findings offer a robust method for generating high-fidelity tripartite entangled states with potential applications in quantum computation.

[1] Sander Driessen, Ji Zou, Even Thingstad, Jelena Klinovaja, and Daniel Loss, Phys. Rev. Research 8, 033153 (2026).

Dynamical Signatures of Strongly Correlated Quantum States in Moiré Heterostructures

Michael Knap

TU München

Recent advances in two-dimensional moiré heterostructures have enabled the observation of fractional quantum anomalous Hall states, generalized anomalous Hall crystals, and superconductivity, even within the same gate-tunable device. In this talk, we will discuss anyon superconductivity as a possible mechanism connecting fractional quantum Hall physics and superconductivity. Near a topological transition between a fractional Chern insulator and a topologically ordered charge-density-wave, charge-(2e) anyon pairs can become energetically favorable relative to individual anyonic excitations. This unconventional energy hierarchy provides a microscopic route to superconductivity in a purely repulsive system. Using tensor networks methods we numerically analyze a triangular lattice Hofstadter model and identify characteristics of this topological quantum phase transition. We then explore dynamical signatures of these exotic phases in single-particle spectral functions and charge-neutral collective modes. In particular, we predict characteristic fractionalized continua and enhanced damping of plasma modes near topological quantum phase transitions. These observables can be accessed with emerging probes such as the quantum twisting microscope, opening a new window into the dynamics of correlated and topologically ordered moiré phases.

Qubits based on Majorana bound states in Kitaev chains

Leo Kouwenhoven

QuTech, Delft University of Technology

We have realized Majorana bound states (MBS) in Kitaev chains consisting of a sequence of quantum dots separated by superconductors. The quantum dots are spin-polarized and connected to each other via tunneling as well as Cooper pair splitting, mediated by a sandwiched superconductor. At sweet spots in the parameter space of chemical potentials and (tunnel) coupling strengths, MBS arise at the two ends of the chain. The sweet spots grow in size when making the chain longer, expected to develop a topological superconducting phase for chains with five quantum dots or more. We have experimentally studied chains from two to six quantum dots, observing an increased stability of the MBS. In devices with two chains coupled to each other, we have realized qubits where the basis states are parity states of occupying the chain with an even or odd number of particles. Ongoing studies focus on enhancing qubit stability.
More info at qutech.nl and references at arxiv.org

Quantum Cooling Algorithms: State Preparation, Efficiency, and Robustness

Barbara Kraus

TU München

I will discuss two recent works on quantum cooling algorithms for preparing low-energy states of many-body systems. We analyze cooling by repeated coupling to simple auxiliary systems, characterize its efficiency and robustness to noise, and compare it with coherent approaches such as adiabatic evolution and QAOA. Our results identify regimes in which quantum cooling provides a simple and robust route to quantum state preparation.

References:

D. Molpeceres, S. Lu, J. I. Cirac, and B. Kraus, Quantum algorithms for cooling: a simple case study, Phys. Rev. Research 7, 033162 (2025).

D. Molpeceres, S. Lu, J. I. Cirac, and B. Kraus, Benchmark of quantum algorithms for ground state preparation in the presence of noise, arXiv:2606.20551 (2026).

Superconductivity and Magnetism in Flatlands

Jeanie Lau

Ohio State University

In this talk I will discuss our latest results on in situ tuning of the strength and lengthscale of Coulomb interactions in van der Waals structures, such as twisted bilayer and trilayer graphene, and layer-dependent magnetism and evidence for geometric frustration in monolayer FeGaS.

Topological Mott Transitions: Green function zeros, chargeon edge states and superconductivity at a topological Mott transition

Andrew Millis

Columbia University, New York

A topological Mott transition is an interaction-driven transition between a conventional topological insulator and a topological Mott insulator. This talk shows how the transition may be characterized in terms of changes in Green function zeros and via edge state reconstruction. The interface between a topolgical Mott insulator and a topological band insulator is shown to support charge e spin zero 'chargeon' excitations, and doping either a topological band insulator or a topological Mott insulator is shown to lead to superconductivity, with the phase stiffness enhanced near the transition point. This work is performed in collaboration with Daniele Guerci, Giorgio Sangiovanni, Nicholas Wagner, Tomohiro Soejima, Christopher Roth, Steven White, Cesar Gallegos and Rafael Magaldi and is based on PRL 133, 126504 (2024), Phys. Rev. B 113, 064412 (2026), arXiv:2607.14221, arXiv:2608.02753

Two twists, twice the fun: multi-moiré graphene

Carmen Rubio-Verdú

ICFO – The Institute of Photonic Sciences, Castelldefels

tba

Hybrid Rydberg platform for the observation of long-lived spin-exchange interactions

Clément Sayrin

Laboratoire Kastler Brossel, Paris

Circular Rydberg atoms, i.e., Rydberg atoms with maximum angular momentum, ideally combine long coherence times and strong interactions. Their lifetimes, hundred times longer than their low-momentum counterparts, make them ideal for quantum simulation of the dynamics of interacting quantum systems. However, local manipulation and detection of individual atoms in an array through direct optical excitation is possible with low-momentum Rydberg levels only.
In this talk, I will present our hybrid platform that couples an array of data qubits, encoded in circular Rydberg states, to an auxiliary array of ancilla atoms. We excite the latter to a laser-accessible Rydberg level, that resonantly interacts with a circular Rydberg level. Rydberg blockade of the optical excitation of the ancilla performs quantum nondemolition detection of the data qubit. Conversely, optical control of the ancilla leads to otherwise impossible local manipulation of the circular Rydberg atoms. Recently, we have used this platform to record resonant spin-exchange interactions between two circular Rydberg atoms over unprecedented timescales, with the observation of spin oscillations over more than 60μs and 40 oscillations periods. This in particular allowed us to observe the coupling between spin and motional degrees of freedom for the laser-trapped Rydberg atoms through a collapse and revival of the spin oscillations.

Probing and controlling isospin order with an Andreev cavity

Amir Yacoby

Harvard University, Cambridge, MA

A ballistic Josephson junction can act as an electronic "Andreev cavity," in which repeated Andreev reflections confine low-energy electronic states and modify the ground state of an embedded quantum material. Here, we use such a cavity to probe and control gate-tunable spin and valley isospin order in Bernal bilayer graphene. Josephson interferometry reveals interaction-driven 0-to-pi transitions that identify a partially polarized phase as a spin-polarized intervalley-coherent state that spontaneously breaks time-reversal symmetry, while a second spin-polarized phase exhibits an anomalous interference pattern that persists throughout the ordered state. Beyond probing these phases, the Andreev cavity actively reshapes the phase diagram: a small in-plane magnetic field enables coherent equal-spin triplet pairing whose condensation energy dramatically stabilizes isospin ferromagnetism. This cavity-induced reconstruction brings competing isospin orders into direct contact and produces a chiral Josephson interference response. These results establish Andreev cavities as a platform for jointly measuring and controlling superconductivity, magnetism, and isospin order in quantum materials.

Probing Spatial Correlations in Strongly-Interacting Fermi Gases

Tarik Yefsah

CNRS and École Normale Supérieure, Paris

The last decades have seen the emergence of ultracold atom experiments as powerful platforms for the exploration of complex many-body systems, owing to their ability to probe large ensembles of particles in a well-characterized, tunable, and isolated environment.
Among the various quantum many-body problems within reach of quantum gas experiments, interacting fermionic systems play a special role. While they constitute a cornerstone of quantum matter covering a broad fundamental and technological scope, their understanding still represents a major challenge for existing theoretical approaches, which are widely plagued by the infamous sign-problem.
In this talk, I will present our recent work on quantum gas microscopy of fermionic many-body systems in continuous space, how we characterize them at previously inaccessible levels of resolution, and gain new insight into their microscopic inner workings.

Quantum Dynamics as a Computational Resource

Susanne Yelin

Harvard University, Cambridge, MA

Quantum systems provide computational resources that extend beyond the standard circuit model. In this talk, I will discuss how controlled quantum dynamics can be used for computation and for extracting information from complex quantum systems. I will highlight connections to analog quantum computing and quantum learning, and illustrate how these perspectives can suggest new approaches to scientific computing.

5 Contributed Talks

List of Contributed Talks

1. Ivan Amelio (Université libre de Bruxelles): Fri, 12:20
   Pair and single-particle superfluidity in bosonic quasi-flat bands: competition, Gaussian states and quantum simulation

2. Luca Asteria (Kyoto University): Thu, 12:20
   New phenomena in anomalous Floquet topological states

3. Georg Bruun (Aarhus University): Wed, 12:20
   Excitons as optical sensors for electronic spin and charge correlations

4. Iliya Esin (Bar-Ilan University, Ramat Gan): Fri, 10:10
   Self-organized Floquet topology in cavity-driven quantum materials

5. Maria N Gastiasoro (DIPC, San Sebastián): Wed, 15:45
   Ferroaxial order in 1T-TiSe2

6. Tsung-Sheng Huang (ICFO – The Institute of Photonic Sciences, Castelldefels): Wed, 10:10
   Dissipative preparation of moiré superconductivity

7. Sergi Julia (Pasqal): Fri, 16:10
   One-to-one quantum simulation of the low-dimensional frustrated quantum magnet $TmMgGaO_4$ with 256 qubits

8. Ivan Morera Navarro (ETH Zurich): Wed, 16:05
   Spectroscopy of Strongly Correlated Matter with Quantum Simulators

9. Mathias Svendsen (Institut für Theoretische Physik, Universität Tübingen): Thu, 10:10
   Topological phases in two-dimensional Rydberg lattices

10. Emre Yazici (ETH Zurich): Fri, 14:40
    Quantum Optical Twist and Scan Microscopy

Pair and single-particle superfluidity in bosonic quasi-flat bands: competition, Gaussian states and quantum simulation

Ivan Amelio

Université libre de Bruxelles

The interplay between interactions and quantum geometry can drive weakly dispersive bosons into different exotic many-body phases. In this work we study a quasi flat-band model in one dimension that exhibits an extended pair-superfluid (PSF) phase in the all-flat-band limit. Introducing single-particle hopping leads to an intriguing competition with a more conventional single-particle superfluid (SF). In our study, we make use of a variational Gaussian state approach that provides a unified description of the single-particle and pair superfluid phases, regarding both the ground state wavefunction and the collective excitation spectrum. In particular, we derive a general relation between the speed of sound and a "quantum geometric kernel", thereby extending earlier connections to the quantum metric, which relied on single-particle mean-field theory. The quantum simulation of the PSF-SF transition with fluxonium qutrit arrays is also discussed.

I Amelio, Q Ficheux, N Goldman, arXiv:2601.21507
M Burgher, S Loddo, L Vanderstraeten, N Goldman, I Amelio, arXiv:2605.26231

New phenomena in anomalous Floquet topological states

Luca Asteria

Kyoto University

Anomalous Floquet topological states are found only in driven systems, as one of their distinct features are edge modes in the pi-gap of the quasienergy. They can be realized by driving near-resonantly with the bandwidth of the unmodulated system. Here we provide experimental and theoretical evidence that they can also be obtained by an 'adiabatic' drive, much slower than other time-scales, in analogy to the topology of a Thouless pump. We propose a novel method to detect anomalous topology in real-space, and apply it to verify the adiabatic realization of anomalous states. The adiabatic realization is promising as more robust to disorder, (interaction-induced) Floquet heating, and issues with initial state preparation.
We conclude with future plans on how to exploit this robustness for generating novel many-body topological states.

Excitons as optical sensors for electronic spin and charge correlations

Georg Bruun

Aarhus University

In this talk, I discuss how excitons can be used to detect spin and charge correlations between electrons. Using theories that have been benchmarked against high precision quantum simulation experiments with cold atoms, I show that interactions between the electrons and the excitons can lead to the formation of new quasiparticle states called polarons. I give three examples of how the spectrum of such polarons can be used to infer information regarding the correlations between the surrounding electrons.

Self-organized Floquet topology in cavity-driven quantum materials

Iliya Esin

Bar-Ilan University, Ramat Gan

Floquet engineering has emerged as a powerful route to dynamically control band structure and topology in quantum materials, but most implementations rely on externally imposed laser fields that are power intensive, difficult to integrate into devices, and weakly coupled to the electronic system. We propose and analyze an alternative paradigm in which Floquet topology emerges self consistently in an electrically driven cavity material system. We consider a semiconductor layer embedded in a cavity and coupled to external leads and a bath of acoustic phonons, where dc pumping leads to the buildup of a coherent intracavity field through light matter coupling. We determine the resulting nonequilibrium steady state self consistently and show that, above threshold, the coupled system settles into a stable time periodic limit cycle with a field amplitude set by the cavity quality factor and dissipation. This emergent periodic field Floquet-dresses the electronic bands, generating finite Berry curvature and a transverse Hall response in the absence of an external magnetic field. We demonstrate that the resulting Hall conductivity can be directly probed via in plane dc transport measurements. Our work establishes a route to Floquet topological phases without external laser illumination, highlighting self organized cavity driven steady states as a platform for electrically controlled nonequilibrium phases.

Ferroaxial order in 1T-TiSe2

Maria N Gastiasoro

DIPC, San Sebastián

Charge density waves (CDWs) with multi-component order parameters can break unexpected symmetries through the interplay of nearly degenerate instabilities. In the widely investigated material 1T-TiSe2, whether the observed CDW spontaneously breaks mirror and inversion symmetries to form a chiral state has remained controversial, with previous experiments reporting conflicting results. Here, we resolve this controversy by identifying the bulk broken symmetry as ferroaxial, corresponding to the breaking of vertical mirrors while preserving inversion symmetry. Simultaneous symmetry-resolved elastoresistivity and elastocaloric measurements uncover a hierarchy of symmetry-breaking transitions: the primary CDW is followed by a ferroaxial instability, which in turn acts as the parent state for a second nematic instability.

None of the possible configurations of the leading CDW mode, which transforms as the L1- irrep, can produce ferroaxial order, and symmetry requires a secondary mode belonging to a different irrep to break the vertical mirrors. We develop a Landau theory for the leading CDW mode coupled to relevant secondary mode candidates, analyze the resulting phase diagrams in the presence of strain, and consider the implications for the candidates.

Dissipative preparation of moiré superconductivity

Tsung-Sheng Huang

ICFO – The Institute of Photonic Sciences, Castelldefels

Dissipative preparation of quantum order offers a route to superconductivity that does not rely on enhancing attractive interactions. Here we propose a driven–dissipative protocol to prepare superconductivity as a steady state in a two-dimensional moiré heterostructure. The key ingredient is a bilayer moiré platform in which the layer degree of freedom acts as a pseudospin, allowing the pseudospin structure required for pairing to be implemented through optically induced spatial operations. We show that this preparation scheme requires local dissipation, which arises naturally from nearly nondispersive bosonic modes in the heterostructure. In contrast, in the opposite regime of collective dissipation, the same platform exhibits an early-time superradiant burst. Our results establish driven–dissipative moiré heterostructures as a promising platform for preparing superconductivity, while also revealing a connection between steady-state pairing and transient superradiance.

One-to-one quantum simulation of the low-dimensional frustrated quantum magnet $TmMgGaO_4$ with 256 qubits

Sergi Julia

Pasqal

Rydberg-atom quantum processing units (QPUs) operated in analogue mode offer a versatile platform for simulating low-dimensional quantum materials at scales where entanglement limits classical methods. However, analogue simulators have largely focused on universal Hamiltonians rather than material-specific comparisons. Here [1], we use a Rydberg-atom QPU to study the bulk-layered frustrated quantum magnet $TmMgGaO_4$. Magnetisation measurements from the simulator show excellent quantitative agreement with new sample measurements in the magnetic laboratory. We investigate the same antiferromagnetic phase transition on both platforms, despite their magnetic energy scales differing by five orders of magnitude. We further probe quantum fluctuations through snapshot analysis and connect our results to integrated inelastic neutron-scattering data. Finally, we use the quantum simulator to access non-equilibrium dynamics on picosecond material timescales, including frequency response and the thermalisation of observables.

[1] Leclerc, L., Julià-Farré, S., et al. (2026) *One-to-one quantum simulation of a frustrated magnet with 256 qubits*. arXiv.2603.20372 (2026).

Spectroscopy of Strongly Correlated Matter with Quantum Simulators

Ivan Morera Navarro

ETH Zurich

Recent advances in quantum simulators based on ultracold atoms and Rydberg tweezer arrays are transforming these systems into powerful spectroscopic probes of strongly correlated matter. By combining microscopic control, single-particle resolution, and coherent drives, they enable measurements that parallel established spectroscopic techniques while offering capabilities beyond those of conventional solid-state experiments. I will illustrate this emerging paradigm through two examples.

First, I will discuss a Rydberg-tweezer platform that realizes doped quantum magnets with hard-core bosons. Quasi-adiabatic state preparation enables access to low-temperature states of frustrated triangular-lattice magnets, revealing unconventional magnetic phases and the first direct observation of kinetically induced hole–magnon bound states. I will then show how coherent local excitation protocols, combined with single-atom imaging, enable spatially resolved spectroscopy analogous to scanning tunneling microscopy (STM), providing direct access to local spectral functions and quasiparticle excitations.

I will then turn to recent developments in optical lattices that establish a quantum-simulation analogue of optical Raman spectroscopy and resonant inelastic x-ray scattering (RIXS) by performing lattice modulation spectroscopy. These measurements provide direct access to the magnetic excitations of the doped Fermi–Hubbard model and reveal a universal energy scale governing both its thermodynamic and dynamical properties at finite doping.

Topological phases in two-dimensional Rydberg lattices

Mathias Svendsen

Institut für Theoretische Physik, Universität Tübingen

We propose theoretically a simple two-dimensional system consisting of two square lattices of Rydberg atoms for the exploration of topological phenomena. In particular, we exploit the strong dipole-dipole interactions between Rydberg atoms to simulate a two-dimensional Su-Schrieffer-Heeger model. This model reveals a plethora of topological phases, which can be reached by varying the lattice geometry. We predict not only the emergence of edge and corner states, which characterize topological insulators, but also the appearance of pairs of topologically charged Dirac points and cones in gapless semimetallic phases. Moreover, the position, tilt, and degree of anisotropy of the cones, which may determine the transport properties in the system, are tunable via the lattice parameters. This establishes Rydberg lattice gases, which are already at the forefront of quantum simulation platforms, as the ideal setup for the exploration of topological phenomena.

Quantum Optical Twist and Scan Microscopy

Emre Yazici

ETH Zurich

The twist angle in van der Waals heterostructures is a key control parameter of moiré physics, but is typically fixed during fabrication. Building on the Quantum Twisting Microscope (QTM), we are developing an optical QTM that combines in situ twist-angle control with optical spectroscopy of the twisted interface. I present the experimental realization of this platform, and discuss the correlated electronic and excitonic phenomena it is intended to probe. I also present initial experimental results.

6 Posters

List of Posters

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Fractional Chern insulator in an amorphous lattice

Isidora Araya Day

DIPC, San Sebastián

The combination of a flat Chern band and strong interactions provides a natural route to fractional Chern insulating phases. While these phases are usually formulated in crystalline lattice models, their defining signatures are topological and many-body in nature. In this work we ask: can fractional Chern phases also emerge in geometrically disordered systems that lack long-range spatial order?

We find a positive answer to this question by considering a model of hard-core bosons on an amorphous kagome lattice at filling 1/6. Using DMRG techniques, we observe several signatures of a fractional insulating phase: a robust ground-state degeneracy, a quantized fractional pumped charge, and a characteristic entanglement spectrum. These diagnostics indicate that fractional topological order can persist even when translation symmetry and momentum-space band geometry are absent. To the best of our knowledge, this is the first example of a fractional Chern insulator in a system without spatial order.

Wannier center spectroscopy to identify boundary-obstructed topological insulators

Dario Bercioux

DIPC, San Sebastián

The hallmark of topological crystalline insulators is the emergence of a robust electronic state in a bandgap localized at the boundary of the material. However, end, edge, and surface states can also have a nontopological origin. Unfortunately, topological invariants such as the winding number and Zak phase are often not directly experimentally accessible for solids. In addition to topological invariants, the position of the Wannier centers provides a fingerprint for the topological character of a material. Here, we demonstrate a method to experimentally determine the location of Wannier centers in artificial lattices made of Cs/InAs(111)A by integrating the density of states. We determine the locations of the Wannier centers for various 1D chains, topological and trivial, and corroborate our findings with tight-binding simulations.

Interaction Effects in Topological Non-Trivial Quantum Few Body Systems

Jyoti Bisht

Okinawa Institute of Science and Technology, Japan

The topological properties of quantum many body systems are a topic of interest that can be investigated in condensed matter and ultracold atomic systems. In this presentation I first show that in the interacting Su-Schrieffer-Heeger chain one can observe the transmigration of edge states from the physical charge gap to a higher energy gap as the interaction strength increases [1]. Next, I investigate the Arbitrary Finite Kronig-Penney (AFKP) model, which is a continuum system, to explore the robustness of topological features against the local disorder [2, 3]. Motivated by these insights, I finally investigated the effect of spatial modulation on the spectral function within the AFKP. The insights obtained from this study about the interplay of topology, interaction, and continuum potentials may lead to new topological phases in ultracold atomic systems.

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Exploring supersolid phases and droplet formation in ultracold dipolar systems with quantum Monte Carlo

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Due to the long-range and anisotropic nature of dipolar interactions, ultracold dipolar systems have emerged as a unique platform for exploring exotic phases of matter. This talk focuses on two remarkable achievements that have boosted the field in recent decades: the formation of ultradilute quantum droplets and the observation of supersolid states of matter in arrays of such droplets. Recent advances in creating Bose–Einstein condensates (BECs) with ultracold dipolar molecules complement previous experiments with magnetic dipolar atoms, providing access to different regimes of interaction strength. In this talk, I discuss the differences and similarities between droplets formed in BECs of magnetic dipolar atoms [1] and electric dipolar molecules [2], and how this enriches the variety of supersolid states that can be found in ultracold dipolar systems, which give rise to different exotic phenomena. For example, in recent years, the emergence of supersolid states after heating a gaseous BEC has been discussed [3,4].

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Quantum Resistance Paradox of Low-Dimensional Superfluids

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ETH Zurich

Resistance in standard conductors decreases with increasing cross-section. Yet, in low-dimensional superconductors and superfluids residual resistance arises from topological fluctuations of the order parameter manifesting as phase slips in one-dimensional (1D) and vortices in two-dimensional (2D) systems. How resistance and dissipation evolve as geometry interpolates between these regimes remains an open question. This evolution is masked in solid-state experiments by disorder, impurities, and geometric imperfections, and poses theoretical challenges due to competing dissipative processes and pronounced finite-size effects. Here, we use a defect-free unitary Fermi gas in a digitally programmable transport geometry to isolate geometric effects on superfluid dissipation and discover a paradox: in the crossover from 1D to 2D, the resistance reaches a minimum. There, widening a channel increases its resistance. Narrower, quasi-1D channels show dissipation described by Langer-Ambegaokar-McCumber-Halperin theory of phase slips. In this regime, varying the channel width yields the predicted exponential scaling of the activation factor over more than ten orders of magnitude. Wider, quasi-2D channels show dissipation consistent with a finite-size vortex model. The minimal dissipation in the dimensional crossover reflects a transition in the dominant dissipative mechanism, with both phase slips and vortices simultaneously suppressed. Our measurements suggest a route to minimizing dissipation in superconducting devices and provide a benchmark for theoretical efforts aimed at describing the dimensional crossover.

Fractional Quantum Hall States and Chern Number with Quantum Computing

Juan Borge

Universidad del Pais Vasco (UPV-EHU)

We investigate the use of variational quantum algorithms to prepare and characterize fractional quantum Hall states on near-term quantum processors. Focusing on the $(\nu = 1/3)$ Laughlin phase described by the V1 Haldane pseudopotential, we formulate the lowest-Landau-level problem in second quantization and implement particle-number-preserving variational circuits combined with the variational quantum eigensolver (VQE) and variational quantum deflation (VQD). We benchmark the approach in two complementary geometries: the Haldane sphere, where the Laughlin state appears as a unique zero-energy ground state, and the torus, where the system retains its genuinely two-dimensional periodic character and displays the threefold topological ground-state degeneracy expected for the $(\nu = 1/3)$ phase. We compare noiseless simulations, noisy quantum-processor results, and error-mitigated estimates with exact diagonalization, using both energy estimates and subspace-overlap diagnostics. We further discuss how twisted boundary conditions and momentum-resolved state preparation provide a natural route toward the extraction of many-body Chern numbers from variationally prepared states. Our results indicate that hybrid quantum algorithms can approximately reconstruct the low-energy structure of small fractional quantum Hall systems and provide a stepping stone toward quantum simulations of fractional Chern insulators and strongly correlated topological phases in realistic two-dimensional materials.

From crystals to correlations: a robotic sample pipeline for neutron-based entanglement witnesses

Petr Čermák

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Quantum Fisher information (QFI) provides a route to placing lower bounds on multipartite entanglement in quantum magnets through the dynamical spin susceptibility measured by inelastic neutron scattering. Extending this approach from individual benchmark experiments to systematic studies of quantum materials, however, requires sufficiently large, well-characterized and reproducibly aligned single-crystal samples. We present a robotic pipeline for the preparation of neutron-ready samples, connecting crystal synthesis and Laue-based orientation and automated co-alignment of multiple crystals. The spin-5/2 triangular-lattice antiferromagnet $Na_2BaMn(PO_4)_2$ serves as a first demonstrator. Our recent single-crystal neutron-diffraction study [1] established its field-dependent spin structures and phase diagrams and showed that frustrated interlayer exchange organizes its unexpectedly rich sequence of magnetic phases. We have subsequently collected inelastic neutron-scattering data that provide access to its dynamical spin correlations. Using this material as an example, we discuss how automated sample preparation and standardized sample geometry can improve the throughput, reproducibility and comparability required for momentum-, temperature- and field-resolved QFI studies. The aim is to move neutron-based entanglement witnesses from bespoke experiments toward a systematic screening and characterization tool for quantum magnets.

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Designing topological quantum matter with atomic precision

Deung-Jang Choi

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Topological superconductors provide a compelling platform for exploring emergent quantum phenomena and realizing new paradigms for quantum information. I will discuss our efforts to engineer and investigate exotic quantum states in superconducting systems using atomic-scale manipulation and scanning tunneling microscopy (STM). By assembling magnetic nanostructures atom by atom on superconducting surfaces, we tailor their electronic and magnetic properties and systematically control their interactions [1]. Through high-resolution spectroscopic measurements of the local density of states, we probe the emergence of unconventional bound states and their evolution as a function of the engineered structure. These measurements provide direct access to the interplay between magnetism, superconductivity, and topology, allowing us to test theoretical predictions and investigate quantum topological phase transitions driven by magnetic impurities and their configurations. Particular emphasis will be placed on the emergence and manipulation of Majorana bound states and the signatures associated with their non-Abelian nature. By combining atomic-scale design, spectroscopic characterization, and theoretical modeling, our work establishes a direct connection between engineered quantum matter and its microscopic electronic structure [2,3,4]. These results highlight the potential of atomic manipulation as a route toward designing and controlling topological quantum phases, with implications for the realization of robust platforms for topological quantum computation.

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Majorana fermions from 2 to 1 dimension

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Majorana fermions (MFs) are unique quasiparticles that act as their own antiparticles. In two-dimensional superconductors, they possess exotic statistical properties as non-Abelian anyons, making them a highly promising platform for hardware-protected topological quantum computation. In this work, we present an interferometric protocol designed to directly measure the non-Abelian nature of these quasiparticles and demonstrate its capacity to distinguish between different anyonic species. Furthermore, we show how a variant of this protocol can be utilized to transfer a conventional spin qubit into a topological, anyonic qubit. Extending our scope to lower dimensions, where realizing physical models that host MFs remains challenging, we demonstrate that signatures of Majorana physics can persist even within a simple, gapless, number-conserving one-dimensional system. Finally, we illustrate how this 1D model can be feasibly implemented using ultracold dipolar molecules.

Electron Quantum Optics with Graphene Nanoribbon Networks

Thomas Frederiksen

DIPC, San Sebastián

Graphene nanoribbons (GNRs) are emerging as versatile platforms for quantum technologies owing to their tunable electronic and Π-magnetic properties. Their weak spin-orbit and hyperfine interactions make them attractive candidates for spin filters, spin qubits, and electron quantum optics devices [1].

We theoretically investigate electronic transport in crossed zigzag GNR devices using a mean-field Hubbard model combined with Green's function techniques. When two ribbons intersect at an angle of approximately 60°, electrons injected from one electrode are coherently split into two of the three outgoing ports. Accounting for edge spin polarization, we show that these junctions can operate as efficient spin-polarizing electron beam splitters [2].

We further study Mach-Zehnder-like interferometers based on zigzag GNR networks, demonstrating coherent quantum interference and highlighting the potential of GNR architectures for realizing more complex quantum electronic devices [3].

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Electronic properties of Mg@C60 and potential Rydberg blockade-like mechanism from ab initio simulations

Donghang He

University of Cambridge

Endohedral fullerenes are molecular systems in which atoms or clusters of atoms are encapsulated in a fullerene cage. Studies have shown their applications in quantum technologies. In this work, the electronic properties, superatomic molecular orbitals (SAMOs), and excitations of a magnesium atom encapsulated in buckminsterfullerene (Mg@C60) and its dimer system are investigated using density functional theory. The transition dipole moment and shift in excitation energy of one Mg@C60 induced by the excitation of its neighbour are evaluated under a frozen orbital approximation. The numerical results demonstrate the potential applications of the Mg@C60 dimer system in quantum technologies via a Rydberg blockade-like mechanism.

Beyond standard DFT: advanced ab initio many-body approaches to exciton phenomena in van der Waals matter

Daniel Hernangómez Pérez

CIC nanoGUNE, San Sebastian

Van der Waals materials are atomically thin layered systems known for their unique electronic and optical properties, notably their rich excitonic behavior. Their complex excitonic spectra can be shaped by an intricate interplay of many-body correlations, geometry, and magnetic order, posing a significant challenge to simple models but also to density functional theory - the traditional ab initio atomistic workhorse. In this talk, I will present two advanced, complementary approaches to describe magneto-optical phenomena in different dimensionalities of van der Waals matter. First, I will discuss a many-body perturbation theory framework using the GW-Bethe-Salpeter equation (GW-BSE) to understand the excitonic g-factor, which characterizes the shift of the photoluminescence signal under external magnetic fields. Using a monolayer transition metal dichalcogenide as an example, I will show how our theory naturally reveals the magnetic-field hybridization of higher-energy excitons (p, and d like) and can resolve a long-standing puzzle in the field associated to experimentally observed non-monotonic Rydberg series in these materials. This framework offers a comprehensive approach to investigate signatures of quantum geometry, selection rules and excitonic fine structure within many-body states. Second, and in order to bypass the high computational cost of full many-body perturbation theory in magnetic van der Waals systems, I will present an alternative based on a generalized Kohn-Sham density functional approach with on-site corrections that accurately reproduces electronic bandstructures, optical spectra, exciton binding energies of CrSBr, a layered van der Waals antiferromagnet. Using a minimally tuned two-parameter set tuned, we achieve excellent agreement across a broad range of optoelectronic and magnetic properties. Together, these developments establish a robust and versatile predictive toolkit for exploring, rationalizing, and controlling novel many-body magneto-optical signatures in layered quantum matter. This work has been carried out in collaboration with P. E. Faria Junior (University of Central Florida), T. Amit & S. Refaely-Abramson (Weizmann Institute of Science), A. Ramasubramaniam (University of Massachusetts, Amherst), J. Junquera (Universidad de Cantabria) and M. Camarasa-Gómez [Centro de Física de Materiales (CFM-MPC)].

Ergotropy Extraction Under Observational Constraints

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Coherent energy transfer in quantum systems plays an increasingly important role in emerging platforms such as quantum batteries and engineered many-body quantum systems. In this setting, ergotropy, the maximum work extractable from a quantum state via unitary operations, quantifies the operationally accessible energy stored in a quantum system. Standard formulations of ergotropy assume complete knowledge of the quantum state, allowing one to construct a globally optimal work-extraction unitary. We instead consider the experimentally relevant setting in which one has access to many identical copies of an unknown quantum state, but only to a restricted set of coarse-grained measurements that one can perform on these copies. Such an observational constraint fundamentally limits the information we can obtain about the state and therefore the amount of extractable work. This raises the following questions: can one design an ergotropy extraction protocol that operates under restricted measurement access, and can such a protocol be realized on an existing experimental platform? In this poster, we present an observational ergotropy extraction protocol introduced in [1] and analyze the feasibility of its implementation within a trapped-ion quantum simulator architecture.

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Accelerated Tensor Network Simulation of 1D Fermi-Hubbard Quench Dynamics Beyond Current Quantum Simulations

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Establishing quantum advantage requires comparison against the best achievable classical simulation. A recent quantum simulation of quench dynamics of the one-dimensional Fermi-Hubbard model on an IBM processor completed a $L = 60$ evolution to time $t = 6$ in under three minutes, claiming a $3000\times$ speedup over a classical TDVP benchmark at bond dimension $\chi = 4096$ — a benchmark that failed to converge in the high-entanglement regime $t \in [5.2, 6]$, leaving the most challenging window of the experiment unverified. Here, we push the boundaries of classical simulation by exploiting the full $U(1) \times SU(2)$ symmetry of the Fermi-Hubbard Hamiltonian combined with GPU-accelerated tensor contractions. Reaching bond dimensions up to $\chi \approx 62,000$ on four NVIDIA H200 GPUs — fifteen times larger than the prior classical baseline — we achieve fully converged results across the entire simulation window, including rigorous certification of the previously unresolved high-entanglement regime $t \in [5.2, 6]$, and advance the classical frontier to t=7, beyond any previously verified classical evolution of the full wavefunction. At comparable bond dimension, our GPU implementation completes in ~ 100 minutes, directly reducing the claimed $3000\times$ quantum advantage to $\sim 36\times$. These results substantially narrow the quantum-classical performance gap and establish a new standard for tensor-network benchmarking of large-scale quantum simulations.

Quantum Advantage: A Tensor Network Perspective

Augustine Kshetrimayum

Multiverse Computing

We review the recent quantum advantage experiments by IBM, D-Wave, and Google, focusing on cases where efficient classical simulations of the experiment were demonstrated or attempted using tensor network methods. We assess the strengths and limitations of these tensor network–based approaches and examine how the interplay between classical simulation and quantum hardware has advanced both fields. Our goal is to clarify what these results imply for the next generation of quantum advantage experiments. We identify regimes and system features that remain challenging for current tensor network approaches, and we outline directions where improved classical methods could further raise the standard for claiming quantum advantage. By analyzing this evolving competition, we aim to provide a clear view of where genuine, scalable quantum advantage is most likely to emerge.

Dynamical current as a spin-state discriminator in open-shell GNR's

Nico Leumer

Wroclaw Tech

The recent advances of surface synthesis unlocked the potential of open-shell physics in graphene nanoribbons (GNRs) which ever since have gained significant attention. Normally chemically unstable, these structures feature unpaired, localized pZ-lectrons pinned at zero energy, giving rise to the unique phenomenon of Π-magnetism. At half-filling certain GNRs host quasi degenerate spin singlets/triplets states with a vanishing energy gap for long ribbons and without significantly increasing the gap conventional current-based measurements hardly distinguish these spin textures.

In our setup charge current I(t) discriminates between the responsible states –even for a vanishing gap– by means of a Spin-Pauli blockade (SPB). We discuss how our setup preserves the states, how their distinct spatial profile causes different charging energies and such that a variation of the reservoirs chemical potentials allow the isolation of singlet/triplet signals. Rather than considering only ensembles of measurements or repetitions, our setup allows for single-shot experiments simulated by Monte-Carlo trajectories. We report on the fidelity to identify properly the spin state by measurements on a finite time scale.

Tuning topological phases and exceptional points in a non-Hermitian Rice–Mele model beyond nearest neighbors

Carolina Martinez-Strasser

DIPC, San Sebastián

Exceptional points are degeneracies characteristic of non-Hermitian operators, where eigenvalues and eigenvectors coalesce, rendering the Hamiltonian defective. We investigate the exceptional-point structure and topological properties of a generalized non-Hermitian Rice–Mele model with balanced gain and loss, as well as next-nearest-neighbor hopping. The system hosts only second-order exceptional points under both periodic and open boundary conditions. Under periodic boundary conditions, the exceptional points in parameter space lie on lines and ellipses that are independent of the next-nearest-neighbor hopping, since the latter enters the bulk Hamiltonian only as an identity contribution. Under open boundary conditions, this independence is broken: the next- nearest-neighbor hopping not only shifts the energy of existing exceptional points but also generates new ones, with a specific condition signaling a topological gap closing observed only in the open- boundary spectrum. At special parameter points, multiple simultaneous second-order exceptional points yield degenerate configurations whose degeneracy grows with system size. Exceptional point locations are identified numerically via the condition number of the eigenvector matrix and confirmed by Jordan decomposition. The topological phase diagram, computed via a winding number framework for non-Hermitian systems without symmetry protection, reveals sectors with zero, one, and two edge states. The bulk-boundary correspondence is confirmed, and the non-Hermitian skin effect is absent.

Generation of autonomous quantum resources by dissipative quantum systems

Tomas Novotny

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Theory of open quantum systems, i.e., systems coupled to thermal bath(s) in the quantum regime [1] despite of its age still constitutes a vivid research field addressing various aspects of the general question how the dissipative coupling to a bath, which inevitably also brings quantum noise, influences the quantum dynamics of the studied system. The question is particularly important in the context of quantum information setups where quantum resources such as coherence or entanglement should be prevented from the (supposedly) detrimental effects of the noise. However, as it has turned out recently, the sole dissipative coupling of a quantum systems without any further external control (such as driving fields) can, in fact, also be used for generation of such quantum resources, which are then called autonomous. Our contribution addresses two complementary situations for generation of quantum resources — autonomous coherence generated by coupling to an equilibrium quantum bath [2,3] and generation of autonomous quantum entanglement in a nonequilibrium setup [4,5].

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Quantum Spin Liquids and Locality from Global Cavity Interactions

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Neutral atoms individually trapped in arrays of optical tweezers that feature strong Rydberg interactions have emerged as a leading platform for exploring correlated quantum phenomena. More recently, there have been experimental efforts to integrate Rydberg arrays with high-finesse optical cavities, with the primary motivation of quantum networking. Here, we explore such interfaces as a novel platform for strongly correlated physics, driven by the competition of short- and long-range interactions and the breakdown of locality.

We propose Rydberg array-cavity systems as a route to prepare and investigate quantum spin liquids (QSLs). Topological quantum spin liquids are exotic phases characterized by long-range entanglement and emergent gauge fields. We specifically consider a minimal model of a Rydberg array-cavity interface, consisting of a frustrated short-range J1-J2 Ising interaction and an antiferromagnetic all-to-all cavity-mediated XX interaction. Our result motivates a broader program to deepen our understanding of correlated phases of matter and topological order in an intrinsically non-local setting. Whether standard techniques and intuition of short-range correlated phases can be meaningfully extended to non-local systems—or whether entirely new conceptual tools are required—remains an open frontier.

Fullerene quantum magnets

Bo Peng

University of Cambridge

Molecules provide more tuneable building blocks than atoms [1,2] and can self-assemble into larger structures [3,4] with richer structural behaviours [5] for quantum devices. Using pure-carbon fullerene molecules that were believed to be non-magnetic [6], we show that magnetism in this material family can be induced purely by symmetry [7]. We can then use this pure-carbon magnetic material to design various quantum platforms, based on experimentally synthesised monolayers [8,9], to realise exotic quantum phenomena such as ferromagnetic Chern insulators [10], antiferromagnetic spin chain [11], altermagnetism and quantum spin liquid [12], as well as magnetoelectrics where spins can be controlled by electric fields. If time allows, I will also discuss my ongoing research that combines both atomic and molecular building blocks. With this approach, we can unlock even more exciting applications such as quantum timekeeping and quantum simulation.

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Quantum twisting microscopy as a momentum-resolved probe of quantum geometry and sublattice symmetries

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In two-dimensional (2D) flat-band systems, as engineered, for instance, by stacking and twisting van der Waals materials, the momentum dependence of the Bloch states is a key factor in determining the interaction-induced emergence of different phases. Hence, methods of probing this form of "quantum geometry" are crucial to understanding these systems. Yet, a momentum-resolved experimental probe of the underlying quantum geometric tensor is missing for 2D systems. Here, we propose employing a quantum twisting microscope (QTM) with a sublattice-polarized tip to fill this gap. We show how expectation values of the sublattice Pauli matrices can be probed across the scanned momentum path. This allows to directly measure crucial symmetries characterizing the different candidate instabilities in graphene-based moiré systems. We furthermore show that the quantum metric component along the scan direction can also be extracted. The full quantum geometric tensor is also accessible, given that more than one sublattice polarization can be used. Our work illustrates the potential and extends the versatility of the QTM approach. If implemented in future experiments, this would provide unprecedented access to the symmetry signatures of the correlated phases and to the underlying quantum geometry in twisted bilayer graphene and related systems.

Inelastic confinement-induced resonances in multiwell potentials

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Recently, resonance features associated with multiwell effects have been reported in a fascinating experiment conducted with a quantum simulator of ultracold atoms [Y. Kyung Lee, H. Lin, and W. Ketterle, Phys. Rev. Lett. 131, 213001 (2023)]. The results were explained as a consequence of superexchange, which determines the spin dynamics in a single-occupied Mott insulator, by allowing the virtual population of two particles on the same site.

In this communication, we provide a complementary interpretation of the resonance features as a consequence of inelastic confinement-induced resonances, manifested as avoided crossings in the two-particle spectrum, showing excellent agreement with the experimental results. The comparison of the results of the single- and double-well descriptions of the optical trapping potential confirm the multiwell origin of the experimental features. Furthermore, the double-well model is already sufficient to provide an explanation of the apparent symmetry violation that is observed within the single-well approach. To conclude, certain limitations of the harmonic approximation are also discussed.

Ancilla-Induced Connectivity Disorder and Confinement in Facilitated Rydberg Chains

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We investigate a facilitated Rydberg chain locally coupled to ancillary atoms, providing a programmable platform to engineer correlated many-body dynamics. In the regime of strong system-ancilla coupling and frozen ancilla dynamics, the ancillary degrees of freedom selectively suppress resonant cluster hopping processes. As a result, ancilla configurations induce an effectively quenched connectivity disorder in the hopping graph of excitation clusters. Using an effective pseudoparticle description of the facilitated dynamics, we show that the accessible Hilbert space decomposes into disconnected finite sectors determined by the ancilla configuration. This ancilla-induced graph fragmentation strongly constrains transport and leads to exponential confinement of disorder-averaged excitation dynamics. We derive analytically a confinement length controlled solely by the ancilla preparation statistics and benchmark our predictions against numerical simulations. Our results identify connectivity disorder as a distinct mechanism for localization-like behavior. More generally, they demonstrate how programmable ancillary degrees of freedom in Rydberg quantum simulators can be exploited to engineer and control emergent correlated dynamics, opening new possibilities for designing synthetic quantum matter with tailored transport properties.

Circulation Statistics and Migdal Area Rule Beyond the Kibble-Zurek Mechanism in a Newborn Bose-Einstein Condensate

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The Kibble-Zurek mechanism (KZM) predicts that a newly formed superfluid prepared by a finite-time thermal quench is populated with vortices. The universality of vortex number statistics, beyond KZM, enables the characterization of circulation statistics within any region of area A enclosed by a loop C. Migdal's minimal area rule of classical turbulence predicts that the probability density function of circulation around a closed contour is independent of the contour's shape. We verify the Migdal area rule for small loops with respect to the distance between the vortex and antivortex pairs and further characterize its universal breakdown for bigger loops. We further uncovered the nonequilibrium universality dictated by the KZM dynamics, which results in power-law scalings of the moments of the circulation statistics as a function of the quench time.

Control of canalized hyperbolic polaritons in a natural van der Waals quantum material

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Polaritons in van der Waals crystals provide a powerful route to confine and control light far below the diffraction limit. In anisotropic materials, these collective light–matter excitations can exhibit hyperbolic dispersion, enabling high-momentum propagation, directional energy flow, and canalization. Here, we present $MoOCl_2$ as a natural van der Waals platform for controlling hyperbolic plasmon polaritons at telecommunication wavelengths. Using analytical modeling and full-wave electromagnetic simulations, we show that thin $MoOCl_2$ layers support strongly anisotropic polariton modes whose dispersion and propagation can be engineered through the surrounding dielectric environment. In particular, placing $MoOCl_2$ on a gold substrate induces a high-momentum canalization regime, where polariton energy propagates as a collimated, diffraction-free beam along a crystallographic direction, enabling a pattern-free waveguiding concept. We further discuss $MoOCl_2$ polaritonic crystals, defect cavities, twist-tunable band structures, and Purcell enhancement, highlighting the potential of this material for controlling collective optical excitations in anisotropic quantum materials and for developing compact nanophotonic and quantum-optical functionalities at telecom wavelengths.

Dysprosium tweezer arrays for Quantum Simulation and Computation

Eder Vera

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Magnetic lanthanides have recently showed interest to the quantum-simulation and quantum-computation communities due to the enhanced control over ultracold atoms and their interactions. The partially-filled inner 4f shell of elements, such as, erbium (Er) and dysprosium (Dy), results in large orbital quantum numbers and large magnetic moments. This gives rise to a rich atomic spectrum and series of transitions useful for laser cooling, optical manipulation and Rydberg excitation [1, 2].

In this poster, I will show the progress of the new dysprosium lab (DyPQ-S) currently being built at DIPC. The experiment aims to load single Dy atoms into optical tweezer arrays after a 2D magnetic-optical-trap (MOT) stage. Existing experiments including a 2D MOT configuration have reported issues when trapping the 161Dy isotope mainly due to its inverted hyperfine structure [3, 4].The setup at DIPC is engineered to solve this issue and have the ability to trap both the bosonic and fermionic isotopes. The experiment at DyPQ-S will open the doors to the study of Rydberg physics and quantum information. In specific, exciting single atoms to high-angular-momentum states lead to long-lived spin–orbit coupling beneficial for high-fidelity multi-qubit gates [2, 5, 6].

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Synthetic non-Abelian topological charges in ultracold atomic gases

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Topological phases associated with non-Abelian charges can exhibit a distinguished bulk-edge correspondence compared with Abelian phases, although elucidating this relationship remains challenging in traditional solid-state systems. In this paper, we propose a theoretical framework for synthesizing non-Abelian quaternion charges in ultracold atomic gases. By designing artificial spin-orbit coupling patterns, the topological edge modes demonstrate a clear correspondence with the band topology determined by various quaternion charges. This paves the way for observing the interface modes whose existence is attributed to the nonconservation multiplication relation, which is fundamental to non-Abelian charges. This scheme can be readily implemented using current ultracold atom techniques, offering a promising approach to explore the intriguing non-Abelian characteristics of the system.

Absence of Measurement-Induced Phase Transitions in 1D Disordered Free Fermions

Can Yin

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We report the absence of measurement-induced phase transitions (MIPTs) in monitored one-dimensional disordered free fermionic chains with nearest-neighbor hopping by analytically mapping the quantum trajectories associated with real-time state evolution to a non-linear sigma model (NLSM). The addition of on-diagonal disorder breaks the sublattice symmetry of the clean fermionic Hamiltonian, changing the symmetry class of the NLSM from BDI to AIII and leading to different RG universalities, while leaving the area-law phase intact. These theoretical results are confirmed by explicit numerical simulations on graphics processing units (GPUs), which enable us to reach system sizes of $L \sim 20000$, an order of magnitude larger than those in previous studies.

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