XLI Trobades Científiques de la Mediterrània-Josep Miquel Vidal

Workshop and School on *"Frontiers in ultracold quantum gases"*

Book of Abstracts

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Abstracts of the talks

Vortex avalanches and collective motion in neutron stars

Andrew Baggaley

Lancaster University

We simulate the dynamics of about 600 quantum vortices in a spinning-down cylindrical container using a Gross–Pitaevskii model. For the first time, we find convincing spatial-temporal evidence of avalanching behavior resulting from vortex depinning and collective motion. During a typical avalanche, about 10–20 vortices exit the container in a short period, producing a glitch in the superfluid angular momentum and a localized void in the vorticity. After the glitch, vortices continue to depin and circulate around the vorticity void in a similar manner to that seen in previous point-vortex simulations. We present evidence of collective vortex motion throughout this avalanche process. We also show that the effective Magnus force can be used to predict when and where avalanches will occur.

Quantum Monte Carlo applied to ultracold atomic gases

Jordi Boronat

Universitat Politècnica de Catalunya

Quantum Monte Carlo methods are nowadays one of the most powerful techniques to study quantum many-body systems. Starting from the Hamiltonian of the system, these methods allow for very accurate estimations of many energetic and structure properties of quantum fluids and crystals. I will discuss the diffusion Monte Carlo (DMC) method to tackle the problem in the limit of zero temperature. The infamous sign problem linked to Fermi statistics will also be discussed. In a second part, I will introduce the path integral Monte Carlo (PIMC) method that allows for studying, also in an ab initio form, quantum matter at finite temperature. Examples of application of quantum Monte Carlo methods to ultracold atomic gases will also be shown.

Fermionic superfluidity: From Short-Range Pairing to Dipolar Quantum Matter

Cesar Cabrera

Hamburg University

Understanding how fermions pair and how superfluidity emerges from this pairing is a central challenge in quantum many-body physics, with implications ranging from conventional superconductivity to neutron stars. Ultracold Fermi gases with tunable interactions provide a uniquely controlled platform to explore this question across the BEC–BCS crossover, continuously bridging the physics of tightly bound molecules and weakly correlated Cooper pairs. During my talk, I will present two complementary experimental probes of fermionic superfluidity. Using momentum-resolved Bragg spectroscopy, we directly map the low-energy excitation spectrum and observe the emergence of the pairing gap throughout the crossover. I will also show how we nucleate vortices in low-dimensional systems and use them as a real-space probe of phase coherence, establishing superfluidity in a regime where fluctuations are enhanced, and long-range order is fundamentally modified. Finally, I will discuss how dipolar interactions, with their long-range, anisotropic character, open new routes to unconventional pairing mechanisms and geometry-dependent superfluid phases inaccessible with contact interactions.

Superfluid Vortex Dynamics on Curved Surfaces

Mônica Andrioli Caracanhas

Instituto de Física de São Carlos - University of São Paulo - Brazil

Recent advances in ultracold atomic gases have renewed interest in Bose–Einstein condensates (BECs) confined to curved geometries. While several theoretical studies have focused on condensates trapped in spherical shell potentials, the dynamics of quantized vortices on more general curved surfaces remains largely unexplored. Experimentally, shell-shaped condensates can now be realized through a variety of approaches. These include radio-frequency dressed adiabatic potentials combined with gravity compen- sation in terrestrial experiments, phase-separated binary condensates in which one component forms a hollow shell around the other, and microgravity platforms such as the NASA Cold Atom Laboratory aboard the International Space Station. Together, these developments provide unprecedented opportuni- ties to investigate superfluid dynamics on curved and axisymmetric surfaces.

Motivated by these experimental advances, we investigate the dynamics of quantized vortices on general compact axisymmetric surfaces without holes. We develop a conformal mapping approach that transforms the curved surface onto a plane, enabling the use of hydrodynamic stream-function methods to describe vortex motion. This transformation introduces an additional geometric contribution to the vortex dynamics that depends explicitly on the local curvature of the surface.

Within this framework, vortices constitute a Hamiltonian dynamical system whose canonical variables are the angular coordinates of the vortices. We show that the resulting dynamics conserves both the total energy and a generalized angular momentum. Furthermore, our analysis reveals a pronounced anti-correlation between vortex velocity and local curvature, demonstrating how geometry fundamentally shapes the motion of quantized vortices on curved superfluid films.

Ultracold dipolar Bose gases of magnetic atoms: how supersolid states emerge, and current investigations of their structural transitions

Lauriane Chomaz

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Thanks to their high degree of control and tunability, ultracold atomic gases provide a rich platform for the study of quantum many-body effects. Ultracold gases of highly magnetic atoms exhibit unique interaction properties that lead to striking behaviors, both at the mean-field level and beyond [1]. At mean field, depending on the gas geometry, the competition of contact and long-range dipolar interaction may yield novel excitation features, including a roton mode reminiscent of the physics of superfluid helium, and modifies the stability of the system. Furthermore, a universal stabilization mechanism driven by beyond mean field effects and preventing the gas to collapse at the mean-field instability was experimentally discovered a decade ago. This mechanism allows the emergence of exotic states of matter, including ultradilute quantum droplets, crystallized quantum states, and – most notably – supersolids, which combine the seemingly antithetical properties of superfluids and solids [2].

In my talk, I will review the physics of dipolar quantum Bose gases, including roton excitations, stabilization beyond mean field, and stabilized states. I will outline the theoretical description of these systems via an effective mean-field treatment, including the effect of quantum fluctuations via an effective higher-order interaction. I will describe the seminal observations of these phenomena in gases of magnetic atoms and how they were made possible from the long-standing progress in the field. I will present our current understanding of the properties of the stabilized states and in particular of dipolar supersolids, as well as the ongoing research in my group at Heidelberg University, where we explore quantum phase transitions between dipolar supersolids with different crystal organization [3].

References

[1] L. Chomaz et al., "Dipolar physics: A review of experiments with magnetic quantum gases," Reports on Progress in Physics 86, 026401 (2023)

[2] L. Chomaz, "Quantum-stabilized states in magnetic dipolar quantum gases." Annual Review of Condensed Matter Physics 17 (2025)

[3] K. Chandrashekara et al., in preparation (2026)

Josephson junctions with ultracold atomic Fermi gases

Giulia Del Pace

University of Florence

The Josephson effect is one of the most striking manifestations of a macroscopic system phase coherence. When two superconductors or superfluids are connected by a thin insulating barrier, a dissipationless current may arise across the junction, merely sustained by the phase difference between the two reservoirs. Besides representing a powerful probe of phase coherence, Josephson junctions are also fundamental building blocks for quantum technologies. In this talk, I will provide a review of the experimental techniques to study atomic Josephson junction and the main results achieved in this field. I will report experiments on AC and DC Josephson effect, as well as the recent observation of Shapiro steps in atomic junctions under AC drive.

Quantum gases in bubble traps

Romain Dubessy

Aix-Marseille University, CNRS UMR 7345, PIIM, 13397 Marseille, France

In this presentation, I will discuss certain properties of quantum gases trapped in what are known as 'bubble traps', drawing primarily on recent experimental results. I will outline the various methods used to create shell-shaped trapping potentials and explain why it is particularly difficult to confine a quantum gas on a closed surface. I will then present several experiments illustrating the behaviour of a superfluid on a curved surface, and discuss future prospects.

Engineering unconventional superfluids with ultracold bosonic mixtures

Sarah Hirthe

ICFO

Ultracold atoms are a powerful tool to study quantum many-body phenomena. In our quantum simulator in ICFO, we employ bosonic mixtures with tunable interparticle interactions and a precisely engineered dispersion relation to realize unconventional superfluids. In my talk I will guide you through several experiments which have realized quantum states with exotic properties ranging from beyond mean field effects to chirality and supersolidity. By tuning the inter- and intra-species interactions to a situation where the mean field energy cancels, one can reveal beyond mean field effects. In this setting, a novel phase of matter emerges, so called quantum liquid droplets, which are stabilized by quantum fluctuations. This self-bound state is eight orders of magnitude more dilute than liquid Helium, but has similar liquid-like properties.

In a different parameter regime, we use synthetic spin-orbit coupling, where the internal state of the atoms is linked to their momentum through optical coupling. This technique alters the single-particle dispersion relation and leads to effective dressed particles with momentum- dependent spin and interaction properties. By exploiting the interplay of the dispersion relation with tunable interactions, we can realize a supersolid phase of matter. Supersolidity is an exotic phase of matter that spontaneously breaks both gauge and translation symmetry, thus combining the frictionless flow of a superfluid and the crystalline structure of a solid. We can experimentally study the peculiar dynamics of this phase and demonstrate that it has a compressible crystalline structure.

Bose-Einstein Condensates on Curved Surfaces

Natalia Salomè Moller

Slovak Academy of Sciences

The bubble trap experiment opens the possibility of exploring geometric and topological properties in the behavior of quantum systems. Much theoretical and experimental work has already been done to explore the bubble trap experiment, however, a detailed conceptual analysis of geometrical effects was still lacking.

In this seminar, I will present a theoretical analysis of BECs confined on curved surfaces [Oliveira and Móller, AVS Quantum Science 7, 033203 (2025)], where we compute the ground state and investigate curvature-induced effects. Under uniform confinement, we find that atoms preferentially accumulate in regions with the largest difference between the principal curvatures. For a prolate ellipsoid, this leads to atom accumulation at the equator, in contrast to earlier studies that predicted polar accumulation in bubble traps. This discrepancy arises because polar accumulation is driven by confinement anisotropies, while equatorial accumulation is a purely geometric effect.

For clarity, I will first present the main physical insights and results, followed by a discussion of our methodology, which can be adapted to other kinds of 2D quantum systems. Our approach involves a dimensional reduction of the Gross–Pitaevskii equation and relies only on basic mathematical tools: differential and integral calculus, together with the Dirac delta distribution.

Exploring quantum Hall physics with ultracold atomic gases

Sylvain Nascimbène

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Ultracold atomic gases provide a highly controllable platform for investigating quantum many-body phenomena. However, realizing quantum Hall physics in these systems remains challenging due to the charge neutrality of atoms.

In this presentation, I will review key techniques developed to engineer effective magnetic fields for neutral atoms, including rotating gases, Floquet-engineered (shaken) optical lattices, and synthetic dimensions.

I will then present the experimental realization of a quantum Hall system using ultracold dysprosium atoms. In our approach, a synthetic dimension is encoded in the electronic spin manifold with total angular momentum J=8. This platform enables the observation of hallmark signatures of quantum Hall physics, including a quantized Hall response and gapless chiral edge modes.

Finally, I will discuss our recent study of a topological phase transition induced by an additional lattice potential. I will emphasize the system's behavior in the critical regime and explore its connection to the parity anomaly.

Townes soliton beyond mean field

Dmitry S. Petrov

Université Paris-Saclay, CNRS, LPTMS, 91405 Orsay, France

The term quantum anomaly refers to the quantum-mechanical breaking of a symmetry existing in the classical limit. In this talk we discuss this phenomenon in two-dimensional gases with short-range interactions. In particular, we will describe the self-bound ground state and excited breathing states of N two-dimensional attractive bosons bridging the few-body quantum limit with the classical soliton solution for infinite N. The breathing mode in this case is a consequence of the broken mean-field scale symmetry. We discuss implications of these findings and give an outlook for future studies.

Dynamics of finite-temperature shell-shaped Bose-Einstein condensates

Brendan Rhyno

Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Shell-shaped Bose-Einstein condensates (BECs) are a novel platform to study the behavior of quantum fluids on curved manifolds, where the spherical topology influences both quantized vortices and low-energy collective excitations. Interest in these systems has continued to grow since ultracold atomic bubbles were first observed aboard the International Space Station using the Cold Atom Lab (CAL). Motivated by ongoing CAL operations and upcoming microgravity experiments using the Einstein-Elevator at the Leibniz University of Hannover, we investigate the impact of the shell geometry on BEC thermodynamics and nonequilibrium dynamics. Starting from an initial thermal state, we consider an isotropic bubble trap potential and develop formalism to compute n-point correlation functions in different parameter regimes. In the dilute regime, where two-body interactions can be ignored, we study nonequilibrium bubble inflation protocols for arbitrary temperatures. In the ultra-thin 2-sphere regime, at very low-temperatures, we employ Bogoliubov techniques to compute nonequilibrium correlators on the surface of the sphere. We conclude by highlighting the relevance of our results to ongoing experimental efforts.

Statistical Physics of Ultracold Atoms on the Surface of a Sphere

Luca Salasnich

University of Padova

We review recent results about quantum gases of bosons and fermions confined on the surface of a sphere. We analyze the crucial role of the curvature of the sphere on the quantum physics and thermodynamics of these systems.

Cold Atoms, Spin Squeezing, and Quantum Metrology

Alice Sinatra

Laboratoire Kastler Brossel, ENS-Université PSL, CNRS, Université de la Sorbonne et Collège de France, 24 rue Lhomond, 75231 Paris, France

Spin squeezing is a well-established “quantum technology” in which carefully designed correlations in a set of two-level systems reduce the statistical uncertainty in spectroscopic experiments. The presentation will cover recent advances in multi-parameter quantum metrology achieved using Bose-Einstein condensates, the fundamental limits imposed by decoherence, and some promising developments.

Matter-Wave Interferometry Toolbox for Two-dimensional Quantum Gases

Shinichi Sunami

University of Oxford

In this talk, I will introduce various new experimental techniques to prepare and probe two-dimensional quantum gases in continuum, which allows detailed studies of Berezinskii-Kosterlitz-Thouless universality and beyond. This includes selective matter-wave interferometry [1,2], noise interferometry [3,4], and contrast full-counting statistics [5], which provides access to two-point and higher-order phase correlation function of the underlying Bosonic field. I will then report several recent experimental results using these tools [1-5].

[1] Phys. Rev. Lett. 128, 250402 (2022)
[2] Science 382, 443 (2023)
[3] Phys. Rev. Lett. 134, 183407 (2025)
[4] Nat. Commun. 16, 7201 (2025)
[5] arXiv:2601.16204 (2026)

Saturating interaction in coherently coupled two-component Bose-Einstein condensates

Sara Tiengo

Université Paris-Saclay, Institut d'Optique Graduate School

In coherently coupled two-component Bose-Einstein condensates with competing intra- and inter-species interactions, radio-frequency spin coupling enables independent tuning of both two- and three-body interactions. Mixtures of 39K provide an ideal platform, where three-body effects can even dominate the equation of state [1]. Optimal control of the interaction strength in our condensate is achieved thanks to the recently attained ppm-level stability for magnetic fields of tens of Gauss [2]. This technical advancement opens experimental access to a strongly nonlinear regime in which interactions dominate over Rabi coupling, and where mean-field theory predicts a saturation effect of the interaction energy. We experimentally demonstrate this saturation by measuring the expansion of a Bose-Einstein condensate as a function of both the detuning and the Rabi coupling strength in spin mixtures of 39K [3].

References

[1] A. Hammond, L. Lavoine, and T. Bourdel. Tunable Three-Body Interactions in Driven Two-Component Bose-Einstein Condensates. Phys. Rev. Lett. 128 (8 2022) p. 083401.
[2] S. Tiengo, R. Eid, M. Apfel, G. Brulin, T. Bourdel; A simple magnetic field stabilization technique for atomic Bose–Einstein condensate experiments. Rev. Sci. Instrum. 1 June 2025; 96 (6), p. 063201.
[3] R. Eid, S. Tiengo, M. Lévi, T. Bourdel; Saturating interaction in coherently coupled two-component Bose-Einstein condensates. Phys. Rev. A 112 (6 2025), p. 063322.

Low-energy physics for ultracold atoms with non-renormalizable Lattice EFTs

Manuel Valiente

Universidad de Murcia

We consider Lattice regularizations of continuum theories of ultracold gases and liquids. In some physically relevant regimes (such as positive effective range), the resulting Lattice Field Theories are not renormalizable, yielding correlation functions that do not possess a continuum limit. We use generalized short-range universality to show that low-energy properties can nevertheless be extracted close to but not directly in the continuum limit, and are in excellent agreement with Monte Carlo and DMRG calculations.

Abstracts of the posters

Heat Engines Rashba Rings

Sergio Arias Rangel

Universitat de Barcelona

We propose a mesoscopic ring interferometer as a quantum thermal machine utilizing Aharonov-Bohm and Aharonov-Casher effects. Using the Landauer-Büttiker formalism, we analyze a semiconductor ring featuring Rashba spin-orbit coupling (RSOC) and asymmetric gate voltages. Evaluating its charge and spin thermoelectric coefficients reveals that quantum coherence and RSOC effectively tune thermodynamic properties. Notably, the device excels in spin caloritronics, exhibiting enhanced spin Seebeck responses. Furthermore, the Rashba field can externally tune the spin polarization direction. Finally, we identify conditions where broken time-reversal symmetry impacts the overall efficiency of the device as a heat engine.

Macroscopic quantum self-trapping in bosonic Josephson junctions: an exact quantum treatment

Andrea Bardin

University of Padova

We analyze the exact quantum evolution of population imbalance in a symmetric Bose-Josephson junction using the two-mode Bose-Hubbard model. While mean-field theory predicts persistent macroscopic quantum self-trapping (MQST), we demonstrate that for any finite number of particles this regime eventually breaks down. Through symmetry arguments and spectral analysis, we uncover characteristic eigenvalue branching and structured imbalance amplitudes, revealing two distinct dynamical regimes. For large particle numbers, a long-lived quasi-MQST regime emerges. Our results connect mean-field and exact quantum descriptions and shed light on how classical nonlinear dynamics emerges from finite quantum many-body systems.

Pozsgay Balázs

Eötvös Loránd University, Budapest, Hungary

(TBA)

Metrological Sensitivity of Coupled Atomic Dipoles in the Presence of Collective Decay

Ismael Barroso Clarós

Universitat Politècnica de Catalunya

This work investigates the Quantum Fisher Information (QFI) of an ensemble of N coupled atoms subjected to external coherent driving and a dissipative environment. By modeling the system using a master equation approach, we analyze how atom-atom interactions and collective decay influence the precision of parameter estimation. We identify regimes where inter-atomic coupling compensates for decoherence induced by the external bath, potentially preserving metrological advantage.

Spectral properties of Bose-Fermi mixtures in two dimensions

Pietro Bovini

University of Bologna

We study spectral properties of 2D Bose-Fermi mixtures at T=0 using a many-body T-matrix approach, already successfully applied to 3D systems. We study the evolution from the Fermi-polaron regime to the case of a finite concentration of partially condensed bosons, with the latter topic being almost absent in the literature. We find that: The polaronic picture is no longer valid towards the density-matched case. The condensate creates in the bosonic spectral weight function a new structure at negative frequencies. The bosonic Goldstone mode displays a non-trivial dependence on interactions, with a peak in its stiffness at intermediate BF attraction.

Analogue many-body gravitating quantum systems with a network of dipolar Bose–Einstein condensates

Dario Cafasso

CNR-INO Florence, and University Federico II Naples

"Operational probes of the interface between quantum mechanics and general relativity in the Newtonian regime — via mass–energy equivalence in clocks or spatial superpositions in interferometers — share a common description in terms of an effective qubit-qubit coupling. Here we generalize both paradigms to interacting N–level effective qudits made of atomic ensembles. We study the relevant contributions to the entangling dynamics, and how the interplay between local and non-local couplings increases the effective interaction rate, facilitating the observation of gravitationally induced entanglement and decoherence. This talk/poster covers the theoretical description of gravitating quantum systems and is complementary to that proposed by Youssef Trifa. "

Emergence of Zonal Flows in an imbalanced Point-Vortex System

Jorge Carreño Donoso

Institut de Physique de Nice, Université Côte d'Azur

We study the dynamical properties of a system of point vortices with different circulations in a disk with free-slip boundary conditions, inspired by the quantum case of Bose-Einstein condensates, where vortices are quantized. In particular, we consider an imbalance in the number of positive and negative vortices. We observe the formation of large-scale coherent structures using methods from statistical physics, such as Monte Carlo simulations and mean field theory. The numerical results reveal large-scale structural patterns, such as clusters and ring formations that are aligned with zonal flows, as a function of energy and angular momentum. We interpret these structures as corresponding to negative (generalized) temperatures. This study provides insights into the mechanisms of self-organization in such systems, with potential applications in quantum turbulence and geophysical flows through a classical–quantum analogy.

Quantum Fluids of Light

Núria Castillo Ariño

Universitat Autònoma de Barcelona

Quantum fluids of light provide a highly controllable platform for probing many-body quantum phenomena such as superfluidity. In this work, the propagation of a laser beam through a hot rubidium vapor in the nonlinear optical regime is described as a paraxial photon fluid, which can be mapped onto a dilute Bose–Einstein condensate. The primary objective is to investigate the dispersion relation of density excitations in the photon fluid, with the aim of identifying a Bogoliubov-like dispersion relation and the emergence of a superfluid regime. In addition, the medium is characterized via saturated absorption spectroscopy of the rubidium D2 line and nonlinear refractive index measurements based on far-field ring intensity patterns.

Particle-hole origin of thermal beating in dipole-compression modes of a 1D Bose gas

Giulia De Rosi

Universitat Politècnica de Catalunya - BarcelonaTech (UPC)

Using generalized hydrodynamics, we study the thermal behavior of dipole-compression collective oscillations in a harmonically trapped one-dimensional (1D) Bose gas across the crossover from weak to strong repulsive contact interactions. A key scale controlling this behavior is the temperature of the hole-induced anomaly, associated with the thermal population of hole excitations. In contrast to classical hydrodynamics, which predicts a single oscillation mode, we find a beating signal composed of two frequencies. As the temperature increases, both frequencies evolve from the low-temperature phononic hydrodynamic regime toward the collisionless limit around the anomaly temperature, without saturating at the values expected in the high-temperature collisional hydrodynamic regime. The lower frequency originates from hole excitations and is associated to low-energy oscillations, while the higher frequency emerges from particle excitations and corresponds to the dipole-compression mode. The thermal evolution of the relative excitation strengths of the two frequencies reflects the changing population imbalance between particle and hole spectral states across the anomaly. Our results reveal direct connections between excitations, thermodynamics, correlations, dynamics, and interparticle collisions, and may prove relevant to other atomic, nuclear, solid-state, electronic, and spin systems exhibiting similar anomalies or thermal second-order phase transitions.

Analytic Phase Solution and Point Vortex Model for Dipolar Quantum Vortices

Ryan Doran

Lancaster University

In quantum fluids that have long-range anisotropic interactions, vortex cores become elliptical and their phase profile is modified. I present the exact analytic expression for the vortex phase in a dipolar Bose-Einstein condensate, capturing anisotropic effects. This provides a foundation for a dipolar point vortex model (DPVM), incorporating both phase-driven flow and dipolar forces. The DPVM reproduces key features of vortex pair dynamics seen in mean-field simulations, including anisotropic velocities, deformed orbits, and directional motion, offering a minimal and accurate model for dipolar vortex dynamics. These establish a new platform for exploring vortex dynamics and turbulence in dipolar quantum systems.

Bose-Einstein condensation in exotic lattice geometries

Kamil Dutkiewicz

Donostia International Physics Center

We study Bose-Einstein condensation on fractal and hyperbolic lattices and show that geometry strongly affects both the condensation temperature and fluctuations. Fractal lattices lower the condensation temperature and enhance fluctuations, while hyperbolic lattices show the opposite behavior, with a condensation temperature that increases with system size. Including strong repulsive interactions via a multi-site Gutzwiller approach, we obtain the Mott insulator-superfluid phase diagram and show that the shape of the Mott lobe is tied to the dimensionality of the system.

Correlated impurities in ultracold gases: Non-equilibrium dynamics and applications to thermometry

Thomás Fogarty

Okinawa Institute of Science and Technology

We study the correlated decoherence dynamics of two mobile impurities in an ultracold fermionic gas. Using a mean-field approach, we model impurity motion during collisions with the gas, while computing internal-state decoherence exactly via a functional determinant method. We examine nonequilibrium dynamics triggered by a sudden change of the impurities' internal state, accessible through Ramsey interferometry. We find that impurity motion strongly influences decoherence, producing significant deviations from Anderson's orthogonality catastrophe when the impurity–gas mass imbalance is small. Finally, we show that mobile impurities act as sensitive thermometers, with bath-mediated correlations improving low-temperature performance.

Fermi gas on the surface of a sphere

Lorenzo Frigato

Università degli Studi di Padova

Recent experimental realizations of ultracold atoms bubble traps in microgravity conditions have triggered the exploration of quantum many-body physics in curved geometries, beyond the flat-space paradigm. We investigate a two-component Fermi gas on a spherical surface, investigating how the interplay between curvature and interactions modifies its physical properties at finite and zero temperatures. Starting from the non-interacting case, we derive the finite-temperature Stoner criterion for repulsive interactions, examining the spin-balanced phase stability. Furthermore, we explore the BCS–BEC crossover, highlighting the role of the curvature while the system evolves between a weakly paired (BCS) and a strongly paired (BEC) regime.

Study of the Quantum Oscillator Based on an Ion Oscillating in a Penning Trap: Perspectives for Studying 229m Th 3+

Lucía García Fernández-Santaella

University of Barcelona

This work presents the efforts of the Ion Traps and Lasers Laboratory at the University of Granada to improve single-ion detection sensitivity in Penning traps, enabling experiments with two-ion Coulomb crystals and Doppler laser cooling of 40Ca+. The study focuses on the experimental preparation for investigating 229mTh3+, a thorium isotope with a low-energy nuclear isomer proposed as a nuclear clock candidate, including the effects of a 7 T magnetic field on its atomic and nuclear structure. Quantum-optics techniques, high-finesse cavities, single-photon detection, and technical aspects of Penning-trap experiments are also addressed.

Salvatore Marco Giampaolo

Ruđer Bošković Institute

(TBA)

Rearrangement of two-dimensional dipolar supersolids under dipole tilt

Christian Gölzhäuser

Universität Heidelberg

A supersolid is an exotic phase of matter known for its property of exhibiting both superfluidity and crystalline order. In our experiment at Heidelberg we investigate two-dimensional dipolar supersolids of dysprosium atoms. We are able to control the interplay of contact and dipolar interactions and the orientation of the dipoles and thus access a variety of crystal arrangements, including triangular, square and stripe lattice types. We report on our investigations into the phase diagram of finite sized supersolids focusing on the rearrangement of crystal structure between a triangular lattice to a stripe-like density modulation as the dipole orientation is varied.

Self-Assembled Chains and Solids of Dipolar Atoms in a Multilayer

Grecia Guijarro

Universitat Politècnica de Catalunya

We predict that ultracold bosonic dipolar gases, confined within a multilayer geometry, may undergo self-assembling processes, leading to the formation of chain gases and solids. These dipolar chains, with dipoles aligned across different layers, emerge at low densities and resemble phases observed in liquid crystals, such as nematic and smectic phases. We calculate the phase diagram using quantum Monte Carlo methods, introducing a newly devised trial wave function designed for describing the chain gas, where dipoles from different layers form chains without in-plane long-range order. We find gas, solid, and chain phases, along with quantum phase transitions between these states. Specifically, we predict the existence of quantum phase transitions from gaseous to self-ordered phases, as the interlayer distance is decreased. Remarkably, in the self-organized phases, the mean interparticle distance can significantly exceed the characteristic length of the interaction potential, yielding solids and chain gases with densities several orders of magnitude lower than those of conventional quantum solids.

The Bose-Hubbard polaron from weak to strong coupling

Tanul Gupta

CESQ, University of Strasbourg

We study the zero-temperature behavior of a mobile impurity in a bosonic bath on a square lattice using exact large-scale grand-canonical quantum Monte Carlo simulations. We consider both attractive and repulsive impurity-bath coupling across different bath interaction strengths. For weak coupling, the polaron mass ratio decreases near the bath's Mott insulator to superfluid transition, confirming the impurity as a probe of this transition. For strong coupling in the Mott regime, the impurity binds to an extra particle or a hole, depending on interaction sign. Our results benchmark lattice Bose polaron theories and are directly relevant to cold-atom optical-lattice experiments.

Universal momentum tail of identical one-dimensional anyons with two-body interactions

Raul Hidalgo Sacoto

Okinawa Institute of Science and Technology

Non-relativistic anyons in 1D possess generalized exchange statistics in which the exchange of two identical anyons generates a non-local phase that is governed by the spatial ordering of the particles and the statistical parameter α. We identify a many-body Hamiltonian with additive two-body zero-range interactions that supports bosonic and fermionic anyon eigenstates, which are, for arbitrary interaction strength, related through a generalized bosonic-anyon—fermionic-anyon mapping, an extension of the celebrated Bose-Fermi mapping for zero-range interacting 1D systems. Our work reveals intricate connections between the generalized exchange statistics, the universal two- and three-body Tan contact of N identical particles systems, and the emergence of statistics-induced chiral symmetry breaking.

Enhancement of work extraction in many-body quantum batteries using one-dimensional ultracold atoms

Tuan Duc Hoang

Okinawa Institute of Science and Technology (OIST), Japan

In this work, we study the charging performance of a many-body bosonic quantum battery powered by a one-dimensional harmonic-oscillator charger. By tuning the charger frequency, the transferable energy increases and the system can reach resonance, enabling efficient energy transfer and maximal extractable work. In the weak-coupling limit, an effective two-level model accurately predicts stored work, ergotropy, and optimal charging times. Many-body effects enhance charging power and reduce quantum speed limits compared to single-particle batteries, with a comparable irreversible work production. We also show that interactions strongly influence performance: repulsive interactions reduce efficiency, while attractive ones enhance it and create additional resonances.

Fluxonium Qubits for Quantum Simulation: Characteristics and Advantages over Conventional Superconducting Qubits

Pau Jimenez Daban

Universitat Politècnica de Catalunya

Superconducting qubits are a leading platform for quantum technologies, with different architectures offering distinct advantages. In this work, I present a study of fluxonium qubits, focusing on their characteristic properties in comparison with more conventional designs such as transmon qubits. Using Hamiltonian modeling and numerical analysis, I explore energy spectra, anharmonicity, and sensitivity to external flux. These features are discussed in the context of quantum simulation and adiabatic quantum computation. The results highlight the potential of fluxonium circuits for studying quantum dynamics and many body effects, and provide insight into their suitability for emerging quantum technologies.

Boris Krippa

London School of Economics and political science

The dynamics of the binary asymmetric boson mixtures is analysed in the framework of functional RG. We analyse condensates, renormalisation factors, sound velocities and stability criteria. A noticeable deviation from the Bogoluibov theory is found.

Probing the Nature of the Heavy Fermi Polaron

Tobias Krom

University of Heidelberg

We experimentally probe 133Cs impurities embedded in a 6Li Fermi Sea. Using spectroscopic techniques, we measure the polaron energies of the excited and ground states for various interaction strengths, polaron formation dynamics, and the continuously driven polaron. For our mass ratio of 22.2, the well-known quasiparticle picture introduced by Landau becomes questionable since in the limit of infinitely heavy impurities the many-body state becomes fully orthogonal to the initial Fermi Sea – which is known as the Anderson orthogonality catastrophe. With our experiment we test the current understanding of impurity physics, in the heavy but finite impurity mass limit.

Simulating Out-of-Equilibrium Many-Body Dynamics: A Temporal Entanglement Approach for Benchmarking Quantum Simulators

Joaquin Gabriel Marquez Olguin

University of Barcelona

Simulating out-of-equilibrium dynamics is crucial for benchmarking state-of-the-art ultracold quantum gas experiments. While Tensor Networks are incredibly accurate at characterizing many-body ground states, their ability to track real-time evolution is severely limited by the rapid growth of spatial entanglement. This poster presents a novel method to bypass this computational barrier by shifting the focus to temporal entanglement. By analyzing the structure of temporal correlations and employing transverse contraction techniques, we demonstrate how to efficiently compute long-time quantum dynamics in systems like the Transverse Field Ising Model or more complex models like the Next-to-Nearest Neighbours Models. Ultimately, this approach aims to build a scalable computational toolkit capable of providing theoretical validation for current and future analog quantum simulators.

Photoassociation of strontium 87 on the intercombination line

Lily Marquie

Laboratoire de Physique des Lasers

Strontium-87 is a spin-9/2 atom exhibiting SU(N)symmetric spin interactions, leading to exotic physics in strongly correlated systems. Our team's goal is to exploit dissipative mechanisms to produce correlated quantum states: a photoassociation laser induces spin-selective two-body losses, made possible by Pauli's exclusion principle. This drives the system into Dicke states, which hold great promise for quantum simulation or sensing due to the possibility of sub-standard-quantum-limit measurements and to the suppression of interaction shifts. Here I will present our spectroscopy experiments of the photoassociation lines below the transition 1S0-3P1 of strontium, on the two isotopes 88Sr, for calibration against the state of the art, and 87Sr, yet unexplored.

Towards a Tweezer-Lattice Hybrid Quantum Simulator with Single-Site Resolution

Benjamin Millward

University of Cambridge

Optical tweezers are quickly becoming a staple for quantum simulation with ultracold atoms. We are building a new experiment that combines the single-site addressing of optical tweezers and the scalability of an optical lattice. An 8-fold quasicrystalline lattice geometry will be used, giving additional control over the localisation of the atoms. We will explore applications in quantum simulation and sensing with initial goals that include Rydberg dressing and Floquet engineering. The experiment will provide a platform for simulations requiring a large number of atoms, single-site addressing, Rydberg dressing, and access to both bosonic and fermionic species.

Superfluid fraction of interacting bosonic gases

Daniel Pérez Cruz

Polytechnic University of Catalonia

"The superfluid fraction f of a quantum fluid is defined in terms of the response of the system to a weak and constant drag. Notably, Leggett derived two simple expressions providing bounds for f. Our work presents a comprehensive study of the behaviour of both f and the bounds in a wide variety of potentials.

We derive a sufficient condition for the external potential to yield an isotropic superfluid response. Nonetheless, the Leggett's bounds generally feature a strong angular dependence, and here we find the optimal direction along which each bound should be measured."

Study on localizated, ergodic and multifractal quantum states in a double chain with inverse power law hopping and dipolar interaction

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We investigate the emergence of localized, ergodic, and multifractal quantum states in a double-chain lattice with long-range tunneling governed by an inverse power-law hopping and interchain dipolar interactions. Our study focuses on the characterization of the regimes in which eigenstates transition from spatially localized to fully ergodic behavior, as well as intermediate multifractal phases characterized by nontrivial scaling of inverse participation ratios. The competition between inverse power-law hopping and dipolar interchain coupling leads to rich critical behavior, including mobility-edge-like structures and non-universal multifractal scaling exponents. These results provide insight into the interplay between long-range coherence and interaction-driven localization in low-dimensional quantum systems, with relevance for engineered platforms such as cold atoms, trapped ions, and dipolar quantum materials.

FFLO transition and non-Fermi-liquid in the 2D spin-imbalanced Fermi gas at zero temperature

Leonardo Pisani

University of Bologna

The zero-temperature phase diagram "population imbalance versus coupling strength" of the transition to the superfluid state with finite momentum pairing (FFLO) in a two-dimensional Fermi gas is studied. We provide a comprehensive theoretical characterization of the FFLO transition going beyond the historical mean-field characterization by adopting a diagrammatic T-matrix approach within two schemes: the non-self-consistent scheme and the partially self-consistent scheme. At the critical polarization line, we examine the effect of quantum fluctuations on the quasi-particle scattering rate and the quasi-particle weight finding a non-Fermi-liquid behaviour with the resulting breakdown of the Hertz and Millis theory of quantum phase transition.

Quantum sensing of a quantum field

Ricard Ravell Rodríguez

ICFO

Estimating a classical parameter encoded in the Hamiltonian of a quantum probe is a fundamental and well-understood task in quantum metrology. A textbook example is the estimation of a classical field's amplitude using a two-level probe, as described by the semi-classical Rabi model. In this work, we explore the fully quantum analogue, where the amplitude of a coherent quantized field is estimated by letting it interact with a two-level atom. For both metrological scenarios, we focus on the quantum Fisher information (QFI) of the reduced state of the atomic probe. In the semi-classical Rabi model, the QFI is independent of the field amplitude and grows quadratically with the interaction time τ. In contrast, when the atom interacts with a single coherent mode of the field, the QFI is bounded by 4, a constant dictated by the non-orthogonality of coherent states. We find that this bound can only be approached in the vacuum limit. In the limit of large amplitude α, the QFI is found to attain its maximal value 1.47 at $\tau = O(1)$ and $\tau = O(\alpha^2)$, and also shows periodic revivals at much later times. When the atom interacts with a sequence of coherent states, the QFI can increase with time but is bounded to scale linearly due to the production of entanglement between the atom and the radiation (back-action), except in the limit where the number of modes and their total energy diverge. Finally, in the continuous-field limit, where the atom interacts with a continuous source of weak coherent states, this back-action can be simply interpreted as spontaneous emission; we find that the optimal atomic QFI rate is finite, depends on the source intensity, and is upper bounded by the constant rate at which the QFI is emitted by the radiation source.

Simulating two one-dimensional anyons in a harmonic trap using spin-orbit coupling

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"The study of anyons in one dimension has recently attracted the attention of the community, motivated by the experimental creation of systems exhibiting anyonic behavior on continuous and discrete platforms [1, 2]. Compared with bosons (or fermions), for which under a permutation of two particle coordinates, the wavefunction acquires a phase +1 (-1), for anyons, this phase is complex, i.e., they exhibit fractional statistics. Under the appropriate mapping, one can transform the bosonic wavefunction to a fermionic one, or also to anyonic wavefunction [3].

We have developed a method to simulate a one-dimensional anyonic system using an ultracold atom setup. To do that, we studied a system of two particles trapped in a harmonic oscillator potential. We used two-component bosons that interact via a contact potential, modeled by a delta function and a spin-orbit coupling Hamiltonian with a tunable transferred momentum inspired by Ref. [4]. Under the appropriate range of parameters, e.g., in the Tonks Girardeau limit and weak spin-orbit coupling, we obtain a ground state as a function of the transferred momentum between components, which exhibits anyonic properties such as chiral momentum distribution of each component. The transferred momentum of the spin-orbit coupling allows us to change the anyonic phase.

We have obtained results from both theoretical and numerical approaches. On the one hand, we have implemented perturbation calculations up to the fourth order. At the same time, we have implemented numerical calculations using exact diagonalization methods. With both methods, we obtain the same physics properties. Our work provides a simple recipe to realize fractional statistics in one dimension, using the simple but fundamental two-bosonic system in a harmonic oscillator.

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A laser module for laser cooling atomic Cesium

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In the recently started Atomic Quantum Science Lab at UB, we are building a cold-atom apparatus to cool and trap atomic cesium. The choice of the atom is motivated by its well-resolved hyperfine structure and its widely tunable interactions via a Feshbach resonance. In this poster, I will describe the assembly of an 852 nm laser module that will be used for laser cooling and detection. The system consists of several optical elements, an atomic vapor cell and control electronics. By implementing Doppler-free saturated absorption spectroscopy, we can resolve the spectrum of the cesium D2 transition, which will be used to realize a frequency lock of the laser.

Engineering tunnel-coupled tweezer trap potentials for quantum microscopy using a digital micromirror device

Lucile Sanchez

University of Strathclyde

Spatial light shaping devices enable to investigate phenomena appearing beyond lattice geometries. We report on the development of an optical setup aiming at creating tweezer microtraps arranged in a custom geometry using a Digital Micromirror Device. The arbitrary-shaped laser intensity distribution will be superimposed on the atoms through the microscope objective of our quantum gas microscope. We present our feedback algorithm performance to converge to the desired light pattern with spatially coherent and incoherent laser light. Moreover, we investigate the effect of intensity noise and trap homogeneity on atomic tunnelling using a Maximally-localised Wannier functions code developed at Rice University.

Self-graviting chared systems in GR

Hannah Seer

Universidad de Murcia

A model to describe systems of charged particles under the influence of their own gravitational and electromagnetic field is the Einstein-Vlasov-Maxwell system. We study the existence of solutions to this system in the case that it is static and spherical symmetric including also a small cosmological constant. This is done by combining methods from previous works on the system with a vanishing cosmological constant and works on the uncharged Einstein-Vlasov system with a nonvanishing cosmological constant.

A Self-Consistent Quantum Kinetic Theory for Ultracold Bose Gases with Long-Range Interactions

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We present a generalized stochastic quantum kinetic theory for finite-temperature ultracold Bose gases with long-range interactions, derived within the Schwinger-Keldysh formalism. The framework self-consistently couples a stochastic Gross-Pitaevskii equation for the condensate and low-lying modes to a Quantum Boltzmann equation for high-lying modes, while incorporating non-local interactions such as dipolar interactions. The theory reproduces established results for Bose gases with contact interactions and includes the Lee-Huang-Yang correction, providing a plausible scheme for interpolating between quantum and thermal dominated regimes.

Analogue many-body gravitating quantum systems with a network of dipolar Bose–Einstein condensates

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"Operational probes of the interface between quantum mechanics and general relativity in the Newtonian regime share a common description in terms of an effective qubit-qubit coupling. Here, we study the generalization of these approaches to qudit-qudit interaction, with large atomic ensembles. We show that these interactions can be simulated by trapped bimodal Bose–Einstein condensates with long-range coupling, providing a programmable analogue platform to explore gravitating quantum dynamics at accessible time and energy scales. Using qudits allow for a many-body enhancement that facilitates the observation of gravitationally induced entanglement and decoherence, certified by experimentally accessible metrological witnesses."

Fragmentation temperature of 1D and 3D quantum droplets in a BEC mixture

Jeroen Van Loock

University of Antwerp

In a mixture of two Bose-Einstein condensates, the interactions can be tuned such that self bound objects called quantum droplets appear. Whereas the ground states of such quantum droplets at finite temperature have been studied for three- and one-dimensional configurations, the possible fragmentation of these droplets has so far not been considered in these studies.

We show that droplets can lower their free energy by splitting or fragmenting in a combination of multiple smaller droplets and/or a gas. Our results provide important insights on the stability of these droplets.

A Compact Apparatus for Cesium Atomic Arrays

Andrés Felipe Vargas Londoño

Universitat Politècnica de Catalunya

In the recently started Atomic Quantum Science Lab at UB, we are building an apparatus to prepare atomic arrays of cesium. This work presents our preliminary design for the experimental apparatus. In particular, we plan to separate the MOT and the optical-tweezer arrays in two different chambers. To bridge these regions, atoms will be efficiently transported using a conveyor-belt potential based on a running-wave optical lattice. We will discuss what are the most suitable wavelengths for this moving trap and estimate its performance.

Equilibrium and dynamical quantum phase transitions of double well trapped dipolar atoms

Cesare Vianello

Università di Padova

Ultracold dipolar atoms in a double-well potential can be described by an extended Bose-Hubbard model where long-range interactions induce pair tunneling between wells. We investigate how this correlated process affects both zero-temperature equilibrium properties and real-time dynamics. Using mean field theory and exact diagonalization, we analyze equilibrium quantum phase transitions, marked by non-analyticities in the ground state energy, and dynamical quantum phase transitions, identified through singularities in the Loschmidt return rate. We show that pair tunneling significantly reshapes the phase diagram, producing both qualitative changes in the nature of the transitions and quantitative shifts in critical behavior.

Developing a Quantum Gas Microscope with Programmable Lattices

Constanze Vogel

IST Austria

Ultracold atoms in optical lattices provide powerful tools for studying strongly correlated quantum matter. However, current setups are often limited by rigid lattice configurations and slow cycle times. In this poster, we present our approach to building a next-generation quantum gas microscope for fermionic and bosonic lithium atoms. By combining auxiliary optical tweezers with direct optical cooling, we aim to assemble small lattice systems with sub-second experimental cycles. Using holographic projection techniques, we create tailored optical lattices with dynamically reconfigurable geometries. This platform enables a wide range of research, from simple Fermi-Hubbard systems to unconventional lattice geometries.

Sorting atomic positions in an optical tweezer atom array

Matias Volante

Universitat de Barcelona

We report on the sorting and control of atomic positions in an optical tweezer array for strontium-88. Our system uses crossed acousto-optic deflectors (AODs) driven by an arbitrary waveform generator (AWG) to generate and dynamically steer optical tweezers for trapping and transporting atoms. This platform enables flexible control over tweezer positioning and atomic rearrangement within programmable array geometries. We characterize the performance of the tweezers with emphasis on parameters relevant to atom transport and sorting, including transport velocity, motion profile of the protocol, trap lifetime, and multitone control. In addition, we investigate sorting algorithms and geometry-dependent rearrangement strategies aimed at improving filling fraction and scalability of the array. These studies establish the functionality and operational limits of the tweezer system and contribute toward reliable, high-fidelity control of neutral atoms in optical tweezer platforms.

Topological bound states in a lattice of rings with nearest-neighbor interactions

Yunjia Zhai

Universitat Autònoma de Barcelona

We study interaction-induced bound states in a system of ultracold bosons loaded into the states with orbital angular momentum in a one-dimensional staggered lattice of rings. We consider the hard-core limit and strong nearest-neighbor interactions. Focusing on the manifold of such bound states, we derive the corresponding effective model for doublons. With orbital angular momentum l=1, the effective model consists of two Su-Schrieffer-Heeger (SSH) chains and two Bose-Hubbard chains. In a structure that alternates l=1 and l=0 states, the effective doublon model corresponds to an extended Creutz ladder.