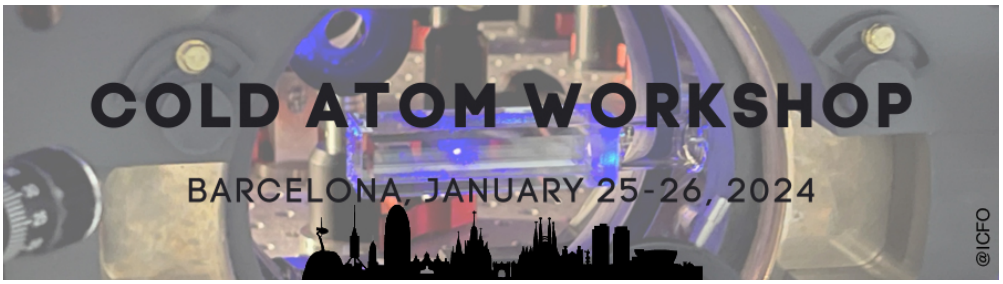
Cold Atom Workshop Barcelona

Thursday, 25 January 2024 - Friday, 26 January 2024

UB Physics Faculty



Book of Abstracts

List of Invited Talks

Session I

Chair: Anna Sanpera (Universitat Autònoma de Barcelona)

25th January, 10:00-10:20

Verònica Ahufinger

Universitat Autònoma de Barcelona

Bosonic orbital Su-Schrieffer-Heeger model in a lattice of rings

We study the topological properties of interacting and non-interacting bosons loaded in the orbital angular momentum states $l = 1$ in a lattice of rings with alternating distances [Phys. Rev. A 108, 023317 (2023)]. At the single-particle level, the two circulation states within each site lead to two decoupled Su-Schrieffer-Heeger lattices with correlated topological phases. We characterize the topological configuration of these lattices in terms of the alternating distances, as well as their single-particle spectrum and topologically protected edge states. Secondly, we add on-site interactions for the two-boson case, which lead to the appearance of multiple bound states and edge bound states. We investigate the doublon bands in terms of a strong-link model and we analyze the resulting subspaces using perturbation theory in the limit of strong interactions. All analytical results are benchmarked against exact diagonalization simulations.

25th January, 10:20-10:40

Michele Modugno

Universidad del País Vasco UPV/EHU & IKERBASQUE

Topological phase diagram of optimally shaken honeycomb lattices

By means of a simple non-perturbative numerical approach, we compute the topological phase diagram for ultracold atoms in shaken honeycomb lattices, under the optimal driving discussed by A. Verdeny and F. Mintert [Phys. Rev. A 92, 063615 (2015)]. These results are used to provide a general discussion of different approaches for computing the effective Floquet Hamiltonian of periodically driven systems.

25th January, 10:40-11:00

Diego Porras Torre

Consejo Superior de Investigaciones Científicas

Phononic Topological Dissipative Phases in Trapped Ions

Trapped ions can be used to simulate a rich variety of bosonic many-body phases that can be implmented with the vibrational degrees of freedom. We will show that by using parametric couplings, phonons in trapped ions can undergo topological dissipative phase transitions. The latter are the phononic counterparts of topological amplifiers, and can be used for sensing ultraweak forces and electric fields. We will present a theoretical framework for the description of dissipative topological phases that goes beyond trapped ions and can be used in other optomechanical, photonic, or ultracold atom systems.

25th January, 11:00-11:20

Tobias Grass

DIPC - Donostia International Physics Center

Bosons in a flat band

Different systems with (nearly) dispersionfree energy bands have appeared in the past years, from magic angle twisted bilayer graphene to optical lattices with exotic lattice geometries, such as the Lieb lattice or the Kagome lattice. Flat bands provide a fascinating arena for strongly correlated many-body phenomena, since their physics is automatically dominated by interactions. In the context of bosonic systems, an intriguing question arises: Will bosons in flat bands condense, and if yes, where? We have analyzed flat band condensates numerically and via a mean-field description. Our results do not only confirm that condensation in the flat band of a Kagome lattice is possible, but also that the condensate may even carry topological properties induced by interactions.

Session II

Chair: Leticia Tarruell (ICFO-The Institute of Photonic Sciences)

25th January, 11:50-12:10

Daniel Barredo

Consejo Superior de Investigaciones Científicas

Exploring quantum magnetism and spin squeezing with Rydberg atom arrays

Rydberg atoms in arrays of optical tweezers offer new perspectives for applications in quantum simulation, quantum computation, and quantum metrology. In this talk, I will describe our recent efforts to control dipolar interactions between Rydberg states to engineer a 2D XY spin Hamiltonian. In this model, we adiabatically prepare low-temperature states of both the XY ferro- and antiferromagnet. In the ferromagnetic case, we observe the presence of long-range order enabled by long-range interactions [1]. I will further show that by performing quantum quenches we can probe the dispersion relation of the excitations in the system [2]. Finally, I will illustrate that, by carefully steering the out-of-equilibrium dynamics, we can generate sizable spin squeezing, which could be used for metrological applications [3].

[1] Chen et al., Nature 616, 691 (2023).
[2] Chen et al., arXiv:2311.11726.
[3] Bornet et al., Nature 621, 728 (2023).

25th January, 12:10-12:30

Sandra Buob

ICFO - The Institute of Photonic Sciences

A strontium quantum-gas microscope in a clock-magic lattice

Quantum-gas microscopy is a powerful tool to study individual particle behavior in quantum many-body systems. Realizing those systems with alkaline-earth atoms such as strontium gives rise to exciting phenomena. For example, bosonic strontium in sub-wavelength atomic arrays exhibits strong cooperative effects in atom-photon scattering. The fermionic isotope in the optical lattice enables studying SU($N \leq 10$)-Fermi systems which give rise to exotic magnetic phases beyond the limits of natural materials.

We have realized a strontium quantum-gas microscope which will allow us to study these systems experimentally. We produce quantum-degenerate clouds of bosonic strontium by evaporative cooling in an elliptical sheet beam which provides confinement in a two-dimensional plane. Then, we load the gas into a square optical lattice of 575nm spacing which arises from the four-fold interference of the bow-tie configuration of the lattice beams. Both the lattice and the sheet beam are operated at 813nm, the clock-magic wavelength of strontium, and have a combined power of around 3W. For imaging, we capture photons scattered at the 461nm transition with a high-NA objective while exploiting the narrow 689nm transition for efficient Sisyphus cooling. We obtain high signal-to-noise-ratio single-site resolved images where the atoms can be imaged for several tens of seconds without observing significant hopping. Furthermore, we detect evidence of superfluid 84Sr in the optical lattice with our quantum-gas microscope.

25th January, 11:00-11:20

Romain Veyron

ICFO - The Institute of Photonic Sciences

Quantum jump photo-detection and quantum trajectory analysis in a single atom experiment

Session III

Chair: Miguel Ángel Cazalilla (DIPC - Donostia International Physics Center)

25th January, 15:00-15:20

Sarah Hirthe

ICFO - The Institute of Photonic Sciences

Exploring the supersolid stripe phase in a spin-orbit coupled BEC

Supersolids are an exotic phase of matter that combines seemingly opposing characteristics of solids and superfluids. They display spontaneous translational symmetry breaking manifesting in crystalline order, while also possessing superfluid properties like frictionless flow. Supersolids were originally predicted over fifty years ago in the context of solid Helium, but were first observed only few years ago in ultracold atomic systems. Cavity-mediated interactions, dipolar interactions, or optically induced spin-orbit coupling can spontaneously break translational symmetry in a Bose-Einstein condensate. Here, we characterize supersolidity in a spin-orbit coupled Bose-Einstein condensate of potassium. We optically dress the system to engineer a single-particle dispersion relation with two minima at distinct momenta. Matter-wave interference between the condensates in the two minima gives rise to a density modulation, which constitutes the spontaneous breaking of translational symmetry and thus realizes the so-called supersolid stripe phase. We are able to observe this spontaneous density modulation in-situ, by employing a matter-wave lensing technique to magnify the density stripes. We achieve a spatial period larger than our optical imaging resolution, which allows us to characterize the crystalline structure of the stripe phase.

25th January, 15:20-15:40

Yuma Watanabe

ICFO - The Institute of Photonic Sciences

Supersolid Phase in Multi-Band Bose-Hubbard Model with Long-Range Interactions

Ultracold bosons in optical lattices provide a fertile platform for studying strongly-correlated many-body systems in a highly controllable manner. Bose-Hubbard (BH) models well describe bosons in optical lattices and have been widely investigated theoretically and experimentally. The conventional BH model consists of the nearest neighbor hopping and on-site interaction between bosons confined in the lowest-Bloch band and exhibits the quantum phase transition between the superfluid and the Mott-insulator, which has been witnessed experimentally with ultracold atoms. Theoretical works have also examined generalizations of the standard BH model, leading to enriched many-body physics. A paradigmatic example concerns long-range interactions: these lead to novel phases, such as the Haldane insulator in 1-dimension, density waves, and the most intriguing supersolid phase. While the experimental realization of long-range interacting Bose Hubbard models has been challenging, recent progress has been made with both cold atomic systems and excitons in semiconductor devices. Interestingly, in the last year, a multi-band extended Bose Hubbard model was realized in a GaAs double well device describing strongly interacting indirect (dipolar) excitons forming a density wave state in a two-dimensional square lattice. Motivated by these experimental breakthroughs, we theoretically investigate two-band physics with on-site and nearest-neighbor interactions in an extended one-dimensional BH model. In particular, we focus on proximity effects due to the interplay of the two bands. With this aim, we consider the case where the intraband parameters of the two bands considered independently support different phases and study the effects of inter-band interactions. We find that coupling a density wave state in one band to a superfluid state in the other can lead to lattice supersolids. Depending on the filling of the bands and the interband interaction strength, the supersolid phase competes with phase separation, superfluid order, or insulating density-wave orders. Interestingly, our results point to a novel possibility of stabilizing a supersolid phase by thermally exciting one of the two bands, which counterintuitively gives rise to a supersolid obtained from heating.

25th January, 15:40-16:00

Aitor Alaña Alvarez de Eulate

University of the Basque Country (UPV/EHU)

Supersolid formation time shortcut and excitation reduction by manipulating the dynamical instability

Supersolids are a phase of matter exhibiting both superfluidity and a periodic density modulation typical of crystals. When formed via quantum phase transition from a superfluid, they require a formation time before their density pattern develops. Some protocols/schemes are proposed for experimental applications, building on earlier descriptions of the role roton instability plays in the supersolid formation process and the associated formation time. In particular, the Parachutejump scheme sought to lessen the excitation produced when crossing the phase transition, and the Bang-Bang method sought to shorten the formation time. The proposed schemes are able to fulfill their objectives successfully as both the shortening of the formation process and the reduction of excitation are achieved within the framework of extended Gross Pitaevskii theory.

25th January, 16:00-16:20

Chen-How Huang

DIPC - Donostia International Physics Center

Modeling Particle Loss in Open Systems using Keldysh Path Integral and Second Order Cumulant Expansion

For open quantum systems, integration of the bath degrees of freedom using the second order cumulant expansion in the Keldysh path integral provides an alternative derivation of the effective action for systems coupled to general baths. The baths can be interacting and not necessarily Markovian. Using this method in the Markovian limit, we compute the particle loss dynamics in various models of ultra-cold atomic gases including a one-dimensional Bose-Hubbard model with two-particle losses and a multi-component Fermi gas with interactions tuned by an optical Feshbach resonance. We explicitly demonstrate that the limit of strong two-body losses can be treated by formulating an indirect loss scheme to describe the bath-system coupling. The particle-loss dynamics thus obtained is valid at all temperatures. For the one-dimensional Bose-Hubbard model, we compare it to solutions of the phenomenological rate equations. The latter are shown to be accurate at high temperatures.

Session IV

Chair: Grigory Astrakharchik (Universitat Politècnica de Catalunya)

25th January, 16:50-17:10

Antonio Tiene

Universidad Autónoma de Madrid

Multiple polaron quasiparticles with dipolar fermions in a bilayer

We study the impurity problem with dipolar Fermi atoms in a bilayer geometry. By evaluating the polaron spectrum, we disclose the appearance of a Rydberg-like series of attractive branches when the distance between the layers becomes smaller. We relate them to the appearance of newly bound molecular states by evaluating their orbital angular momentum component. We observe an interchange of orbital character between these states when the system parameters such as the gas density or the interlayer distance change.

25th January, 17:10-17:30

Raúl Bombín Escudero

Universitat Politècnica de Catalunya

Dysprosium density functional: A Quantum Monte Carlo based functional to study dipolar droplets and supersolidity

We present the Dysprosium density functional (Dy-DF), a density functional to describe droplet formation and supersolidity in dipolar systems. Making use of quantum Monte Carlo we compute with accuracy the equation of state of ^{162}Dy. The quantum correlation energy contribution is used to modify the usual Lee-Huang-Yang term that accounts for quantum correlations in the widely used extended Gross Pitaievskii equation (eGPE). To validate our functional we show that it reproduces the available experimental data for the minimum critical number of atoms needed to form a droplet. Due to its critical nature, the prediction of this quantity is challenging and many theories only achieve a qualitative approximation. Furthermore, we show that our functional can be used also to study the BEC-supersolid transition in these systems. The Dy-DF functional outperforms the state-of-the-art eGPE description without increasing the computational cost.

25th January, 17:30-17:50

Juan Sánchez-Baena

Universitat Politècnica de Catalunya

Effects of curved geometry and finite temperature in dipolar Bose Einstein Condensates

We explore the thermal effects in the phase diagram of a dipolar BEC confined in a tubular geometry, and show that temperature significantly shifts the low density point where the order of the phase transition between the supersolid and fluid phases changes. We also investigate the effect of a shell-shaped confinement in dipolar physics at zero temperature, and show that it leads to the emergence of a rich variety of ring-shaped solids and supersolids.

25th January, 17:50-18:10

Enes Aybar

Universitat Politècnica de Catalunya

TBA

Session V

Chair: Giulia De Rosi (Universitat Politècnica de Catalunya)

26th January, 09:30-09:50

Rosario González-Férez

Universidad de Granada

Rydberg blockade due to the charge-dipole interaction between an atom and a polar molecule

26th January, 09:50-10:10

Fernando Sols

Universidad Complutense de Madrid

Superfluidity from correlations in driven boson systems

We investigate theoretically the superfluidity of a one-dimensional boson system whose hopping energy is periodically modulated with a zero time average, which results in the suppression of first-order single-particle hopping processes. The dynamics of this Floquet-engineered flat-band system is entirely driven by correlations and described by exotic Hamiltonian and current operators. We employ exact diagonalization and compare our results with those of the conventional, undriven Bose–Hubbard system. We focus on the two main manifestations of superfluidity, the Hess-Fairbank effect and the metastability of supercurrents, with explicit inclusion of an impurity when relevant. Among the novel superfluid features, we highlight the presence of a cat-like ground state, with branches that have opposite crystal momentum but carry the same flux-dependent current, and the essential role of the interference between the collective components of the ground-state wave function. Calculation of the dynamic form factor reveals the presence of an acoustic mode that guarantees superfluidity in the thermodynamic limit.

26th January, 10:10-10:30

Miguel Ángel Garcia-March
Universitat Politècnica de València

Quantum correlations in mixtures of a few ultracold bosons

26th January, 10:30-10:50

Maria Arazo
Universitat de Barcelona

Chiral currents in Bose-Einstein condensates subject to current-density interactions

Persistent currents in quasi-one-dimensional Bose-Einstein condensates become chiral in the presence of current-density interactions. This phenomenon is explored in ultracold atoms loaded in a rotating ring geometry, where diverse current-carrying stationary states are analytically found to generalize previously known solutions to the mean-field equations of motion. Their dynamical stability is tested by numerical simulations that show stable currents for states with both constant and modulated density profiles, while decaying currents appear only beyond a unidirectional velocity threshold. Recent experiments in the field place these states within experimental reach.

26th January, 10:50-11:10

Juan Ramón Muñoz de Nova
Universidad Complutense de Madrid

Multiple symmetry breaking in spontaneous Floquet states

We study multiple symmetry-breaking in many-body systems, focusing on the specific case of an atomic condensate. We discuss the quantization procedure of the Goldstone mode associated to each broken symmetry. This quantization involves a Berry-Gibbs connection which depends on the macroscopic conserved charges associated to each broken symmetry and is not invariant under generalized gauge transformations. Our results suggest that some traveling solutions in a ring can be potentially misidentified as time crystals since they do not arise from a genuine breaking of time-translation symmetry but rather from a spatial-translation symmetry breaking plus some constant drift. We extend the formalism to a spontaneous Floquet state, a periodic state which breaks continuous time-translation symmetry. We find that each broken symmetry now has an associated Floquet-Goldstone mode with zero quasi-energy. Thus, the temporal Floquet-Goldstone mode arising from the continuous time-translation symmetry-breaking is the characteristic signature of a spontaneous Floquet state, absent in conventional (driven) Floquet systems, and its quantum amplitude provides a rare realization of a time operator in Quantum Mechanics. We apply this formalism to the CES state, which breaks U(1) and time-translation symmetries, providing a temporal analogue of a supersolid. Using numerical simulations based on the Truncated Wigner method, we show that the temporal Floquet-Goldstone can be measured from the density-density correlations.

Session VI

Chair: Cesar Cabrera (University of Hamburg)

26th January, 11:50-12:10

Javier Argüello-Luengo

ICFO - The Insitute of Photonic Sciences

Analog simulators for high harmonic generation

The demanding experimental access to the ultrafast dynamics of materials challenges our understanding of their electronic response to applied strong laser fields. In this work, we show that trapped ultracold atoms with highly controllable potentials can become an enabling tool to describe phenomena in a scenario where some effects are more easily accessible and twelve orders of magnitude slower. For this purpose, we characterize the mapping between the attoscience platform and atomic simulators, and propose an experimental protocol to simulate the emission yield of High Harmonic Generation, a regime that has so far been elusive to cold atom simulation. As we illustrate, the benchmark offered by these simulators can provide new insights on the conversion efficiency of extended and short nuclear potentials, as well as the response to applied elliptical polarized fields or ultrashort few-cycle pulses. We will also review recent work done in the group where long-range interactions can lead to new phenomena in problems related to quantum transport, ultrafast processes and frustrated phases of matter.

26th January, 12:10-12:30

Pierpaolo Fontana

Universitat Autònoma de Barcelona

Efficient formulations of non-Abelian lattice gauge theories

TBA

26th January, 12:30-12:50

Alberto Muñoz de las Heras

Instituto de Física Fundamental - CSIC

Variational quantum algorithms for quantum optical systems

Variational quantum algorithms (VQAs) have emerged as a powerful tool to make the best out of the quantum hardware available nowadays. The key idea is to use a classical optimizer to find the set of parameters of a parametrized quantum circuit implemented on the hardware such that it minimizes a given cost function. Beyond digital architectures, VQAs also hold great promise for analog quantum optical simulators, i.e., systems in which ensembles of quantum emitters (e.g., neutral atoms, ions, or excitons) interact with photons.

In the first part of this talk, we will adiabatically eliminate the photons, which give rise to effective interations between the emitters. I will illustrate the power of such interactions in creating wave function Ansätze that capture accurately the ground state of quantum critical spin models (XXZ and Ising) [1].

In the second part, we will focus on the photons. By employing the quantum and classical Fisher information as cost function, I will show how to deterministically generate metrologically-relevant states with large photon numbers exploiting tunable quantum optical non-linearities [2].

[1] C. Tabares, AMH, L. Tagliacozzo, et al., Phys. Rev. Lett. 131, 073602 (2023).

[2] AMH, C. Tabares, J. T. Schneider, et al., arXiv:2309.09841 (2023).

26th January, 12:50-13:10

Fabio Revuelta

Universidad Politécnica de Madrid

Inelastic confinement-induced resonances under 3D confinement

Inelastic confinement-induced resonances (ICIRs) [1] offer an alternative way to control atom-atom scattering besides Feshbach resonances [2]. These resonances have their origin in the coupling between the center-of-mass and the relative motion due to the anharmonicities in the optical confinement, irrespective of its shape (optical lattice, optical tweezer, etc.), and of the interatomic potential.

Since the first experimental observation of ICIRs under quasi-1D confinement, their existence has CIRs been also demonstrated under quasi-2D confinement [4] and even in mixed dimensional systems [5]. In this communication [6], we report on the observation of confinement-induced resonances for strong 3D confinement. Starting from a Mott-insulator state with predominantly single-site occupancy, we detect loss and heating features at specific values for the confinement length and the 3D scattering length. Two independent models predict the resonance positions to a good approximation, suggesting a universal behavior. The relation of our work with that recently reported in the Ref. [7] will be also discussed.

Our results extend confinement-induced resonances to any dimensionality and open up an alternative method for interaction tuning and controlled molecule formation under strong 3D confinement.

[1] S. Sala, P.-I. Schneider, and A. Saenz, Phys. Rev. Lett. 109, 073201 (2012); S.-G. Peng, H. Hu, X.-J. Liu, and P. D. Drummond, Phys. Rev. A 84, 043619 (2011).
[2] C. Chin, R. Grimm, P. Julienne, and E. Tiesinga, Rev. Mod. Phys. 82, 1225 (2010).
[3] E. Haller, M. J. Mark, R. Hart, J. G. Danzl, L. Reichsöllner, V. Melezhik, P. Schmelcher, H.-C. Nägerl, Phys. Rev. Lett. 104, 153203 (2010).
[4] B. Fröhlich, M. Feld, E. Vogt, M. Koschorreck, W. Zwerger, and M. Köhl, Phys. Rev. Lett. 106, 105301 (2011).
[5] G. Lamporesi, J. Catani, G. Barontini, Y. Nishida, M. Inguscio, and F. Minardi, Phys. Rev. Lett. 104, 153202 (2010).
[6] D. Capecchi, C. Cantillano, M. J. Mark, F. Meinert, A. Schindewolf, M. Landini,1 Alejandro Saenz, F. Revuelta, H.-C. Nägerl, arXiv:2209,12504 (accepted in Phys. Rev. Lett.).
[7] Y. Kyung Lee, H. Lin, W. Ketterle, arXiv:2208,06054 (accepted in Phys. Rev. Lett.).

List of Posters
(alphabetically sorted by last name)

Grigory Astrakharchik
Universitat Politècnica de Catalunya

Gas-to-soliton transition of attractive bosons on a spherical surface

We investigate ground state properties of N bosons with attractive zero-range interactions characterized by the scattering length $a > 0$ and confined to the surface of a sphere of radius R. For finite N we observe a smooth crossover from the uniform state in the limit $a/R \gg 1$ (weak attraction) to a strongly localized state at small a/R. With increasing N this crossover narrows down to a discontinuous transition from the uniform state to a soliton of size $\sim R/\sqrt{N}$.

Julia Bergmann
UAB/ICFO

Engineering lattice gauge theories with a Rydberg atom processor

In the last years, Rydberg atoms in reconfigurable optical tweezers proved to be an excellent platform to implement Spin Hamiltonians in ultracold atom experiments [1]. An important subject in this matter is the exploration of Ising models with S = 1/2 and higher in one, two and three dimensions, including the investigation of gauge theories emerging in condensed matter physics [2]. As an example, I consider the well-known Rokhsar-Kivelson Hamiltonian, a 2D U(1) lattice gauge theory describing quantum dimer and spin-ice dynamics, in different geometries and investigate the resulting phase diagrams [3]. I explain how to engineer tunable anisotropic attractive as well as repulsive interactions with so-called superatoms by organizing two or more individual atoms in small clusters sharing one Rydberg excitation. The control of the couplings translates in blockade and antiblockade conditions arising in the dual formulation of the Rokhsar-Kivelson Hamiltonian [4]. In collaboration with experimentalists, I develop protocols to investigate this and other gauge theories with Rydberg atoms in reconfigurable tweezer arrays. *Authors:* Julia Bergmann, Leticia Tarruell and Alessio Celi.

[1] A. Browaeys, T. Lahaye, Nat. Phys. 16, 132142 (2020)
[2] S. Sachdev, Phil. Trans. R. Soc. A. 374, 0248 (2016)
[3] D.S. Rokhsar, S. A. Kivelson, Phys. Rev. Lett. 61, 23762379 (1988)
[4] A. Celi, B. Vermersch, O. Viyuela, H. Pichler, M. D. Lukin, P. Zoller, Phys. Rev. X 10, 021057 (2020)

Josep Cabedo Bru
UAB / ICFO

Anyon statistics in a Raman-dressed 1D lattice

Cesar Raymundo Cabrera Cordova

University of Hamburg

Revealing the order parameter dynamics in an ultracold Fermi gas

Superfluidity and superconductivity, exotic phenomena relying on bosonic particles occupying the lowest energy state, are well described using the BEC-BCS crossover. Here the bosonic field, so-called order parameter, emerges by pairing electrons into a composite particle evolving from a Cooper pair to a bosonic diatomic molecule. Remarkably in a two-fluid model, this bosonic field represents the superfluid fraction with its dynamics governed by the Klein-Gordon and Gross-Pitaevskii equation, respectively. Accessing the superfluid fraction experimentally and the connection between these quantum field theories presents challenges due to the absence of direct probes of the bosonic field. Here we explore these bosonic excitations in an ultracold quasi 2D Fermi gas, focusing on the transversal quasiparticles along the confined direction. Spectroscopic analysis via trapping modulation reveals a long-lived mode of the bosonic field throughout the crossover, transitioning from a coherent breathing-of-the-order parameter into a well-defined Higgs-amplitude mode on the weakly interacting BCS side. Analogous to second sound, this mode selectively couples to the superfluid density, offering a unique avenue to investigate superfluid properties along the crossover. Remarkably, the dynamics of the bosonic field follow a crossover from a non-relativistic to a relativistic harmonic oscillator, providing a versatile platform for simulating quantum field theories using a quantum simulator.

Miguel Angel Cazalilla

DIPC - Donostia International Physics Center

Itinerant SU(N) Ferromagnetism on the Bethe Lattice

Miguel Clavero Rubio

Consejo Superior de Investigaciones Científicas

Topological dissipative phases with trapped ions

We show how to implement topological dissipative phases in a one-dimensional chain of trapped ions. The existence of topologically non-trivial phases lead to the presence of edge states which produce amplification being robust against disorder. We study this effect both in regimes with N=2,3 ions and in large chains where Coulomb long-range couplings become apparent. The control of the parametric driving terms is achieved by taking advantage of state-of the art Floquet engineering techniques. We characterize the stability of the system and find stable topologically non-trivial steady-state phases in regions dominated by local losses. For short times, when the steady-state is not achieved yet, we also analyze their transient dynamics.

Giulia De Rosi
UPC - Universitat Politècnica de Catalunya

Thermal fading of the $1/k^4$-tail of the momentum distribution induced by the hole anomaly

I present our results on an intriguing anomaly in the temperature dependence of the specific heat of a one-dimensional (1D) contact repulsive Bose gas. The observed peak holds for arbitrary interaction strength and remembers a superfluid-to-normal phase transition in higher dimensions, but phase transitions are not allowed in 1D. The presence of the anomaly signals a region of unpopulated states which behaves as an energy gap and is located below the hole branch in the excitation spectrum. The anomaly temperature is found to be of the same order of the energy of the maximum of the hole branch. We rely on the Bethe Ansatz to obtain the specific heat exactly and provide interpretations of the analytically tractable limits. The dynamic structure factor is computed with the ab-initio Path Integral Monte Carlo (PIMC) method for the first time. We notice that at temperatures similar to the anomaly threshold, the energy of the thermal fluctuations become comparable with the maximal hole energy, leading to a qualitative change in the structure of excitations. This excitation pattern experiences the breakdown of the quasi-particle description for any value of the interaction strength at the anomaly, similarly to any superfluid phase transition at the critical temperature. We provide indications for future observations and how the hole anomaly can be employed for in-situ thermometry, identifying different collisional regimes and understanding other anomalies in atomic, solid-state, electronic, spin-chain and ladder systems [1].

I show our PIMC calculation of the momentum distribution. We explore all interaction and thermal regimes. We find that at large momentum k and temperature above the hole-anomaly threshold, the tail C/k^4 of the distribution (proportional to the Tan contact C) is screened by the $1/k^3$-term due to a dramatic thermal increase of the internal energy. The same fading is consistently revealed in the short-distance behavior of the one-body density matrix (OBDM) where the cubic dependence disappears for temperatures above the anomaly. We obtain a new general analytic tail for the momentum distribution and a minimum k fixing its range of validity, both calculated with Bethe-Ansatz and valid for any interaction strength and temperature, crossing from quantum to classical gas limit [2].

[1] G. De Rosi, R. Rota, G. E. Astrakharchik, and J. Boronat, Hole-induced anomaly in the thermodynamic behavior of a one-dimensional Bose gas, SciPost Phys. 13, 035 (2022)
[2] G. De Rosi, G. E. Astrakharchik, M. Olshanii, and J. Boronat, Thermal fading of the $1/k^4$-tail of the momentum distribution induced by the hole anomaly, arXiv:2302.03509 (2023)
[3] G. De Rosi, R. Rota, G. E. Astrakharchik, and J. Boronat, Correlation properties of a one-dimensional repulsive Bose gas at finite temperature, New J. Phys. 25 043002 (2023)

Carlos Gas Ferrer
ICFO - The Institute of Photonic Sciences

Characterization and transverse laser cooling of a strontium atomic source

A strontium atomic source is characterized in terms of flux and angular distribution in this project. Atomic beam collimation via a microcapillary nozzle is studied and tested against theoretical models. Further improvement of the atomic beam via one-dimensional transverse cooling is demonstrated.

Grecia Guijarro

UPC - Universitat Politècnica de Catalunya

Ultradilute Quantum Solid of Dipolar Atoms in a Multilayer

We predict that ultracold bosonic dipolar atoms can form ultradilute quantum solids when trapped in a multilayer geometry. In these solids, the mean interparticle distance between atoms can significantly exceed the characteristic length of the interaction potential. The phase diagram is determined by means of quantum Monte Carlo simulations. We report a quantum phase transition from gas to a solid phase at a critical interlayer distance, which depends on and decreases monotonically with the number of layers. The density of the resulting solid is several orders of magnitude smaller than the one of conventional quantum solids. Moreover, we report the existence of a metastable phase at low densities where the dipoles form a gas of chains across the layers, which shares several features with the nematic phase of a liquid crystal.

Blazej Jaworowski

ICFO - Institut de Ciències Fotòniques

Laughlin-like physics in small subwavelength atom arrays

Atom arrays offer exciting possibilities of quantum optics, such as harnessing wave interference and collective absorption/emission to e.g. increase the efficiency of quantum optical devices beyond standard limits. The current frontier in array physics is the many-body regime, where complex effects are expected due to interaction between atomic excitations. To find intuitions about the behavior of such systems, one can seek for analogous solid-state systems for which the many-body problem was already thoroughly studied.

In this work, we propose that the low-energy physics of small hexagonal flakes of three-level atoms in magnetic field can be understood in analogy to the fractional quantum Hall systems. It was shown that in arrays of three-level atoms, magnetic field can induce a topologically nontrivial single-particle band structure. If such topological bands are flat enough, they may host fractional quantum Hall states on the many-particle level. Here, we show that at small lattice constant and in presence of parabolic confinement potentials, small hexagonal flakes of honeycomb three-level atom arrays exhibit a characteristic branch in the few-particle spectrum, resembling the edge spectrum on the top of the $\nu = 1/2$ Laughlin state. Although the band structure of an infinite lattice exhibits divergences near the light cone, finite-size effects smooth out these divergencies, and, as a result, small flakes dominated by near-field interaction behave similarly to a topological flat-band system. We evaluate the overlap between the states in the edge branch and the model Laughlin states and investigate their optical properties such as decay rates and output light profiles.

Teresa Karanikolaou

ICFO - Institut de Ciències Fotòniques

Near-resonant light scattering by an atom in a state-dependent trap

The optical properties of a fixed atom are exquisitely well-known and investigated: Its extraordinarily strong coherent response to a resonant photon is essential for quantum optics applications. The case of a tightly trapped ion, where the ground and excited states are equally trapped, is also well-known: the heating-causing inelastic scattering reduces for tighter traps. The case of a trapped neutral atom in a state-dependent trap, where the excited state may in fact be untrapped or even anti-trapped has not been thoroughly studied so far, apart from the cases where the photons are far-off resonant. We systematically analyze the consequences of unequal trapping on various aspects of resonant atom-light interactions. Specifically, we focus on how it affects the total and elastic scattering cross sections and influences the motional heating rate of the atoms. Understanding these effects can be valuable for optimizing quantum optics platforms where efficient atom-light interactions on resonance are desired, but achieving equal trapping is not feasible.

Tomas Lamich

ICFO - Institut de Ciències Fotòniques

Novel quantum correlations of light emitted by a single atom in free space

We propose an experimental implementation of a scheme proposed by Goncalves et al. (2021), to produce unusual and tunable photon correlations by interfering resonance fluorescence from a single atom with probe light from a weak laser beam. A number of interesting and potentially useful features are predicted by Goncalves et al., including (under different conditions of pump-probe relative phase and power) the complete extinction of the probe, amplification of the probe, and generation of extremes of anti-bunching and bunching, i.e., $g^{(2)}$ approaching zero or infinity. Interestingly, the expressions for the transmitted power and $g^{(2)}$ can be given in terms of a single parameter, an effective interaction efficiency, suggesting that interference can be used to make up for geometrical and technical limitations on the coupling to single atoms.

We will present the current state of the experimental implementation, using a single atom far-of-resonance trap in a "Maltese cross" geometry system of four high numerical aperture lenses and recent experimental results, as well as the technical considerations we made in order to implement it, including: choice of beam geometry, to minimise the the effects of atomic motion, pump and probe polarisation, optical pumping and coherent population trapping induced by the pump and probe beams, atom heating and methods to mitigate it.

Yingjia Li

University of the Basque Country - UPV/EHU

Shortcuts to Adiabatic Soliton Compression in Active Nonlinear Kerr Media

We implement variational shortcuts to adiabaticity for optical pulse compression in an active nonlinear Kerr medium with distributed amplification and spatially varying dispersion and nonlinearity. Starting with the hyperbolic secant ansatz, we employ a variational approximation to systematically derive dynamical equations, establishing analytical relationships linking the amplitude, width, and chirp of the pulse. Through the inverse engineering approach, we manipulate the distributed gain/loss, nonlinearity and dispersion profiles to efficiently compress the optical pulse over a reduced distance with high fidelity. In addition, we explore the dynamical stability of the system to illustrate the advantage of our protocol over conventional adiabatic approaches. Finally, we analyze the impact of tailored higher-order dispersion on soliton self-compression and derive physical constraints on the final soliton width for the complementary case of soliton expansion. The broader implications of our findings extend beyond optical systems, encompassing areas such as cold-atom and magnetic systems highlighting the versatility and relevance of our approach in various physical contexts.

Genis Lleopart

Universitat Politècnica de Catalunya

Dynamic structure factor of Calogero-Sutherland model

It is rather uncommon to a have an exactly solvable quantum many-body system with finite interactions. This is exactly the case for the Calogero-Sutherland model which describes one-dimensional quantum gas with inverse-square interactions. Although for a moment such a system is lacking explicit physical realization, its low-energy properties are expected to be universal and to coincide with the ones observed in experiments with gapless one-dimensional gases. In this work, we studied the dynamic structure factor of a Calogero-Sutherland interaction potential for interaction between N particles in a box of a size L with periodic boundary conditions. The interaction parameter λ is closely related to the Luttinger parameter $K = 1/\lambda$ and provides a straightforward connection with Luttinger liquid. By using Monte-Carlo techniques, we sampled the Dynamic structure factor for different cases of λ, corresponding to the relationship of the number of quasiparticles r divided by the number of quasiholes s, $\lambda = r/s$.

Francesco Lorenzi

Università di Padova

Scattering of matter-wave soliton from a narrow barrier: transmission coefficient and induced collapse

We report systematic numerical simulations of the collision of a bright matter-wave soliton made of Bose-condensed alkali-metal atoms through a narrow potential barrier by using the three-dimensional Gross-Pitaevskii equation. In this way, we determine how the transmission coefficient depends on the soliton impact velocity and the barrier height. Quite remarkably, we also obtain the regions of parameters where there is the collapse of the bright soliton induced by the collision. We compare these three-dimensional results with the ones obtained by three different one-dimensional nonlinear Schrödinger equations. We find that a specifically modified nonpolynomial Schrödinger equation is able to capture all the main features of the three-dimensional findings. In particular, this simplified but very effective one-dimensional model takes into account the transverse width dynamics of the soliton with an ordinary differential equation coupled to the partial differential equation of the axial wavefunction of the Bose-Einstein condensate.

Pietro Massignan

Universitat Politècnica de Catalunya

Superfluid fraction of non-uniform bosonic gases in two dimensions

Adriana Palos, Daniel de Mercado and Ismael Caballero

Centro Español de Metrología

CEM's $^{40}Ca^{+}$ optical clock for the second quantum revolution

This poster describes the CEM project for the realization of an optical frequency quantum pattern. This will serve as a basis for initiating, at CEM, the development of new patterns based on technologies of the second quantum revolution.

Gerard Pascual López

Universitat Politècnica Catalunya

Polarons and molecules in a two-dimensional Fermi-Hubbard model

A Fermi gas interacting attractively with an impurity of different spin in the continuum undergoes, at zero temperature, a phase transition from a polaron to a molecule state. Here we study the same system but in a $2D$ square lattice and, in particular, we compute the polaron and the molecule ansatzes in a Fermi-Hubbard Hamiltonian. We find that, in the polaron case, the attractive interaction induces a phase transition from zero to a finite momentum at low densities. For the molecule, we also see a phase transition from the Fermi level to another finite momentum. We relate this effect to the finiteness of the momentum space and to the balance between the overall momentum and the particle-hole excitations. Comparing the energies of the polaron and the molecule ansatzes, we observe first a crossover from the polaron to the molecule and, then, a phase transition where the momentum of the molecule ansatz changes.

Jordi Pera

Universitat Politècnica Catalunya

Nature of the ferromagnetic phase transition in Fermi gases

We present a thorough study of the transition nature of Fermi gases. The exploration can be done thanks to the use of a third order perturbation formula for the energy system. At this level, there are three scattering parameters in play, those are, the S-wave scattering length a_0, the S-wave effective range r_0 and the P-wave scattering length a_1. We show that the spin value is not determinant in saying the nature of the phase transition. For any spin value, any kind of phase transition can happen depending on the potential. We show how the different transitions are encountered as a function of r_0 and a_1, which are in units of a_0, for $S = 1/2$ up to $S = 9/2$. Moreover, we then present a model based on Landau theory in order to proof this rich variability.

Ana Pérez

ICFO - The Institute of Photonic Sciences

A new strontium quantum simulator using arrays of Rydberg atoms for simulating lattice gauge theories

Ultracold neutral atoms have proven to be a suitable platform for the study of many-body physics. In particular, in the last decade excited atoms to Rydberg states together with the capability of individually addressing them in programmable optical tweezers have been used to engineer spin-Hamiltonians. An example of such Hamiltonians is the Ising model which accounts for the magnetization of condensed matter systems. More recently, there have been proposals to implement with Rydberg atoms lattice gauge theories relevant in condensed matter physics as well as high energy physics. This work comprises the early steps towards the construction of a new ultracold atom experiment using strontium Rydberg atoms trapped in a programmable tweezer array. Firstly, I motivate the interest in strontium Rydberg atoms. Then, I present an overview of the design of the experiment including the vacuum system, the laser cooling and trapping and the electromagnetic field control. Finally, I discuss on long-term perspectives of the apparatus, which is meant to provide a platform for the study of 2D emerging U(1) lattice gauge theories in decorated Rydberg atom arrays, using a so-called superatom approach.

Alexander Poshakinskiy

ICFO - The Institute of Photonic Sciences

Many-photon scattering and entangling with a Lambda-type atoms

Entangled states of many photons are indispensable for many applications in quantum technologies. However, the schemes to generate entangled many-photons states are usually either probabilistic or involve complicated multi-step protocols. Here, we propose to use a waveguide quantum electrodynamics [1] with three-level atoms to generate many-photon entangled states in a single shot. The atomic levels are supposed to have a Lambda-type arrangement with the two optical transitions coupled to the modes of the orthogonal polarizations. We show that after transmission of a short pulse containing a few co-polarized photons, the final state of the atom and all the photons is a genuine multipartite polarization-entangled state belonging to the W class. To describe the effect quantitatively, we develop the rigorous theory that describes simultaneous interaction of many photons with the Lambda-type atom [2]. It gives the exact expression for the many-photon scattering matrix including the frequency-mixing terms. Using it, we optimize the shape of the input few-photon pulse to maximize the entanglement of the output photons.

[1] A.S. Sheremet, M.I. Petrov, I.V. Iorsh, A.V. Poshakinskiy, A.N. Poddubny, Rev. Mod. Phys. 95, 015002 (2023).
[2] D. Ilin, A.V. Poshakinskiy, arXiv:2309.13969 (2023).

Andrea Richaud

UPC - Universitat Politècnica de Catalunya

Vortices with filled massive cores in Bose-Bose mixtures

In quantum matter, vortices are topological excitations characterized by quantized circulation of the velocity field. They are often modelled as funnel-like holes around which the quantum fluid exhibits a swirling flow. In this perspective, vortex cores are nothing more than empty regions where the superfluid density goes to zero. In the last few years, this simple view has been challenged and it is now increasingly clear that, in many real systems, vortex cores are not that empty. In these cases, the hole in the superfluid is filled by particles or excitations which thus dress the vortices and provide them with an effective inertial mass.

In this talk, I will discuss the dynamics of two-dimensional point vortices of one atomic species that have small cores of a different atomic species. I will show how to derive the relevant Lagrangian itself, based on the time-dependent variational method with a two-component Gross-Pitaevskii (GP) trial function [1]. The resulting Lagrangian resembles that of charged particles in a static electromagnetic field, where the canonical momentum includes an electromagnetic term [2,3]. I will also show some interesting dynamical regimes, including vortex-antivortex annihilation and the spontaneous stabilization of multiply quantized vortices [4]. Eventually, I will point out the unexpected presence of ghost vortices in the wavefunction of the minority component and present a fully analytical framework to quantitatively analyse their dynamical properties starting from the microscopic parameters of the Bose-Bose mixture [5].

[1] A. Richaud, V. Penna, and A. L. Fetter, Phys. Rev. A 103, 023311 (2021).
[2] A. Richaud, P. Massignan, V. Penna, and A. L. Fetter, Phys. Rev. A 106, 063307 (2022).
[3] M. Caldara, A. Richaud, M. Capone, P. Massignan, arXiv:2301.08493, under final review at SciPost Phys.
[4] A. Richaud, G. Lamporesi, M. Capone, A. Recati, arXiv:2209.00493, under review at Phys. Rev. Lett.
[5] A. Chaika, A. Richaud, A. Yakimenko, arXiv:2303.05403, under review at Phys. Rev. Res.

Abel Rojo-Francàs

Universitat de Barcelona

Quantum transport in a fractal lattice

We study some dynamic effects of a single particle in a lattice with a fractal geometry. Specifically, we focus on the quantum transport and its time-dependent scaling, mainly for a Siperiński gasket. We found a non-trivial behavior on the time evolution of the mean square distance (MSD). In addition, we obtain a relation between the time-dependent evolution of the MSD and the energy spectrum. Finally, we studied the interplay between the fractal geometry and the standard triangular lattice.

Lorenzo Rossi

ICFO - The Institute of Photonic Sciences

Topology in the space-time scaling limit of quantum dynamics

I will describe the role of topology in the space-time scaling limit of quantum quench dynamics, where both time and system size tend to infinity at a constant ratio. There, while the standard topological characterization relying on local unitary transformations becomes ill defined, I will show how a different dynamical notion of topology naturally arises through a dynamical winding number encoding the linear response of the Berry phase to a magnetic flux. Specifically, the presence of a locally invisible constant magnetic flux is revealed by a dynamical staircase behavior of the Berry phase, whose topologically quantized plateaus characterize the space-time scaling limit of a quenched Rice-Mele model. I will outline possible experimental platforms for observing the predicted phenomena in finite systems.

Antonio Rubio Abadal

ICFO - The Institute of Photonic Sciences

Quantum-gas microscopy of bosonic strontium-84

The advent of quantum-gas microscopy has brought new ways to probe quantum many-body systems at the single-atom level. While most of these setups work with alkali atoms, there is an increasing interest in the study of alkaline-earth element such as strontium. In this poster we show site-resolved imaging of a quantum gas of strontium for the first time. A clock-magic optical lattice, with a 575-nm spacing, is used to confine the atoms and enable the imaging process. Attractive Sisyphus cooling is employed with the narrow red transition, similar as realized in previous experiments with optical tweezers. Our experiment shows reconstruction fidelities above 95%, and can efficiently image the same cloud several times. We also show how, through evaporative cooling, we are able to prepare a degenerate quantum gas of strontium-84 in the lattice, as indicated by time-of-flight interference. Our experiment might open the door to the study of light-matter interfaces with strontium as well as in situ detection of the SU(N) Fermi-Hubbard model.

Francesc Sabater
Universitat de Barcelona

Universal composite boson formation in strongly interacting one-dimensional fermionic systems

Attractive p-wave one-dimensional fermions are studied in the fermionic Tonks-Girardeau regime in which the diagonal properties are shared with those of an ideal Bose gas. We study the off-diagonal properties and present analytical expressions for the eigenvalues of the one-body density matrix. One striking aspect is the universality of the occupation numbers which are independent of the specific shape of the external potential. We show that the occupation of natural orbitals occurs in pairs, indicating the formation of composite bosons, each consisting of two attractive fermions. The formation of composite bosons sheds light on the pairing mechanism of the system orbitals, yielding a total density equal to that of a Bose-Einstein condensate.

Ayaka Usui
Universitat Autònoma de Barcelona

Simplifying the simulation of local Hamiltonian dynamics

Local Hamiltonians, H_k, describe non-trivial k-body interactions in quantum many-body systems. Here, we address the dynamical simulatability of a k-local Hamiltonian by a simpler one, $H_{k'}$, with $k' < k$, under the realistic constraint that both Hamiltonians act on the same Hilbert space. When it comes to exact simulation, we build upon known methods to derive examples of H_k and $H_{k'}$ that simulate the same physics. We also address the most realistic case of approximate simulation. There, we upper-bound the error up to which a Hamiltonian can simulate another one, regardless of their internal structure, and prove, by means of an example, that the accuracy of a $(k' = 2)$-local Hamiltonian to simulate H_k with $k > 2$ increases with k. Finally, we propose a method to search for the k'-local Hamiltonian that simulates, with the highest possible precision, the short time dynamics of a given H_k Hamiltonian.

Radek Vasicek Ruiz
Universidad de La Laguna

Magnetic effects of synthetic gauge fields on pseudo-spin-1/2 Bose-Einstein condensates

The realization of laser-generated synthetic gauge fields in electrically-neutral, ultracold gases has opened new ways for the exploration of combined electromagnetic and superfluid phenomena in quantum degenerate gases. In particular, highly controlled experimental setups of this type in pseudo-spinor atomic systems have given rise to striking supersolid-like observations in spin-orbit-coupled Bose-Einstein condensates (BECs). The present project aims to learn the rich physics of the latter and related phenomena through analytical calculations and numerical simulations of the underlying equations of motion.

Luyuting Wei

University of the Basque Country

Variational control of matter-wave splitting in harmonic-plus-Gaussian laser trap

We report an efficient protocol for coherent splitting of Bose-Einstein condensates for developing quantum technologies for atomic metrology. Following the variational approximation, we inversely engineer the time-varying Gaussian potential through the auxiliary equation, capturing the wave-packet dynamics in the mean-field approximation, to implement the shortcuts to adiabaticity for Bose-Einstein condensates trapped in harmonic-plus-Gaussian trap. Finally, an atom interferometry is introduced as one of the most straightforward applications.

Yunjia Zhai

Universitat Autònoma de Barcelona / Shanghai University

Patterning by dynamically unstable spin–orbit-coupled Bose–Einstein condensates

In a two-dimensional atomic Bose–Einstein condensate, we demonstrate Rashba spin–orbit coupling can always introduce dynamical instability into specific zero-quasimomentum states in all parameter regimes. During the evolution of the zero-quasimomentum states, such spin–orbit-coupling-induced instability can fragment the states and lead to a dynamically patterning process. The features of formed patterns are identified from the symmetries of the Bogoliubov–de Gennes Hamiltonian. We show that spin–orbit-coupled Bose–Einstein condensates provide an interesting platform for the investigation of pattern formations. *Authors:* Yunjia Zhai and Yongping Zhang.