Q 42: Long-range Interactions

Time: Thursday 11:00–13:00 Location: HS 1015

Invited Talk Q 42.1 Thu 11:00 HS 1015

Theory of robust quantum many-body scars in long-range interacting systems — •Silvia Pappalardi — 77, Zulpicher Strasse, D-50937 Cologne

Quantum many-body scars are exceptional energy eigenstates of quantum many-body systems associated with violations of thermalization for special non-equilibrium initial states. Their various systematic constructions require fine-tuning of local Hamiltonian parameters. In this talk, I will show that the setting of long-range interacting quantum spin systems generically hosts robust quantum many-body scars. I will discuss that this is the combined effect of two ingredients: the integrability of the classical collective limit and the sufficiently strong long-range of the interactions. Broader perspectives of this work range from independent applications of the technical toolbox developed here to informing experimental routes to metrologically useful multipartite entanglement.

Q 42.2 Thu 11:30 HS 1015

Neural Network Quantum States for the Hofstadter Model with Higher Local Occupations and Long-Range Interactions — •Fabian Döschl[1,2], Felix Palm[1,2], Hannah Lange[1,2,3], Fabian Grusdt[1,2], and Annabelle Bohrdt[2,4] — [1]Ludwig-Maximilians-University Munich — [2]Munich Center for Quantum Science and Technology — [3]Max-Planck-Institute for Quantum Optics — [4]University of Regensburg

Neural network quantum states (NQS) have gained significant interest in current research due to their immense representative power. In this study, we show that RNN wave functions can be employed to study systems relevant to current research in quantum many body physics. Specifically, we employ a 2D tensorized gated RNN to explore the Hofstadter Hamiltonian with a variable local Hilbert space cut off. We benchmark the NQS against exact diagonalization for the Hofstadter Hamiltonian with on site interactions on a 6×6 square lattice. Remarkably, this method is capable of effectively identifying and representing the ground state. A further benchmark against DMRG for 12×12 systems will reveal phases that are hard to simulate with the RNN-NQS ansatz. Moreover, we demonstrate that NQSs are capable of capturing interactions over large distances, a task that is far from being solved by current methods. This technique is applied to a Hofstadter Hamiltonian with long-range interactions on a 12×12 square lattice. This work aims to enhance our understanding of representing strongly correlated quantum systems with NQS.

Q 42.3 Thu 11:45 HS 1015

Cavity induced quantum droplets — •Leon Mixa[1], Milan Radonjić[1,2], Axel Pelster[3], and Michael Thorwart[1] — [1]I. Institute of Theoretical Physics, Universität Hamburg, Germany — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Physics Department and Research Center OPTIMAS, University Kaiserslautern-Landau, Germany

Quantum droplets are formed in an interacting atom gas when quantum fluctuations stabilize the gas mechanically which would otherwise be unstable. Subjecting a condensate to interaction with a cavity is known to strongly couple the atomic and cavity fluctuations, creating long-range interactions and roton-like modes. We study the formation of quantum droplets in a three-dimensional homogeneous Bose-Bose mixture placed in an optical cavity. The internal transitions of the atoms are off-resonantly pumped by a beam transversal to the cavity axis. We find that cavity fluctuations influence droplet properties, such that changing the cavity parameters can be used for droplet tuning. Furthermore, cavity fluctuations can create necessary conditions for droplet formation even in the stable mean-field region of the bare mixture.

Q 42.4 Thu 12:00 HS 1015

Bragg Spectroscopy of a Dynamic Instability where two soft modes meet. — Alexander Baumgaertner, Gabriele Natale, •Justyna Stefaniak, Simon Hertlein, David Baur, Dalila Rivero, Tobias Donner, and Tilman Esslinger — ETH Zurich, Switzerland

The excitation spectrum of open many-body systems can give rise to various features e.g. dynamical instabilities and exceptional points. In our experiment, consisting of a Bose-Einstein condensate (BEC) coupled to a cavity mode, we realize two different superradiant crystals and perform Bragg spectroscopy to measure the excitation spectrum. Long-range interactions in quantum gases can give rise to an excitation spectrum with a roton-type minimum in the dispersion relation. In our case, we associate a roton-like mode with each of the superradiant crystals. By changing interaction strength, we observe how the excitation energies, the strength of the density-density correlations and the roton momentum are modified prior to the formation of one of the crystal phases. Dissipation introduces coupling between these two modes and can lead to an amplification of one and a dampening of the other mode. Additionally tuning the strength of the interactions, we found a regime, where two roton-type modes respond at the same energy. In this regime, the presence of dissipation introduces a coupling between these two models and finally leads to a dynamic instability of the system.

Q 42.5 Thu 12:15 HS 1015

Re-entrant phase transition in many-body Cavity QED — •Tom Schmit[1], Tobias Donner[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

We analyse theoretically self-organization of atoms that couple dispersively to an optical cavity and are subject to a transverse pump, in a configuration experimentally studied[1]. The transverse pump laser is blue-detuned w.r.t. the atomic transition, confining the atoms in the intensity minima of the generated optical lattice. The competition of pump and cavity field leads to self-organization of the atoms in an ordered pattern, giving rise to a re-entrant phase transition, such that by increasing the pump intensity above a critical value, one first observes a transition from disorder to self-organized and then, at larger values, again back to a disordered phase. Our theoretical model, founded on a mean-field ansatz, provides a description of the stationary state's phase diagram in relation to pump intensity and detuning from the cavity frequency, aligning well with experimental observations[1]. We show that stability of the ordered pattern is warranted when the scattered light interferes destructively with the pump at the atomic positions, effectively keeping the atoms in darkness. We discuss the connection between this phenomenon and *inverse melting*, observed in (classical) systems with repulsive and competing long-range interactions.

[1] P. Zupancic et al., Phys. Rev. Lett. **123**, 233601 (2019).

Q 42.6 Thu 12:30 HS 1015

Commensurate-incommensurate transition in frustrated Wigner crystals — •Raphaël Menu[1], Jorge Yago Malo[2], Vladan Vuletić[3], Maria Luisa Chiofalo[2], and Giovanna Morigi[1] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]Universita di Pisa, Pisa, Italy — [3]Massachusetts Institute of Technology, Cambridge, USA

Geometric frustration in systems with long-range interactions is a largely unexplored phenomenon. In this work we analyse the ground state emerging from the competition between a periodic potential and a Wigner crystal in one dimension, consisting of a selforganized chain of particles with the same charge. This system is a paradigmatic realization of the Frenkel-Kontorova model with Coulomb interactions. We derive the action of a Coulomb soliton in the continuum limit and demonstrate the mapping to a massive (1+1) Thirring model with long-range interactions. The mean-field limit is a long-range antiferromagnetic spin chain with uniform magnetic field and predicts that the commensurate, periodic structures form a complete devil's staircase as a function of the charge density. Each step of the staircase correspond to the interval of stability of a stable commensurate phase and scales with the number N of charges as 1/ln N. This implies that there is no commensurate-incommensurate phase transition in the thermodynamic limit. For finite systems, however, the ground state has a fractal structure that could be measured in experiments with laser-cooled ions in traps.

Q 42.7 Thu 12:45 HS 1015

Ab initio simulation of dipolar Bose gases with the complex Langevin algorithm — •Philipp Heinen[1], Wyatt Kirkby[1,2], Lauriane Chomaz[2], and Thomas Gasenzer[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg — [2]Physikalisches Institut, Universität Heidelberg

Bose-Einstein condensates (BECs) of atoms with a strong magnetic moment in their ground state, e.g. Erbium or Dysprosium, feature long-range dipolar interactions. These give rise to several peculiar phenomena that are absent from purely contact interacting Bose gases, notably rotonic excitations, supersolidity and quantum droplets. What makes them interesting from the theoretical point of view is that mean-field descriptions based on the Gross-Pitaevskii equation (GPE) fail to predict such states of matter and the effect of quantum fluctuations must be included. This can be done by adding an additional term to the GPE based on the perturbative Lee-Huang-Yang (LHY) correction or by performing ab initio path integral Monte Carlo (PIMC) simulations. The latter are, however, limited to several hundred atoms due to the high computational cost of the method, far below experimentally realistic particle numbers. An alternative is the equally fully exact complex Langevin (CL) algorithm whose computational cost is independent of the particle number and is thus suitable for simulating actual experimental settings from first principles. We will present the results of such simulations on both sides of the superfluid-supersolid transition of a dipolar BEC.