Q 27: Ultra-cold Atoms, Ions and BEC II (joint session A/Q)

Time: Wednesday 11:00–13:00 Location: F303

Invited Talk Q 27.1 Wed 11:00 F303

Realization of the Periodic Quantum Rabi Model in the Deep Strong Coupling Regime with Ultracold Rubidium Atoms — •Stefanie Moll[1], Geram Hunanyan[1], Johannes Koch[1], Enrique Rico[2,3], Enrique Solano[2,3], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany — [2]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, 48080 Bilbao, Spain — [3]IKERBASQUE, Basque Foundation for Science, Plaza Euskadi 5, 48009 Bilbao, Spain

At moderate coupling strengths, the interaction of light and matter is well described in terms of the Jaynes-Cummings model. However, when the coupling strength approaches the optical resonance frequency, the system enters the deep strong coupling regime, where the full quantum Rabi Hamiltonian applies, leading to non-intuitive dynamics.

In our experiment we realize the quantum Rabi model using ultracold Rubidium atoms in an optical lattice potential, creating an effective two-level system, here encoded in different Bloch bands. The bosonic mode is represented by the oscillation of atoms in a superimposed optical dipole trapping potential.

We observe atomic dynamics in the deep strong coupling regime with the cold atoms system. At long interaction times we observe collapse and revival of the initial state, as can be described within the so-called periodic quantum Rabi model.

Q 27.2 Wed 11:30 F303

Metastable phases in spinor Bose-Einstein condensates at finite temperatures — •Eduardo Serrano-Ensástiga[1,2] and Francisco Mireles[1] — [1]Departamento de Física, Centro de Nanociencias y Nanotecnología, Universidad Nacional Autónoma de México, Ensenada, Baja California, México — [2]Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, University of Liège, Liège, Belgium

Spinor Bose-Einstein condensates (BEC) with the spin as a degree of freedom have been studied intensively since its first experimental realization in 1998. A field with current scientific interest is the presence of metastable phases and their role in a variety of phenomena, such as domain formation, quench dynamics, or quantum dynamical phase transitions, among others. In this talk, we present the metastable spin-phase diagrams of a spinor BEC at finite temperatures for spin 1 and 2. The resulting phase diagrams offer further insights of the different quench dynamics observed in experiments, and they allow us to infer similar quench processes due to a sudden change in the temperature or other external fields. Our approach starts with the Hartree-Fock (HF) approximation but takes advantage of the common symmetries between the Hamiltonian and the order parameter. [1] E. Serrano-Ensástiga and F. Mireles, Phys. Rev. A 104, 063308 (2021). [2] E. Serrano-Ensástiga and F. Mireles, arXiv:2211.16428 (2022).

Q 27.3 Wed 11:45 F303

Ultradilute quantum liquid of dipolar atoms in a bilayer — •Grecia Guijarro[1,2], Grigory Astrakharchik[1], and Jordi Boronat[1] — [1]Theoretische Physik, Saarland University, Campus E2.6, 66123 Saarbrücken, Germany — [2]Departament de Física, Universitat Politècnica de Catalunya, Campus Nord B4-B5, 08034 Barcelona, Spain

We show that ultradilute quantum liquids can be formed with ultracold bosonic dipolar atoms in a bilayer geometry. Contrary to previous realizations of ultradilute liquids, there is no need of stabilizing the system with an additional repulsive short-range potential. The advantage of the proposed system is that dipolar interactions on their own are sufficient for creation of a self-bound state and no additional short-range potential is needed for the stabilization. We perform quantum Monte Carlo simulations and find a rich ground state phase diagram that contains quantum phase transitions between liquid, solid, atomic gas, and molecular gas phases. The stabilization mechanism of the liquid phase is consistent with the microscopic scenario in which the effective dimer-dimer attraction is balanced by an effective three-dimer repulsion. The equilibrium density of the liquid, which is extremely small, can be controlled by the interlayer distance. From the equation of state, we extract the spinodal density, below which the homogeneous system breaks into droplets. Our results offer a new example of a two-dimensional interacting dipolar liquid in a clean and highly controllable setup.

Q 27.4 Wed 12:00 F303

strongly-interacting bosons at 2D-1D dimensional crossover — •Hepeng Yao, Lorenzo Pizzino, and Thierry Giamarchi — DQMP, University of Geneva, 24 Quai Ernest-Ansermet, CH-1211 Geneva, Switzerland

Quantum gases at dimensional crossover exhibit fruitful physics which reflects fascinating properties of non-integer dimensions. While various fascinating researches have been carried out in the tight-binding limit [1,2], the smooth dimensional crossover for strongly-interacting ultracold bosons in continuous lattice, which is strongly adapted to current generation of experiments, is rarely studied. In this talk, I will present our study about strongly-interacting bosons under continuous potential at 2D-1D dimensional crossover [3]. Using quantum Monte Carlo calculations, we investigate this dimensional crossover by computing longitudinal and transverse superfluid fractions as well as the superfluid correlation as a function of temperature, interactions and potential. Especially, we find the correlation function evolves from a Berezinskii-Kosterlitz-Thouless (BKT) to Tomonaga-Luttinger liquid (TLL) type, with the coexistence of 2D and 1D behaviors appearing at the dimensional crossover. In the end, I will discuss the consequences of these findings for cold atomic experiments

[1]. M. Cazalilla, A. Ho, and T. Giamarchi, New Journal of Physics 8(8), 158 (2006)

[2]. G. Bollmark, N. Laflorencie, and A. Kantian, Phys. Rev. B 102, 195145 (2020)

[3]. H. Yao, L. Pizzino, T. Giamarchi, arXiv:2204.02240(2022)

Q 27.5 Wed 12:15 F303

Making statistics work: a quantum engine in the BEC-BCS crossover — •Jennifer Koch[1], Keerthy Menon[2], Eloisa Cuestas[2], Sian Barbosa[1], Eric Lutz[3], Thomás Fogarty[2], Thomas Busch[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]OIST Graduate University, Onna, Okinawa, Japan — [3]Institute for Theoretical Physics I, University of Stuttgart, Germany

Heat engines convert thermal energy into mechanical work both in the classical and quantum regimes. However, quantum theory offers genuine nonclassical forms of energy, different from heat, which so far have not been exploited in cyclic engines to produce useful work. In this talk, we present the experimental realization of a novel quantum many-body engine fuelled by the energy difference between fermionic and bosonic ensembles of ultracold particles that follows from the Pauli exclusion principle. We employ a harmonically trapped superfluid gas of ^{6}Li atoms close to a magnetic Feshbach resonance which allows us to effectively change the quantum statistics from Bose-Einstein to Fermi-Dirac. We replace the traditional heating and cooling strokes of a quantum Otto cycle by tuning the gas between a Bose-Einstein condensate and a unitary Fermi gas (and back) through a magnetic field. In the talk, we will focus on the quantum nature of such a Pauli engine, which is revealed by contrasting it to a classical thermal engine and to a purely interaction-driven device. Our findings establish quantum statistics as a useful thermodynamic resource for work production.

[1] Koch, J. et al. arXiv: 2209.14202 (2022)

Q 27.6 Wed 12:30 F303

Induced interaction between ionic polarons in condensates — •Luis Ardila — Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

In this talk, we will discuss ionic polarons and their induced interaction created as a result of charged particles interacting with a Bose-Einstein condensate. Here we show that even in a comparatively simple setup consisting of charged impurities in a weakly interacting bosonic medium with tunable atom-ion scattering length, the competition of length scales gives rise to a highly correlated mesoscopic state. Using quantum Monte Carlo simulations, we unravel its vastly different polaronic properties compared to neutral quantum impurities. Moreover, we identify a transition between the regime amenable to conventional perturbative treatment in the limit of weak atom-ion interactions and a many-body bound state with vanishing quasi-particle residue composed of hundreds of atoms. Contrary to the case of neutral impurities, ionic polarons can bound many excitations and bosons from the condensate, forming many-body bound-states and changing the ground-state properties of the polaron radically. Also, transport properties are accessible by using external electric fields. Finally, we investigate the specific case of two ions that mediate interactions via the bosonic bath. This interaction can be sizable with respect to the Coulomb interaction, giving rise to notable effects which may have direct consequences in the platform employed for future quantum technologies.

Q 27.7 Wed 12:45 F303

Observation of Universal Hall Response in Strongly Interacting Fermions — •Tianwei Zhou[1], Giacomo Cappellini[2,3], Daniele Tusi[2], Lorenzo Franchi[1], Jacopo Parravicini[1,2,3], Massimo Inguscio[2,3], Jacopo Catani[2,3], and Leonardo Fallani[1,2,3] — [1]Department of Physics and Astronomy, University of Florence, 50019 Sesto Fiorentino, Italy — [2]LENS, 50019 Sesto Fiorentino, Italy — [3]CNR-INO, 50019 Sesto Fiorentino, Italy

I will present the recent experiment performed at University of Florence with ultracold 173Yb Fermi gases in optical lattices, in the presence of momentum-dependent Raman coupling between different internal states [1] and strong atom-atom interactions.

Specifically, I will report on the first quantum simulation of the Hall effect for strongly interacting fermions [2]. By performing direct measurements of current and charge polarization in an ultracold-atom simulator, we trace the buildup of the Hall response [3] in a synthetic ladder pierced by a magnetic flux, going beyond stationary Hall voltage measurements in solid-state systems. We witness the onset of a clear interaction-dependent behavior, where the Hall response deviates significantly from that expected for a non-interacting electron gas, approaching a universal value. Our system, able to reach hard to compute regimes also demonstrates the power of quantum simulation for strongly correlated topological states of matter.

References [1] M. Mancini et al., Science 349, 1510 (2015). [2] T.-W. Zhou et al., arXiv:2205.13567 (2022). [3] S. Greschner et al., Phys. Rev. Lett. 122, 083402 (2019).