QUANTUM MENORCA 2019

Workshop on

"Dynamics and interactions in quantum gases"

Scientific organizers

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About the Workshop

The Quantum Menorca 2019 Workshop on "Dynamics and interactions in quantum gases" aims at bringing together experts and younger researchers on ultracold atoms, to discuss very recent developments in the context of:

- Weakly interacting BECs (sound, vortices, droplets)
- Strong interactions (unitary Fermi gases, Bose and Fermi polarons, integrable systems)
- Interaction quenches, Lieb-Robinson bounds, many-body localization
- Rydberg and long-range interactions
- Topological phases

Contents

Poster abstracts

Quantum Metrology with Cold Atoms

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As quantum metrology advanced, it has achieved better sensitivity scaling in estimation of various parameters in dierent quantum mechanical systems. Interferometry is the most suitable method to perform measurements and implement the parameter estimation theories. We obtain interesting results when we merge the eld of ultra-cold matter and quantum metrology. Here, I present numerical simulations of using a two-mode Bose Einstein condensate of Rubidium atoms for performing Ramsay interferometry. It is observed to attain better sensitivity scaling than Heisenberg limit.

Quantum impurity coupled to an exciton-polariton condensate

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In this work we present a theoretical study of the many-body properties of a quantum impurity, resulting from a spin anisotropy, coupled to a Bose-Einstein condensate of exciton-polaritons within a pump-probe spectroscopy scheme. We show results for the impurity's quasiparticle properties as a function of the light-matter energy detuning under the framework of impurity physics and the T-matrix approximation. Also, we explore the influence of the condensate properties on the emergence of an analog effect to a Feshbach resonance, due to the formation a molecular bound-state of two dressed excitons, or biexciton.

Far-from-equilibrium dynamics of molecules in 4He nanodroplets: a quasiparticle perspective

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Angular momentum plays a central role in a plethora of quantum processes, from nuclear collisions to decoherence in quantum dots. We consider a single molecule embedded in a superfluid Helium nanodroplet as a prototype of a fully controllable many-body system in which to reveal angular momentum dynamics: an ultrashort laser pulse induces molecular axis alignment, while imaging of molecular fragments after Coulomb explosion allows to obtain time-resolved molecular alignment measurements. We describe this scenario in terms of the angulon quasiparticle with very good agreement with experimental data for several molecular species and across a wide range of laser fluences.

BKT transition in a system of dipoles

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We study a system of bosonic dipoles that are polarized with all their dipole moments forming a certain angle with the plane containing their movement. In a previous work the superfluid properties of the different phases that appear in the phase diagram of this system were studied at zero temperature (T=0), showing that both for the gas and stripe phase can sustain a superfluid flow. In this work we use Path Integral Monte Carlo technique to extend this study to finite temperature in order to determine the critical temperature T_c at which the transition from superfluid to normal phase occurs. In two dimensional systems this transition is known to be driven by topological vortices that destroy the superfluid signal and follows the Berezinskii–Kosterlitz–Thouless (BKT) scaling. We show that, despite of the anisotropy present when dipoles are tilted, both the gas and the stripe phase follow the BKT scaling allowing us to extract the critical temperature across the phase diagram. We also evaluate the One-Body-Density-Matrix at different temperatures in the stripe phase to show the existence of a quasi-condensate below the critical temperature , which is characteristic of the BKT scenario. Finally the melting point of the stripe phase is estimated.

Slow light and strong interactions in a BEC

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We develop a non-perturbative theory describing light propagating in an atomic Bose-Einstein condensate (BEC) in the presence of strong interactions. Using this, we show that the subtle interplay between light and interactions gives rise to several non-trivial effects. For weak atom-light coupling, there is a well-defined quasiparticle, the polaron-polariton, supporting electromagnetically-induced transparency (EIT) with a resonance condition and spectral width significantly different from the non-interacting case. For strong interactions, there is a cross-over regime where the light is carried by a lossy quasiparticle giving rise to a substantial optical depth.

Cavity-Enhanced Microscope for Cold Atoms

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We are setting up a novel type of microscope consisting of an ultra-cold Fermi gas in a high-finesse cavity, combined with high-numerical-aperture optics (0.38). Atoms in the cavity can be detected through their dispersive interaction with light. A second laser beam, focused tightly onto the lithium cloud, locally enhances the coupling to the cavity, allowing for non-destructive measurements with sub-micron resolution. Controlling this coupling will also allow to tune the cavity-mediated interactions temporally and spatially. This poster summarizes the important ideas and technical developments behind the design and presents the current status of our setup.

Demonstration of narrowband etangled photons with sub-MHz bandwidth from low-optical-depth atomic ensemble

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Biphotons of narrow bandwidth and long temporal length have potential applications in realizing efficient light-matter interface and quantum communication. However, generation of these photons usually requires atomic ensembles with high optical depth or spontaneous parametric down-conversion with delicate optical cavities. We propose and demonstrate narrowband biphotons with sub-MHz bandwidth using four-wave mixing in low-optical-depth atomic ensemble. The bandwidth of the biphotons is only limited by the ground-state decoherence rate. We also demonstrate the potential of shaping these photons.

Coherently-coupled potassium BECs: interaction control and density-dependent gauge fields

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In 39K the interactions between different spin states are highly tunable due to a variety of Feshbach resonances. Through coherent coupling between two spin states of a Bose-Einstein condensate where the intra- and interspecies scattering lengths are all different, we demonstrate fast interaction control, which we use to perform interaction quenches leading to modulational instability. Furthermore, we demonstrate a density dependent gauge field by introducing further coupling between the spin and momentum of the atoms using optical Raman transitions.

Universality in ultradilute liquid Bose-Bose mixtures

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We have studied quantum droplets in Bose-Bose mixtures using quantum Monte Carlo methods at T = 0. Using different interaction models, we determine range of validity of the universal equation of state of the symmetric liquid mixture as a function of two parameters: s-wave scattering length and the effective range. It is shown that the Lee-Huang-Yang correction is sufficient only for extremely dilute liquids with the additional restriction that the range of the potential is small enough. We develop a new density functional which goes beyond the Lee-Huang-Yang term and used it to determine density profiles of self-bound drops.

Floquet engineering by kinetic driving

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We introduce a new form of driving in which the kinetic energy is varied periodically by altering the intersite tunnelling. Using Floquet theory to derive a static effective Hamiltonian that describes the system, we study the properties of the kinetically-driven Bose-Hubbard model. The driving induces both non-local interactions and unusual correlated tunnelling terms, which give rise to exotic many-body effects. At a critical value of the driving, the system passes from a Mott insulator to an unusual superfluid formed by a cat-like superposition of two condensates with opposite momenta. Driving of the kinetic energy thus provides a novel form of Floquet engineering, enabling exotic states of quantum matter to be produced and controlled.

Connecting superfluid dynamics experiments with the point vortex model in two dimensions

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We present the results of two sets of superfluid dynamics experiments for which the point vortex model provides quantitative insights. The first is in a quasi-2D Bose-Einstein condensate which is stirred, leading to the formation of two macroscopic vortex clusters of opposite signs. The system quickly relaxes into a deeply negative temperature Onsager vortex state that persists in quasi-equilibrium for more than fifty cluster turnover times. The second experiment is in a superfluid helium thin film, where optical stirring generates a macroscopic superfluid flow in the system that lifts the degeneracy in frequency of a number of third sound modes. Our measurements and modelling infer that a pinned persistent current slowly decays as a cluster of opposite sign vortices slowly annihilate the central charge.

Thermodynamics of a one-dimensional Bose gas with repulsive contact interactions

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We present a complete study of the thermodynamics of a one-dimensional repulsive Bose gas, discussing in particular beyond Luttinger-liquid corrections. We compute the chemical potential, the pressure and the contact, as a function of temperature and gas parameter with exact thermal Bethe-Ansatz, and provide analytical interpretation of the main features. We find that the Bogoliubov and the hard-core models describe correctly the properties in the regimes of weak and strong contact repulsive interactions, correspondingly, while Sommerfeld and virial expansions are applicable at low and high temperatures. The beyond Luttinger-liquid thermodynamic effects are found to be non-monotonic as a function of gas parameter. Such behavior is explained in terms of non-linear dispersion and "negative excluded volume" effects, for weak and strong repulsion respectively, responsible for the opposite sign corrections in the thermal next-to-leading term of the thermodynamic quantities at low temperatures. Within the beyond Luttinger-liquid description, the contact is proportional to the chemical potential or to the pressure, in the weak and strong interaction limits, respectively, with a prefactor independent on temperature. Our results can be applied to other systems including super Tonks-Girardeau gases, dipolar and Rydberg atoms, helium and quantum liquid droplets in bosonic mixtures.

Scattering from the dark and birefringent modes: new self-organisation phases

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A Bose-Einstein condensate inside an optical resonator can undergo a phase transition to a self-organised state when illuminated with a red-detuned pump beam. In our recent experiment we explore the blue side of the atomic resonance, where the repulsive pump induces coupling to the P-band of the lattice and the positive dispersive shift triggers dynamics of the order parameter, both effects leading to richer phase diagrams. In a second experiment, using the scalar and vectorial atomic polarisability we tune the coupling of the BEC with two non-degenerate polarisation modes of the cavity, which give rise to competing self-organisation phases.

Dissipation induced structural instability and chiral dynamics in a quantum gas

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We report on the discovery of a non-stationary chiral state of a quantum many-body system arising from the interplay between unitary and dissipative dynamics. Our system consists of a spinor Bose gas interacting with an optical cavity. Orthogonal quadratures of the light are coherently coupled to two different spatial atomic modes, while the resonator losses act as a dissipative channel between these modes. Unitary and dissipative terms can be controlled independently; in the regime of dominant dissipative coupling we observe chiral evolution that can be described in terms of a non-conservative positional force. [Reference: Dogra et al., arXiv:1901.05974]

Studies of the 3D-2D crossover in a strongly interacting atomic Fermi gas using Bragg spectroscopy

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Studies of the formation of Cooper pairs in strongly interacting low-dimensional Fermi gases is of great interest and may lead to deeper understandings of related condensed-matter systems. In this framework, the development of universal relations, that connect the bulk thermodynamic properties to the microscopic parameters, represents a major milestone. Bragg spectroscopy at high transferred momentum can enable the study of these universal relations, in particular Tan's contact parameter. In this work we investigate the dynamic and static structure factors using Bragg spectroscopy, to map the behaviour of the contact parameter for different temperatures and condensate fractions.

Bose-Fermi quantum droplets

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I study stability conditions of a mixture of ultracold spin polarized Fermi gas and atomic Bose-Einstein condensate in various spatial dimensions. Conditions for formation of self-bound droplets and a role of quantum fluctuations will be presented.

Calculation of the number PI using two-ball billiard

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We calculate the number PI from the problem of two billiard balls colliding with a wall (Galperin billiard method). We provide a complete explicit solution for the balls' positions and velocities as a function of the collision number and time. Also we show that for general values of the parameters the system is integrable and for some special values of the parameters it is superintegrable and maximally superintegrable. This is a joint work with X. M. Aretxabaleta, N. L. Harshman, S. G. Jackson, M. Olshanii, and G. E. Astrakharchik.

Bilayer system of dipolar bosons: few-body bound states

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Quantum Monte Carlo methods provide a powerful tool for predicting quantitatively the properties of many-body quantum system. At the level of few-body physics, existence of bound-states (trimers, tetramers, etc.) for dipolar molecules in a bilayer is an open and controversial question. Anisotropy of the dipolar interaction (which can be attractive or repulsive) complicates the study but leads to rich physics. The problem of two and three dipolar molecules can be solved analytically, the last one with more effort. However, as the number of dipoles is increased, the problem becomes essentially intractable using standard approaches. At this point Monte Carlo methods become highly competitive. We use Diffusion Monte Carlo method to obtain the ground state energy and spatial distribution function of a bilayer system of dipolar bosons, where dipoles are oriented perpendicularly to the parallel planes. It is known that a dimer exists for arbitrary separation between layers. For three and four dipoles, the bound state does not exist for small separation between the two layers. We find the critical value of the interlayer separation at which the trimer and tetramer appear. For the trimer, we have found that the dominant structure close to the critical separation is halo state, where two dipoles are close to each other while the third is far away. Five- and six-body bound states also exist.

Evolution of large-scale flow from turbulence in a two-dimensional superfluid

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Non-equilibrium interacting systems can evolve to exhibit large-scale structure and order. In two-dimensional turbulent flow the seemingly random swirling motion of a fluid can evolve towards persistent large-scale vortices. To explain such behaviour, Lars Onsager proposed a statistical hydrodynamic model based on quantised vortices. Here we experimentally confirm Onsager's model in a superfluid Bose–Einstein condensate (BEC) with quantised vortices. We drag a grid barrier through an oblate BEC to generate non-equilibrium distributions of vortices. We observe signatures of an inverse energy cascade driven by the evaporative heating of vortices, leading to steady-state vortex configurations characterised by negative absolute temperatures.

Ultracold Plasma triggered by Femtosecond Laser Pulses in a Bose-Einstein-Condensate

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We report on our investigation of ultracold plasma created from a 87Rb Bose-Einstein condensate after exposure to a femtosecond laser pulse. The high atomic densities give rise to strongly coupled plasmas with scalable charge imbalance. Our experiment provides access to the plasma dynamics as the kinetic energy distributions of the charged particles can be measured. We observe a cooling of the photoelectrons having an initial kinetic energy of 0.67 eV down to few meV. Additionally, photoionization of few ultracold atoms with low excess energy enables the instantaneous creation of hybrid atom-ion quantum systems.

Spin-Imbalanced Pairing and Fermi Surface Deformation in Flat Bands

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We study the attractive Hubbard model in multiband lattice systems featuring a flat band. Using a mean-field theory, we find Fulde-Ferrell-Larkin-Ovchinnikov type superfluid phases with a space-dependent order parameter. The flat band is found to play a role in stabilizing these phases. The constant dispersion relation allows for changes in particle momentum distributions at zero energy cost. This facilitates multiband Cooper pair formation wherein the momentum distribution of the spin component residing in the flat band deforms to mimic the Fermi surface of the other component residing in a dispersive band.

Many-body localization in the flat-band Creutz ladder

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Study on a disorder-free many-body localization is presented for the flat-band Creutz ladder, which was recently realized in cold-atoms in an optical lattice. The system indicates the existence of the disorder-free many-body localization. We also find non-ergodic dynamics in the flat-band regime without disorder.

Macroscopic quantum tunnelling of a Bose-Einstein condensate in a periodically driven cubic-plus-quadratic well

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We investigate the dynamics of a metastable Bose-Einstein condensate tunnelling through a cubic-plus-quadratic well. By applying the WKB method and the Gross-Pitaevskii equation, we compute the tunnelling rate of the BEC out of the metastable well and obtain analytical expressions in terms of s-wave scattering length for both static and modulated wells. Our results show that both an increase of the repulsive interaction and the modulation of the potential trap enhance the decay rate of condensate.

Collective modes of an imbalanced unitary Fermi gas

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We study theoretically the collective mode spectrum of a strongly imbalanced two-component unitary Fermi gas in a cigar-shaped trap, where the minority species forms a gas of polarons. We describe the collective breathing mode of the gas in terms of the Fermi liquid kinetic equation taking collisions into account using the method of moments. Our results for the frequency and damping of the longitudinal in-phase breathing mode are in good quantitative agreement with an experiment by S. Nascimb'ene et al. [Phys. Rev. Lett. 103, 170402 (2009)] and interpolate between a hydrodynamic and a collisionless regime as the polarization is increased. A separate out-of phase breathing mode, which for a collisionless gas is sensitive to the effective mass of the polaron, however, is strongly damped at finite temperature, whereas the experiment observes a well-defined oscillation.

Imbalanced electron-hole-photon systems in two-dimensional structures

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Recent technological progress has led to precise and efficient manipulation of electronic and optical properties of semiconductor solid-state devices. Noticeable examples include GaAs heterostructures, while, recently, transition metal dichalcogenide (TMDC) monolayers have emerged as ideal materials for optoelectronic devices. Crucially, both structures have been recently embedded into planar optical cavities, allowing to study the interplay between strong light-matter coupling and electronic doping. This opens the prospect to generate and control novel strongly correlated phases between exciton-polaritons and 2D electron systems. Here, we study the extremely imbalanced limit of one minority particle (e.g., one electron) in a Fermi sea of majority particles (e.g., holes) in doped single quantum wells or bilayers, strongly coupled to a cavity mode. In particular, we focus the attention on the many-body polaritonic bound state with a finite centre of mass momentum which represents the extremely imbalanced limit of the Fulde-Ferrell- Larkin-Ovchinikov (FFLO) condensed phase at finite imbalance. This state is the result of the competition between Coulomb interaction, Pauli blocking of the majority specie Fermi sea, and strong coupling to light. We find that this phase is favoured by long-range unscreened interactions, a small minority particle mass and a finite bilayer distance. The strong coupling to light reduces the parameter region where FFLO occurs, yet leaving a sizeable phase space to observe it in experiments, where an easy detection can occur via far field spectroscopy.

Pair formation in unitary Bose gases

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We study degenerate Bose gases quenched to unitarity by solving a many-body model including three-body losses and second-order correlations. As the gas evolves in this strongly-interacting regime, the buildup of correlations leads to formation of extended pairs bound purely by many-body effects. Through fast sweeps away from unitarity, we detail how the correlation growth and the formation of bound pairs emerge in the remaining fraction of unbound atoms, finding quantitative agreement with experiment. Finally, we discuss the possible role of higher-order effects in explaining the deviation of our results from experiment for slower sweeps and longer times spent at unitarity.

Width and shift of atomic Feshbach resonances

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We revisit the basic properties of atomic Feshbach resonances, namely the relationship between the width and shift of the resonances and their dependence on the low-energy parameters of the system. Unlike what was previously believed [Rev. Mod. Phys. 82, 1225 (2010)], we find that the ratio between the width and the shift of a resonance does not depend only on the background scattering length, but also on a closed-channel scattering length. We illustrate our results for a specific resonance with lithium-6 atoms.

Observation of a Transition Between Dynamical Phases in a Quantum Degenerate Fermi Gas

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We engineer a quantum simulator of the collective Heisenberg model in a gas of weakly-interacting potassium-40 atoms. Initializing a coherent superposition with maximal transverse magnetization, we measure collective magnetization dynamics using a Ramsey sequence. We observe a transition between two steady states: an ordered ferromagnetic state, stabilized by an energy gap, and a demagnetized state. Exploring the dynamical phase diagram by tuning both interaction strength and longitudinal field variance, we find excellent agreement with theoretical calculations. The observed stabilization of many-body coherence opens a new window for generating correlated quantum states in fermions, with applications to enhanced metrology and advanced materials.

Bose polaron at finite temperature

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We employ a new variational approach that systematically includes multi-body correlations between an impurity and a finite-temperature medium. Such an approach yields excellent agreement with recent QMC results for the Bose polaron at zero temperature. For increasing temperature, we find that the number of attractive polaron branches is simply set by the number of hole excitations of the thermal cloud, such that including up to one hole yields one splitting, two holes yields two splittings, and so on. We thus expect that the exact ground-state quasiparticle will evolve into a single broad peak at finite temperature, without any discrete splitting.

From polarons to bipolarons in Bose-Einstein condensates

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Mobile impurities in a Bose-Einstein condensate can form quasi-particles termed Bose- Polarons. In this talk I show how these quasi-particles are originated when a single impurity is dressed by the excitations of the quantum bosonic bath. The most striking advantage of these polarons is the huge degree of controllability of the coupling strength between the impurity and the bosonic bath. Thus, one can realize polarons from weak all the way up to the strong interacting regime [1,2]. For strong interactions two polaron can bind together forming bound bipolarons states. They emerge due to the induced non-local interaction mediated by density oscillations of the bath [3,4]. Polarons and bipolarons in ultra-cold quantum gases could be used as a robust platform for quantum simulation in a condensed matter context.

[1] N. B. Jørgensen, L. Wacker, K. T. Skalmstang, M. M. Parish, J. Levinsen, R. S. Christensen, G. M. Bruun, and J. J. Arlt. Phys. Rev. Lett. 117 . 055302 (2016).

[2] M-G Hu, M. J. V. de Graaff, D. Kedar, J. P. Corson, E. A. Cornell, and D. S. Jin. Phys. Rev. Lett. 117, 055301 (2016).

[3] L. A. P. Ardila and S. Giorgini. Phys. Rev. A 92, (2015).

[4] A. Camacho-Guardian, L. A. P Ardila, T. Pohl, G. M. Bruun. (2018).

Slow and fast entanglement growth and many-body localized states

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It is commonly believed that many-body localization implies a slow growth in the von Neumann entanglement. We discuss that this is not the case as its growth is power-law for states with long-range interactions. We comment on the implications for experimental realization of many-body localization in optical lattices.

Scattering of quantum droplets in Bose-Bose mixtures

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Quantum droplets exhibit many properties known from classical liquids and have a density which can be tuned over a broad range, in particular allowing for creation of possibly the most dilute liquids ever physically observed. In our study we consider droplets obtained as a mixture of two Bose-Einstein condensates. We focus on the analysis of collisions of such droplets, deriving their interaction potential and performing numerical simulations with various impact parameters. Furthermore we identify differences between the regimes of large (incompressible) and small (compressible) droplets and examine the dependence of the scattering behaviour on their relative phase taking into account interference effects, losses as well as the surface vibrations induced by the collisions.

Cooling a lithium 6 fermi gas to degeneracy

Al hyder Ragheed

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I will talk about the new machine built in the group of Christophe Salomon at ENS in Paris. The goal of the machine is studying BCS-BEC crossover in tailored optical potentials using single atom imaging.

Phase separation can be stronger than chaos

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We investigate several dynamical regimes characterizing a bosonic binary mixture loaded in a ring trimer, with particular reference to the persistence of demixing. The degree of phase separation is evaluated by means of the 'entropy of mixing', an indicator borrowed from statistical thermodynamics. In many dynamical regimes, we show that chaos is not able to disrupt the order imposed by phase separation, i.e. boson populations, despite evolving in a chaotic fashion, do not mix. This circumstance can be explained either with energetic considerations or in terms of dynamical restrictions.

Spin-orbit coupling in quantum systems: a quantum Monte Carlo approach

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The interplay between an electron's spin and its momentum, denoted as spin-orbit coupling (SOC), is an effect of major relevance when studying a wide variety of systems in the field of solid-state physics, such as Majorana fermions, spintronic devices or topological insulators. The realization in the last few years of a synthetic SOC interaction in ultracold atomic gases by exploiting the space-dependent coupling of the atoms with a properly designed configuration of laser beams represents an important achievement. This allows for a better understanding of the nature of the SOC interaction, since these type of systems are highly controllable and tunable. Quantum Monte Carlo methods are the tools we use to model and study these ultracold atomic gases featuring a synthetic SOC interaction. In particular, we have developed two different kinds of Diffusion Monte Carlo (DMC) algorithms: the T-moves DMC (DTDMC),; and the Spin-Integrated DMC (SIDMC).

Engineering synthetic Landau levels with atomic dysprosium

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Dysprosium's large spin (J=8) and its strong coupling to light make it a promising candidate to engineer topological quantum states. I will present results from experiments which realise synthetic Landau levels, using dysprosium's magnetic sublevels as an effective spatial dimension with a large bulk and sharp edges. We induce 'spin-orbit coupling' via Raman transitions to create an artificial gauge field, allowing observation of the hallmarks of Landau levels, namely bulk cyclotron orbits and chiral edge modes. We also observe a Hall response in the lowest band consistent with corresponding value for Landau levels. We aim to observe the vortices present in generic lowest band wavefunctions of the Hamiltonian.

Waveguide-QED with atomic matter waves

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We have recently studied [1] spontaneous-emission phenomena with atomic matter waves. For this purpose, we created an array of microscopic atom traps in an optical lattice that emit single atoms, rather than single photons, into the surrounding vacuum. Our ultracold-atom system, which provides a tunable matter-wave analog [2] of photon emission in photonic-bandgap materials (i.e. waveguide QED), revealed behavior beyond standard exponential decay with its associated Lamb shift. It includes non-Markovian backflow of radiation into the emitter, and the formation of a long-predicted bound state in which the emitted particle hovers around the emitter in an evanescent wave. Our system provides a flexible platform for studies of dissipative many-body physics and matter-wave quantum optics in optical lattices.

[1] L. Krinner et al., Nature 559, 589 (2018); M. Stewart et al., PRA 95, 013626 (2017)

[2] I. de Vega, D. Porras, J. I. Cirac, PRL 101, 260404 (2008)

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Mesoscopics of half-quantum vortex pair deconfinement in a trapped spin-one condensate

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By using numerical mean-field calculation for quasi-two-dimensional spin-one BEC with radius R and zero total spin in z direction, we find that the energetic stability of the vortex dissociation from a singly quantized vortex at the center to a pair of half-quantum vortices depends on the ratio of density-density (c_0) and spin-spin coupling constant (c_2): Dissociation is energetically favorable for $c_2/c_0 < (c_2/c_0)_{cr}$. The critical ratio, $(c_2/c_0)_{cr}$, increases when R/ξ_d decreases where ξ_d is density healing length. Also, that critical ratio of the system with harmonic trap is larger than that of the system with box trap.

Formation of vortex structure in the two component BEC by using artificial magnetic field induced from evanescent field

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In the present work, we study the effects of artificial magnetic fields on two component Bose–Einstein condensate in the vicinity of a flat dielectric surface and the formation of the vortices in two-component BEC due to evenecent field. We noumerically show that for a two-dimensional BEC the ratio between inter and intra component coupling coefficients effectively define the number and structurs of vortex formation.

Towards a quantum degenerate Li-Cr mixture

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In the context of ultracold quantum gases, mixtures of different species are drawing increasing attention both in theory and experiment. Despite their unavoidable complexity, they offer additional degrees of freedom compared to single species systems, such as mass imbalance, tunability of both intra- and inter-species interactions and tailoring of species-selective optical potentials. Here we report on the experimental progresses towards the realization of quantum degenerate Li-Cr mixtures. In particular, we describe the unique few-body properties expected for the Fermi-Fermi mixture 6Li-53Cr and their possible impact within a many-body environment.

Current Phase Relation of a Cold Atom Josephson Junction

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The Josephson Effect is one of the hallmark properties of superconductors. Its defining feature is the nonlinear relation between the current and the phase difference across a barrier between two superfluids. Here we report on the observation of this nonlinear current phase relation in an ultracold Fermi gas. We split a two-dimensional pair condensate of ultracold fermions into two separate reservoirs connected by a weak link and imprint a relative phase between the two condensates. From the frequency of the resulting oscillations, we determine the current-phase relation, and find excellent agreement with the theoretical expectation.

Inter-component correlations in attractive one-dimensional mass-imbalanced few-fermion mixtures

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Properties of a two-component mixture of a few fermions in a one-dimensional parabolic trap are studied. It is shown that depending on the mass ratio between atoms, the inter-particle correlations change their properties significantly from a strong pair-like correlation to an almost uncorrelated phase. This change is accompanied by an undergoing change in the structure of the many-body ground state.

Tunable Order of the Superfluid-supersolid Phase Transition in Dipolar Bose-Einstein Condensates

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Long-range interactions between atoms such as dipolar interactions found tremendous interest in recent years. Recent experimental breakthroughs have amplified interest in dipolar quantum gases and the long-standing search for supersolid states in such systems. While evidence for phase-coherent one-dimensional density modulations has been reported very recently, extended supersolids in higher dimensions have remained elusive. We show that dipolar Bose-Einstein condensates are promising candidates for realizing states with a significant superfluid fraction beyond what is possible with systems where quantum fluctuation can be neglected and the critical behaviour at the superfluid-supersolid phase transition can be tuned between first- and second-order.

Interaction Quenches and Rotons

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When we quench the interaction strength from weak to strong, i.e. to a regime with rotons as predicted for example for Rydberg Bose gases, a Bose system can be arrested in a state with long-lived oscillations instead of quickly equilibrating. Our results are obtained with a variational many-body method, with some comparisons to time-dependent variational Monte Carlo.

Critical transport and vortex dynamics in a thin atomic Josephson junction

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We study the onset of a dissipative regime in an atomic Josephson junction due to the presence of vortex rings (VRs) nucleated inside a thin barrier separating two parts of a BEC. This regime is characterized in terms of critical population imbalance and maximum superfluid current both at T=0 and at T=0.4 Tc. Our numerical simulations are compared with the experimental data finding very good agreement. We study the connection between the microscopic VRs dynamics and macroscopic observables such as the superfluid current. Moreover we give a full characterisation of the VR dynamics for different initial population imbalances.

Fingering instabilities and pattern formation in a two-component dipolar Bose-Einstein condensate

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We study fingering instabilities and pattern formation at the interface of an oppositely polarized two-component Bose-Einstein condensate (BEC) with strong dipole-dipole interactions (DDIs) in three dimensions. It is shown that the rotational symmetry is spontaneously broken by fingering instabilities when the DDIs are strengthened. Frog-shaped and mushroom-shaped patterns have been shown with different strengths of the DDIs. A Bogoliubov analysis gives a qualitative understanding of the interfacial instabilities of the two dipolar BECs, and a dispersion relation similar to that in classical fluids is obtained. Spontaneous density modulation and dipolar domain growth in the dynamics have also been demonstrated, in which we have analyzed the characteristic sizes of the dipolar domains corresponding to different patterns at the initial and later times in the evolution. We have also investigated the parameter dependence of the ground states, and found that the droplet patterns are formed due to the population imbalance in the two components. Labyrinthine patterns grow as the trap ratio increases, and a striped phase appears as the angle of tilted polarization increases. Our findings may establish further connections between superfluids and classical fluids.

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