FM 17: Quantum Computation: Simulation I

Time: Monday 16:30–18:00 Location: 1010

FM 17.1 Mon 16:30 1010

Quantum Simulation of the Quantum Rabi Model in the Deep Strong Coupling Regime — •Johannes Koch[1], Geram Hunanyan[1], Simone Felicetti[2], Enrique Rico[3,4], Enrique Solano[3,4], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany — [2]Laboratoire Matériaux et Phénomènes Quantiques, Universite of Paris 7, Bâtiment Condorcet, Case courrier 7021, 75205 Paris Cedex 13, Paris, France — [3]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, E-48080 Bilbao, Spain — [4]IKERBASQUE, Basque Foundation for Science, Maria Diaz de Haro 3, E-48013 Bilbao, Spain

The Quantum Rabi Model describing the interaction between a two-level quantum system and a single bosonic mode has been well studied in the moderate and strong coupling regimes, while the experimental study of more extreme parameter regimes has long been a technical challenge. Here we investigate the Quantum Rabi Model in the deep strong coupling regime, in which the characteristic frequencies of the coupling exceeds those of the two-level system and the bosonic mode.

Our experimental implementation uses ultracold rubidium atoms in a tailored optical lattice potential, with the two-level system provided by two Bloch bands. This effective qubit interacts with a quantum harmonic oscillator mode provided by the atomic motion in an optical dipole potential superimposed to the lattice potential. The time evolution of the system provides insights into the evolution of the Quantum Rabi Model. The present status of the experiment will be presented.

FM 17.2 Mon 16:45 1010

Simulating a Mott insulator using attractive interaction — •Marcell Gall, Chun Fai Chan, Nicola Wurz, and Michael Köhl — Physikalisches Institut, University of Bonn, Wegelerstraße 8, 53115 Bonn, Germany

Particles can be transformed into their anti-particles by a charge conjugation, and a symmetry upon such conjugation plays a crucial role in physics. For example, all fundamental forces, except weak interaction, obey such symmetry. However, even in the low-energy domain of condensed matter physics, the symmetry gives rise to novel effects and provides stability to exotic quantum states.

In our experiment, we study the particle-hole symmetry in a quantum simulator of the two-dimensional Hubbard model using ultracold fermionic atoms in an optical lattice. In this talk we will demonstrate mapping between charge and spin degrees of freedom. In particular, we show the occurrence of a state with incompressible magnetisation for attractive interactions, corresponding to the Mott phase in the density sector and repulsive interactions.

FM 17.3 Mon 17:00 1010

Defect-free assembly of 2D clusters of more than 100 single-atom quantum systems in a multilayer Talbot optical lattice — •Malte Schlosser, Daniel Ohl de Mello, Dominik Schäffner, Tilman Preuschoff, Lars Kohfahl, Jan Werkmann, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Efficient quantum simulation and quantum information processing requires scalable architectures that guarantee the allocation of large-scale qubit resources. In our work, we focus on the implementation of multi-site geometries based on microoptical elements that readily provide thousands of sites for single-atom quantum systems with Rydberg-mediated interactions.

We report on the realization of a novel platform for the creation of 3D multilayer configurations of planar arrays: a microlens-generated Talbot optical lattice [1]. We demonstrate the trapping and imaging of rubidium atoms in integer and fractional Talbot planes and realize the in-plane assembly of defect-free arrays of up to 111 neutral atoms, building on a 361-site subset of traps [2]. By performing multiple assembly cycles in rapid succession, we drastically increase achievable structure sizes and success probabilities. We implement repeated target pattern reconstruction after atom loss and deterministic transport of partial atom clusters.

[1] M. Schlosser et. al., arXiv:1902.05424 (2019).
[2] D. Ohl de Mello et. al., Phys. Rev. Lett. **122**, 203601 (2019).

FM 17.4 Mon 17:15 1010

Simulating long-range interacting systems with cold atoms in resonators — •Simon B. Jäger, Luigi Giannelli, Francesco Rosati, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

Dilute atomic gases in optical cavities are versatile platforms to simulate the statistical mechanics of long-range interacting systems. The long-range potential shares the same non-additivity of gravitational and Coulomb forces and here emerges from multiply-scattered cavity photons. In addition, photon losses and retardation effects give rise to long-range dissipative forces, which are expected to play a peculiar role in the approach to equilibrium. We analyze the stationary phases of cold atoms in optical cavities and their relaxation dynamics towards steady state. We focus in particular on the dynamics following quenches across different stationary phases and investigate the onset and stability of metastable states in the regime in which quantum fluctuations are a small perturbation to the dynamics. Our analysis shows that cold atoms in resonators can provide a promising setup to verify in a laboratory hypothesis developed for the statistical mechanics of cosmic structures.

FM 17.5 Mon 17:30 1010

Ions and atoms in optical dipole traps: a new platform for quantum simulations — Pascal Weckesser, Fabian Thielemann, Isabelle Lindemann, Florian Hasse, Tobias Schaetz, and •Leon Karpa — Physikalisches Institut, Albert-Ludwigs Universität Freiburg, Germany

The combination of ions and neutral atoms has been brought forward as a candidate for realizing novel quantum simulations by making use of their advantageous interaction. One of the most sought after goals in the recently emerged field studying cold ion-atom collisions is gaining access to a quantum dominated regime of ion-atom interactions. So far, experiments in hybrid systems combining ions in Paul traps and optically trapped atoms show that the energy scales in the combined system are limited to temperatures on the order of mK, even in the case of ultracold ensembles. This limitation is the consequence of micromotion-induced heating inherent to all radiofrequency traps.

Here we present a new approach based on all-optical trapping of ions and atoms which avoids the use of any radiofrequency techniques, and show sympathetic cooling of ions to sub-Doppler temperatures. Together with our recent findings demonstrating optical trapping of ion Coulomb crystals and long lifetimes on the order of seconds, these results pave the way to ultracold ion-atom interactions, a novel class of quantum simulations and investigations of structural quantum phase transitions.

FM 17.6 Mon 17:45 1010

Easing the Monte Carlo Sign Problem — •Dominik Hangleiter[1], Ingo Roth[1], Daniel Nagaj[2], and Jens Eisert[1] — [1]FU Berlin, 14195 Berlin — [2]Slovak Academy of Sciences, Bratislava, Slovakia

Quantum Monte Carlo (QMC) methods are the gold standard for studying equilibrium properties of quantum many-body systems – their phase transitions, their ground and thermal state properties – but also quantum circuit simulation. However, QMC methods face the severe limitation of a 'sign problem' for many quantum systems, in particular so for fermionic systems. Here, we introduce a novel universal and versatile framework for 'easing the sign problem' by local basis changes in practical condensed-matter applications, realising that it is a basis-dependent property. We introduce the optimisation problem of finding the basis in which the sign problem is smallest by means of minimizing the positive part of the Hamiltonian matrix. We then demonstrate that this problem is practically feasible using geometric optimization methods by the example of frustrated ladder systems, showing that the sign problem can be greatly reduced. Complementing this pragmatic mindset, as our main rigorous result we show that easing the sign problem can be a computationally hard task, even in situations in which deciding whether an exact solution exists can be done efficiently.