Q 59: Quantum Gases (Bosons) VI

Time: Thursday 10:30–12:45 Location: K 2.020

Q 59.1 Thu 10:30 K 2.020

Dynamical signatures of $\mathbb{Z}_2$ gauge invariance on a single plaquette — •Christian Schweizer[1], Fabian Grusdt[2], Moritz Berngruber[1], Michael Lohse[1], Monika Aidelsburger[1], Luca Barbiero[3], Nathan Goldmann[3], Eugene Demler[2], and Immanuel Bloch[1] — [1]LMU München & MPQ Garching — [2]Harvard University, Massachsetts, USA — [3]Université libre de Bruxelles, Belgium

Synthetic magnetic and electric fields for ultracold neutral atoms have been implemented in various setups with dynamical control over the systems' parameters. However, the realized fields are purely classical and there exists no back-action of the particles on these fields. Here, we present a minimal example that exhibits fully coherent quantum dynamics for the artificial gauge field on a four-site plaquette. The dynamical gauge field emerges through the interaction between impurity atoms and particles represented by different spin species. We place one impurity atom on each horizontal link of the plaquette and probe the dynamical field with a third particle that interacts with the impurities and thus generates a back-action.

Q 59.2 Thu 10:45 K 2.020

Cavity-induced artificial gauge field in a Bose-Hubbard ladder — •Catalin-Mihai Halati, Ameneh Sheikhan, and Corinna Kollath — HISKP, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany

We consider theoretically ultracold interacting bosonic atoms confined to quasi-one-dimensional ladder structures formed by optical lattices and coupled to the field of an optical cavity. The atoms can collect a spatial phase imprint during a cavity-assisted tunneling along a rung via Raman transitions employing a cavity mode and a transverse running wave pump beam. By adiabatic elimination of the cavity field we obtain an effective Hamiltonian for the bosonic atoms, with a self-consistency condition. Using the numerical density matrix renormalization group method, we obtain a rich steady state diagram of self-organized steady states. Transitions between superfluid to Mott-insulating states occur, on top of which we can have Meissner, vortex liquid, and vortex lattice phases. Also a state that explicitly breaks the symmetry between the two legs of the ladder, namely the biased-ladder phase is dynamically stabilized.

Q 59.3 Thu 11:00 K 2.020

A Simple Model for the Temporal Evolution of Cold Dark Matter — •Tim Zimmermann[1], Luca Amendola[1], Massimo Pietroni[2], and Sandro Wimberger[2] — [1]ITP, Universität Heidelberg, 69120 Heidelberg — [2]Dipartimento di Scienze Matematiche, Fisiche e Informatiche, Università di Parma, 43124 Parma & INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma, 43124 Parma

Cold dark matter (CDM) is typically modeled as a collisionless, irrotational fluid, trapped in its own gravitational potential, obeying the classical Euler-Poisson equations. However, a straight forward analyis shows that CDM can also be treated in a quantum dynamical framework if one chooses a particular ansatz for the wave function. In doing so, the temporal evolution of CDM is governed by a nonlinear Schrödinger equation describing CDM as self-interacting, self-gravitating Bose-Einstein condensate. Modeling the dynamics of cold dark matter in terms of the Gross-Pitaevskii-Poisson system turns out to be an elegant describtion of structure formation comparable to classical cosmological approaches, especially on large cosmic scales. On smaller scales gravitational collapse is balanced by a "quantum pressure" that resembles Heisenbergs' uncertainty principle. We present a comprehensive numerical method to perform the time evolution of the described wave-like CDM. Results for both synthetic and cosmological initial conditions are presented.

Q 59.4 Thu 11:15 K 2.020

Self-consistent spin texture in a quantum gas through optomagnetical effects — Katrin Kröger, •Manuele Landini, Lorenz Hruby, Nishant Dogra, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

We experimentally realize opto-magnetic coupling between a multilevel atomic BEC and a single mode of a high-finesse optical cavity. We focus on the role of the vectorial component of the polarizability tensor for spinful condensed atoms. We develop a theory in the context of a modified Dicke model and can explain the observed threshold power for the self-organization phase transition as well as the phase of the light in the organized phase depending on the internal state. When preparing a spin mixture, we identify two distinct regimes of coupling. In the regime of density coupling, the self-organization process generates density modulations in the atomic system. By increasing the ratio of the vectorial over the scalar coupling beyond a critical point, we observe the appearance of a new self-organization pattern consisting of magnetization modulations, a spin texture. Our findings demonstrate a direct competition between self-organization patterns in a single mode optical cavity, paving the way to the exploitation of opto-magnetic effects for quantum simulation of long-range magnetic interactions.

Q 59.5 Thu 11:30 K 2.020

supersolidity of lattice Bosons immersed in strongly correlated Rydberg dressed atoms — •Yongqiang Li[1], Andreas Geissler[2], Walter Hofstetter[2], and Weibin Li[3,4] — [1]Department of Physics, National University of Defense Technology, Changsha 410073, P. R. China — [2]Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt/Main, Germany — [3]School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, UK — [4]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham NG7 2RD, UK

Recent experiments have illustrated that long range two-body interactions can be induced by laser coupling atoms to highly excited Rydberg states. Stimulated by this achievement, we study supersolidity of lattice bosons in an experimentally relevant situation. In our setup, we consider two-component atoms on a square lattice, where one species is weakly dressed to an electronically high-lying (Rydberg) state, generating a tunable, soft-core shape long-range interaction. Interactions between atoms of the second species and between the two species are characterized by local inter- and intra-species interactions. Using a dynamical mean-field calculation, we find two distinctive types of supersolids, where the bare species forms supersolid phases that are immersed in strongly correlated quantum phases, i.e. a crystalline solid or supersolid of the dressed atoms. We show that the interspecies interaction leads to a roton-like instability in the bare species and therefore is crucially important to the supersolid formation.

Q 59.6 Thu 11:45 K 2.020

Coupled order parameters with ultracold atoms in two crossed cavities — •Philip Zupancic[1], Andrea Morales[1], Julian Léonard[1,2], Xiangliang Li[1], Davide Dreon[1], Tilman Esslinger[1], and Tobias Donner[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

The concept of intertwined order describes the simultaneous existence of independent order parameters and can therefore allow materials to feature multiple properties. Examples include multiferroic materials that have coexisting ferroelectric and ferromagnetic orders leading to enhanced functionalities, and materials that are superconducting at high temperatures due to intertwining between charge- and spin-order.

I will report on our recent experimental realization of an intertwined ordered phase in a quantum gas where we can control the interaction between the atoms at the microscopic level. Our system is realized by a BEC that can transit into self-organized phases with the modes of two crossed optical cavities.

For vanishing inter-order coupling we realize a supersolid phase of matter by symmetry enhancement of the composite order parameter to a $U(1)$ symmetry. Here we observe the simultaneous existence of a Higgs and Goldstone mode. Increasing the inter-order coupling, this symmetry breaks down to a $\mathbb{Z}_2 \times \mathbb{Z}_2$, and we observe the emergence of an extended intertwined phase arising from the coupling of the individual order parameters. This coupling enables us to increase or decrease the critical point of one order by controlling the other.

Q 59.7 Thu 12:00 K 2.020

Entanglement entropy across quantum phases of Ultracold Bosons with incommensurate optical lattice due to cavity backaction — •Shraddha Sharma[1], Astrid E. Niederle[2], and

Giovanna Morigi[1] — [1]Theoretical Physics, Saarland University, Campus E2.6, D-66123 Saarbrucken, Germany — [2]Fraunhofer Institute for Experimental Software Engineering IESE, Germany

We consider a bosonic gas in a two-dimensional optical lattice. The atoms interact via s-wave scattering and via long range interactions induced by the coupling with a cavity. We determine the phase diagram when the optical lattice wavelength is incommensurate with the cavity mode wavelength using a mean-field ansatz. In this regime we observe, in addition to the Mott-insulator and the superfluid, also a Bose-Glass and a superglass phase, where the density distribution supports the formation of a stable intracavity field. We explore the behaviour and scaling of entanglement entropy and of entanglement spectrum at the phase transitions using a controlled perturbative expansion above the mean-field ground state.

Q 59.8 Thu 12:15 K 2.020

Self organisation of a BEC in two crossed cavities across an atomic resonance — •Davide Dreon, Andrea Morales, Philip Zupancic, Xiangliang Li, Tobias Donner, and Tilman Esslinger — ETH, Zürich, Switzerland

The interaction of a Bose-Einstein condensate (BEC) with the electromagnetic field of an optical cavity is known to exhibit a superradiant phase transition to a self-organized phase. In our experiment, a ^{87}Rb BEC is placed at the mode crossing of two optical cavities. The BEC is illuminated with a 'pump' laser beam whose detuning from the D_2 atomic line determines the interaction regime. We recently explored different red detunings, where the system reduces its potential energy spontaneously forming an attractive lattice in the cavity mode. Here, we have observed a supersolid phase [1,2] and a phase with intertwined order [3]. In contrast, in the blue detuned case the energy of the atoms is increased by the presence of an optical lattice and therefore spontaneous superradiant scattering in the cavity should be inhibited.

I will report on our most recent experimental results on the blue side of the atomic resonance, where we observe, surprisingly, that self-organization is still possible. We measure the phase diagram of the system and explain our findings with simple energy arguments. In addition to the steady state regime typical of red detunings, dynamical instabilities leading to limit cycles of the cavity field amplitude or chaotic behaviors are expected [4].

[1] Nature, 543, 87-90 (2017), [2] arXiv:1704.05803 (to appear in Science), [3] arXiv:1711.07988, [4] PRL 115, 163601 (2015)

Q 59.9 Thu 12:30 K 2.020

Nanofriction & the Aubry-type transition in self-organized systems under the influence of the crystal environment — •Jan Kiethe[1], Ramil Nigmatullin[2], Dimitri Kalincev[1], Thorben Schmirander[1], and Tanja E. Mehlstäubler[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland — [2]University of Sydney, Sydney, Autralia

The excellent control over trapped ions enables various applications, such as precision spectroscopy and quantum information. Cooling the ions below the potential energy of the Coulomb system will result in crystals, which can be used as quantum simulators or as emulators for non-equilibrium many-body physics. Furthermore, ion traps offer in-situ access to the crystal dynamics, which is often impossible in the emulated systems. While emulating a boundary of two atomically flat solids with a Coulomb crystal with a local defect, we experimentally and numerically found a transition from sticking-to-sliding. Two signatures of an Aubry-type transition were observed: a soft-mode and a symmetry breaking of the crystal configuration. Here we discuss, based on numerical calculations, how the environment of the ion crystal influences the structure and subsequently the phonon spectrum, in order to determine how robust these signatures are. As the actual interacting surface in this model system is inhomogeneously spaced, we also numerically investigate Coulomb crystals with periodic boundary conditions, which exhibit a constant distance between the sliding ion chains, increasing the interacting surface to the complete crystal.