Q 60: Quantum Gases (Bosons and Fermions) II

Time: Friday 10:30–12:30 Location: S HS 037 Informatik

Invited Talk Q 60.1 Fri 10:30 S HS 037 Informatik
Polaronic effects in condensed matter and atomic systems
— •Richard Schmidt — Max Planck Institute of Quantum Optics, Garching, Germany

When an impurity is immersed into an environment, it changes its properties due to its interactions with the surrounding medium. The impurity is dressed by excitations in the bath and, depending on the nature of the environment, new collective states of matter are formed. These states can, for instance, have the character of quasiparticles, called polarons, or can be states that are completely orthogonal to the original, non-interacting state of the system. In this talk, I will present recent experimental and theoretical progress on studying a variety of polaronic phenomena encountered in ultracold atomic systems, and discuss their relation to phenomena of relevance in novel two-dimensional semiconductor materials. I will then focus on employing polaronic effects in Rydberg systems as a probe of their many-body environment. In such systems the interaction between the Rydberg atom and their surrounding atomic gas gives rise to a new polaronic dressing mechanisms, where instead of collective excitations, molecules of gigantic size dress the Rydberg impurity, leading to the formation of Rydberg superpolarons. Using a functional determinant approach which incorporates atomic and many-body theory we show how bosonic and fermionic statistics can be probed by Rydberg excitations and we demonstrate that distinct Fermi and Bose polaron physics can be observed using Rydberg excitations in ultracold quantum gases.

Q 60.2 Fri 11:00 S HS 037 Informatik
Imaging magnetic polarons in the doped Fermi-Hubbard model
— •Joannis Koepsell[1], Jayadev Vijayan[1], Pimonpan Sompet[1], Fabian Grusdt[2,3], Timon Hilker[1], Eugene Demler[2], Guillaume Salomon[1], Immanuel Bloch[1,4], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA — [3]Department of Physics, Technical University of Munich, 85748 Garching, Germany — [4]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München, Germany

Polarons are among the most fundamental quasiparticles emerging in interacting many-body systems, forming already at the level of a single mobile dopant. In the context of the two- dimensional Fermi-Hubbard model, such polarons are predicted to form around charged dopants in an antiferromagnetic background in the low doping regime close to the Mott insulating state. Here we report the microscopic observation of magnetic polarons in a doped Fermi-Hubbard system, harnessing the full single-site spin and density resolution of our ultracold-atom quantum simulator. We reveal the dressing of mobile doublons by a local reduction and even sign reversal of magnetic correlations, originating from the competition between kinetic and magnetic energy in the system. The experimentally observed polaron signatures are found to be consistent with an effective string model at finite temperature. We demonstrate that delocalization of the doublon is a necessary condition for polaron formation by contrasting this mobile setting to a scenario where the doublon is pinned to a lattice site.

Q 60.3 Fri 11:15 S HS 037 Informatik
Doping-induced Ferromagnetism in quantum gases
— •Luca Bayha, Marvin Holten, Keerthan Subramanian, Philipp Preiss, and Selim Jochim — Physics Institute, Heidelberg University, Germany

The emergence of collective behaviour in strongly correlated systems is still not fully understood. This is also the case even if the underlying microscopic Hamiltonian is as simple as in the Fermi-Hubbard model. One specific question is the microscopic origin of Ferromagnetism in itinerant spin systems. Especially intriguing is the discovery of Nagaoka, who calculated that doping the Hubbard model with a single hole away from half filling completely destroys antiferromagnetic ordering and leads to a ferromagnetic ground state for sufficiently large interactions. In our group we want to experimentally tackle this problem by preparing a minimal instance of this system. In this talk I will present our recent progress on deterministically preparing the ground state of a plaquette filled with three Fermions. We use a high resolution objective in combination with a Spatial Light Modulator (SLM) placed in the Fourier plane of the objective to project arbitrary potentials onto the atoms. To probe the system we plan to use the spin and position resolved imaging for single atoms. With only a few florescence photons collected on an EMCCD camera, the scheme does not require cooling and additionally gives access to the momentum space distribution.For the future we plan to merge these minimal instances and study larger systems of strongly correlated matter.

Q 60.4 Fri 11:30 S HS 037 Informatik
Direct measurement of density-dependent Peierls phases in a driven Hubbard dimer
— •Konrad Viebahn, Frederik Görg, Kilian Sandholzer, Joaquín Minguzzi, Rémi Desbuquois, Michael Messer, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, CH-8093 Zurich

The coupling between gauge and matter fields is a key concept in many models of high-energy and condensed matter physics. In these models the gauge fields are dynamical quantum degrees of freedom, i.e. they are influenced by the spatial configuration and motion of the matter field. It has been proposed to implement this coupling mechanism on quantum simulation platforms, ultimately aiming at emulating lattice gauge theories. However, existing methods for generating gauge fields in optical lattices lack the back-action from the atoms. In this experiment we realise the fundamental ingredient for a density-dependent gauge field by engineering non-trivial Peierls phases that depend on the site occupation of fermions in a Hubbard dimer. Our method relies on breaking time-reversal symmetry (TRS) by driving an optical super-lattice simultaneously at two frequencies, at resonance with the on-site interaction. In addition, a constant energy offset between the two sites of the double-well allows us to single out one tunnelling process of which we characterise both the amplitude and the associated Peierls phase. When TRS is not broken the phase exhibits a sudden jump of exactly π, characterised by a $\mathbb{Z}_2$-invariant. For the general case, we determine the winding structure of the Peierls phase which features a Dirac point as a function of driving parameters.

Q 60.5 Fri 11:45 S HS 037 Informatik
Topological Devil's staircase in atomic two-leg ladders
— Simone Barbarino[1,2], Davide Rossini[3], •Matteo Rizzi[4], Rosario Fazio[5,6], Giuseppe E. Santoro[1,5,7], and Marcello Dalmonte[1,5] — [1]SISSA, Trieste, Italy — [2]Technische Universität Dresden, Germany — [3]Università di Pisa and INFN, Italy — [4]Johannes Gutenberg-Universität, Mainz, Germany — [5]ICTP, Trieste, Italy — [6]NEST, SNS & Istituto Nanoscienze-CNR, Pisa, Italy — [7]CNR-IOM Democritos, Trieste, Italy

We show that a hierarchy of symmetry-protected topological (SPT) phases in 1D – a topological Devil's staircase – can emerge at fractional filling fractions in interacting systems, whose single-particle band structure describes a (crystalline) topological insulator. Focusing on a specific example in the BDI class, we present a field-theoretical argument based on bosonization that indicates how the system phase diagram, as a function of the filling fraction, hosts a series of density waves. Subsequently, based on a numerical investigation of spectral properties, Wilczek-Zee phases, and entanglement spectra, we show that these phases can support SPT order. In sharp contrast to the non-interacting limit, these topological density waves do not follow the boundary-edge correspondence, as their edge modes are gapped. We then discuss how these results are immediately applicable to models in the AIII class, and to crystalline topological insulators protected by inversion symmetry. Our findings are immediately relevant to cold atom experiments with alkaline-earth atoms in optical lattices, where the band structure properties we exploit have been recently realized.

Q 60.6 Fri 12:00 S HS 037 Informatik
Towards quantum Hall physics with ultracold erbium atoms
— •Roberto Röll, Cecilien Harnik, David Helten, Daniel Babik, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Deutschland

We report on progress in an ongoing experiment directed at the observation of fractional quantum Hall physics in an integer spin system, using ultracold erbium atoms in a strong synthetic magnetic gauge field.

In alkali atoms with their S-ground state configuration in far detuned laser fields with detuning above the upper state fine structure splitting the trapping potential is determined by the scalar electronic polarizability. In contrast, for an atomic erbium quantum gas with its $L > 0$ electronic ground state, the trapping potential for inner-shell transitions also for far detuned dissipation-less trapping laser fields becomes dependent on the internal atomic state (i.e. spin). Therefore it is expected to reach much longer coherence times in the erbium species with $L > 0$ which will allow for large light-induced magnetic fields in comparison with the usual alkali atoms.

In our Bonn experiment an atomic erbium Bose-Einstein condensate (BEC) is generated in a crossed quasistatic optical dipole trap provided by a focused mid-infrared CO2-laser beam as well as a YAG-laser beam. In the next experimental step, we plan to realize synthetic magnetic fields by phase imprinting with Raman manipulation beams.

Q 60.7 Fri 12:15 S HS 037 Informatik

Dynamical variational approach to Bose polarons at finite temperatures — •David Dzsotjan[1], Richard Schmidt[2], and Michael Fleischhauer[1] — [1]Department of Physics and Research Centre OPTIMAS, TU Kaiserslautern, Germany — [2]Max-Planck Institute for Quantum Optics, Garching, Germany

With recent experiments exploring the behaviour of polarons in quantum gases, there has been a very real motivation to construct theoretical models that give a good description of polarons at temperatures larger than zero. We specifically investigate finite-temperature Bose polarons, i.e., an impurity particle interacting with bosons in a BEC. In our theoretical framework we use a dynamical variational approach to solve the dynamics of a single impurity interacting with the Bogoliubov phonons of a BEC which are initially in a thermal state. We present the model where the temperature dependence is mapped onto a stochastic Hamiltonian that includes impurity-phonon interactions up to the 2-phonon order. The ansatz wavefunction for the phonon state is based on coherent states, allowing for an arbitrary number of exitations in the polaronic system. We subsequently present the numerical results for the polaronic dynamics and excitation spectrum, comparing them to recent experimental findings for an impurity-BEC system in a three-dimensional trap.