TT 41: Matter at Low Temperature: Quantum Liquids, Bose-Einstein-Condensates, Ultra-cold Atoms

Time: Thursday 14:00–19:00 Location: HSZ 105

TT 41.1 Thu 14:00 HSZ 105

Dynamics of Interacting Bose-Bose Mixtures in an Optical Lattice — •Julia Wernsdorfer, Michiel Snoek, and Walter Hofstetter — Institut für Theoretische Physik, Goethe-Universität, D-60438 Frankfurt, Germany

We investigate a bosonic quantum gas consisting of two interacting species in a two-dimensional optical lattice. The equilibrium properties and dynamics of this system are obtained by means of the Gutzwiller method. In particular we study the ramp-up of the optical lattice, which occurs on a time scale comparable to the tunneling time of the bosons. We investigate the adiabaticity of this process with respect to the many body quantum states to analyze whether the bosonic gas is in an equilibrium state when time-of-flight measurements are carried out. The effect of finite temperature is investigated by extending the time-dependent Gutzwiller method to $T > 0$.

TT 41.2 Thu 14:15 HSZ 105

Exploring Local Quantum Many-Body Relaxation by Atoms in Optical Superlattices — •Andreas Flesch[1], Marcus Cramer[2], Ian P. McCulloch[3], Ulrich Schollwöck[1], and Jens Eisert[2,4] — [1]Institut für Theoretische Physik C, RWTH Aachen University, 52056 Aachen, Germany — [2]Institute for Mathematical Sciences, Imperial College London, SW7 2PE London, United Kingdom — [3]School of Physical Sciences, The University of Queensland, Brisbane, QLD 4072, Australia — [4]Institute for Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany

In the study of relaxation processes in coherent non-equilibrium dynamics of quenched quantum systems, ultracold atoms in optical superlattices with periodicity 2 provide a very fruitful test ground. We consider the dynamics of a particular, experimentally accessible initial state prepared in a superlattice structure evolving under a Bose-Hubbard Hamiltonian in the entire range of interaction strengths [1,2]. We investigate the relaxation dynamics of certain correlation functions analytically in the non-interacting and hard-core bosonic limits and numerically for finite interaction strengths using a time-dependent density-matrix renormalization (t-DMRG) approach. Our results show that this setup allows to experimentally probe signatures of the process of local relaxation of subsystems in non-equilibrium dynamics without the need of addressing single sites by exploiting the possibilities offered by optical superlattices.

[1] M. Cramer et al., PRL 101, 063001 (2008)
[2] A. Flesch et al., PRA 78, 033608 (2008)

TT 41.3 Thu 14:30 HSZ 105

Superfluid Boson Currents and Long Range Interactions in 1D Lattices — •Johannes Schachenmayer — Institut für Theoretische Physik, Technikerstr. 26, 6020 Innsbruck, Austria

The decay of superfluid currents for bosons moving in an optical lattice potential has attracted a lot of recent attention. In particular, experiments have shown that the decay of currents in 1D systems differs markedly from the mean-field prediction. We investigate this system here, computing the time evolution within the Bose-Hubbard model using the infinite Time Evolving Block Decimation Algorithm, and find good agreement with the experimental results. We further report on progress in extending the algorithm to allow simulation of long-range interactions.

TT 41.4 Thu 14:45 HSZ 105

Magnetism, coherent many-particle dynamics, and relaxation with ultracold bosons in optical superlattices — •Thomas Barthel[1], Christian Kasztelan[1], Ian P. McCulloch[2], and Ulrich Schollwöck[1] — [1]Institute for Theoretical Physics C, RWTH Aachen University, 52056 Aachen, Germany — [2]School of Physical Sciences, The University of Queensland, Brisbane, QLD 4072, Australia

We study a particular setup of an ultracold two-species boson gas in an optical superlattice. This realizes in a certain parameter regime actually the physics of spin-1/2 Heisenberg magnets describing the second order hopping processes. Tuning of the superlattice allows for controlling the effect of fast first order processes versus the slower second order ones. We provide the evolution of typical experimentally available observables by means of the density-matrix renormalization-group method. The validity of the description via the Heisenberg model is studied numerically and analytically. Contrary to the case of isolated double wells which was recently realized experimentally, here, relaxation of local observables can be observed. The tunability between the Bose-Hubbard model and the Heisenberg model in this setup could be used to study experimentally the differences in equilibration processes for nonintegrable and Bethe ansatz integrable models.
Ref. arXiv:0809.5141.

TT 41.5 Thu 15:00 HSZ 105

Cold bosonic atoms in a π−flux lattice: a superfluid with orbital antiferromagnetic order — •Stephan Rachel and Martin Greiter — Institut für Theorie der Kondensierten Materie, Universität Karlsruhe, 76128 Karlsruhe

We consider a system of neutral, bosonic atoms on a square lattice subject to an artificial magnetic field. We focus on a field strength of half a Dirac flux quantum through every plaquette, which implies two minima in the lower single particle band. For repulsive interactions, we show that the many particle ground state possesses both superfluid and orbital antiferromagnetic order. For attractive interactions, we find a fragmented Bose–Einstein condensate without net orbital currents.

TT 41.6 Thu 15:15 HSZ 105

Condensate density of interacting Bosons at finite temperature: A Functional Renormalization Group calculation — •Christopher Eichler[1], Nils Hasselmann[2], and Peter Kopietz[1] — [1]Institut für Theoretische Physik, Universität Frankfurt, Max-von-Laue-Straße 1, 60348 Frankfurt, Germany — [2]International Center for Condensed Matter Physics, Universidade de Brasilia, Caixa Postal 04667, 70910-900 Brasilia,DF, Brazil

We use the Functional Renormalization Group to study thermodynamics of 3-dimensional interacting bosons at finite temperature. Our calculation is based on a truncated vertex expansion and a momentum independent two-body interaction including wave function renormalization. In particular, we derive the renormalization group flow of the condensate density in the symmetry broken phase and explicitly calculate the critical exponent β. Our result for β agrees quite well with the accepted numerical value for the 3-dimensional XY universality class.

15 min. break

TT 41.7 Thu 15:45 HSZ 105

Bose-Fermi Mixtures in Optical Lattices — •Irakli Titvinidze, Michiel Snoek, and Walter Hofstetter — Institut für Theoretische Physik, Goethe-Universität, D-60438 Frankfurt, Germany

We study a mixture of strongly interacting bosons and fermions with on-site repulsion in optical lattices. We apply the generalized dynamical mean-field theory (GDMFT), which is exact in the infinite dimensions and reliably describes the full range from weak to strong coupling. First we consider spinless fermions. We perform calculations for commensurate filling of the fermions and bosons, in particular for the case when the fermions are half-filled, whereas the filling of the bosons is 3/2. Our calculations show two different Alternating Mott insulator (AMI) phases, in which the bosons are localized, but particle density wave order occurs. These two AMI phases are separated by a supersolid phase, where bosonic superfluidity coexists with large-amplitude particle density wave order. Furthermore we consider a mixture of two-component fermions and hard-core bosons, both at half-filling. In this case in addition to the supersolid and the AMI phase, we also obtain an antiferromagnetic phase.

TT 41.8 Thu 16:00 HSZ 105

Bose-Fermi Mixtures in Disordered Optical Lattices — •Denis Semmler, Irakli Titvinidze, Ulf Bissbort, and Walter Hofstetter — Institut für Theoretische Physik, J. W. Goethe-Universität, D-60438 Frankfurt, Germany

We study strongly interacting bosons and fermions in an optical lattice with correlated on-site disorder. For this purpose we use a stochastic, generalized DMFT scheme, treating the fermions within the well-known dynamical mean-field theory (DMFT) and describing the bosons by the Gutzwiller mean-field theory. This scheme becomes exact in the limit of infinite dimensions. In order to investigate localization phenomena we use the geometric average of the fermionic density of states as well as the geometrically averaged bosonic superfluid order parameter. Our investigation focuses on the influence of the fermions on the bosonic phase diagram, consisting of the Bose glass phase, the Mott insulator and the superfluid. We consider the corresponding fermionic phases, Mott insulator, Anderson insulator and disordered Fermi liquid, as well. The results are related to experimental parameters.

TT 41.9 Thu 16:15 HSZ 105

Real-Space Dynamical Mean-Field Theory for Strongly Correlated Atoms — •Michiel Snoek, Irakli Titvinidze, and Walter Hofstetter — Institut für Theoretische Physik, Goethe-Universitaet Frankfurt

To describe strongly interacting atoms in an inhomogeneous optical lattice, we apply Real-Space Dynamical Mean-Field Theory (R-DMFT). R-DMFT captures the effects of strong correlations and spatial inhomogeneity in a unified, non-perturbative framework. Local correlations are taken into account exactly.

We apply this numerical scheme to antiferromagnetic states of repulsively interacting fermions with spin 1/2 in a harmonic potential. Within R-DMFT, antiferromagnetic order is found to be stable in spatial regions with total particle density close to one, but persists also in parts of the system where the local density significantly deviates from half filling. In systems with spin imbalance, we find that antiferromagnetism is gradually suppressed and phase separation emerges beyond a critical value of the spin imbalance.

We also investigate trapped Bose-Fermi mixtures in an optical lattice with R-DMFT. We look for the effect of the fermions on the bosonic visibility and analyze the stability of a supersolid in an harmonic trap.

TT 41.10 Thu 16:30 HSZ 105

Trionic liquids in exact diagonalization — •Guido Klingschat and Carsten Honerkamp — TP1, Universität Würzburg

Lattice fermions with three internal degrees of freedom ('colors') exhibit a trionic phase with conglomerates of 3 fermions on a single site if the onsite attraction between the different colors is strong enough. Using excact diagonalization we establish an effective Hamiltonian describing these fermionic quasiparticles. The effective theory is validated by a finite size scaling in the low density limit. The stability of the trion phase against breaking of the global SU(3)-symmetry is investigated for asymmetric interactions as well as for different densities per color. Furthermore we compare the trion behavior for one and two lattice dimensions.

TT 41.11 Thu 16:45 HSZ 105

Asymmetric Hubbard Model for Ultracold Fermi-Mixtures on Optical Lattices — •Tobias Gottwald and Peter van Dongen — KOMET 337, Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz

In order to understand the phases occurring in ultracold Fermi-Mixtures we perform a mean-field analysis beyond LDA of an attractive-U Hubbard model with asymmetric hopping $t_\uparrow \neq t_\downarrow$ and a superimposed parabolic trapping potential. Depending on population numbers and on the asymmetry of the hopping we expect charge-density-wave-, BCS- or FFLO-states to minimize the relevant thermodynamic potential. By tuning the asymmetry in the hopping term we can switch between standard Hubbard model physics, where only superfluidity occurs, and Falikov-Kimball model physics, where only CDW-behaviour occurs.

TT 41.12 Thu 17:00 HSZ 105

Quantum critical behavior in strongly interacting Rydberg gases — •Hendrik Weimer[1], Robert Löw[2], Tilman Pfau[2], and Hans Peter Büchler[1] — [1]Institut für Theoretische Physik III, Universität Stuttgart — [2]5. Physikalisches Institut, Universität Stuttgart

We analyze the van der Waals blockade and the quantum evolution of an atomic gas resonantly driven by a laser into a strongly interacting Rydberg state. The main mechanism behind the van der Waals blockade is that once a Rydberg atom is excited, the van der Waals interaction shifts the surrounding atoms out of resonance with the driving laser and therefore suppresses the excitation of additional Rydberg atoms. We show that the system is close to the critical point of a second order phase transition and can be described by a universal scaling function with a critical exponent. We present an effective dynamical theory for the scaling function that provides excellent agreement with a numerical solution of the full Schrödinger equation.

[1] H. Weimer, R. Löw, T. Pfau, H. P. Büchler, Phys. Rev. Lett. **101**, 250601 (2008).

15 min. break

TT 41.13 Thu 17:30 HSZ 105

Quantum trajectories for dispersive readout in superconducting circuit QED — •Ferdinand Helmer and Florian Marquardt — Department of Physics, CeNS, and ASC, Ludwig-Maximilians-Universität, Theresienstrasse 37, D-80333 Munich, Germany

We present applications for the method of quantum trajectory simulations for the realistic simulation of single-shot readout experiments in superconducting circuit QED. Quantum trajectories generated by stochastic master equations allow to obtain a realistic measurement signal while one simultaneously gains access to the internal quantum dynamics of the system in question taking the measurement backaction into account correctly. Thus, useful insights beyond the ensemble average description of a conventional master equation can be obtained.

To illustrate the power of the method, we present two important examples: (i) How to detect single itinerant microwave photons non-destructively (ii) How to generate massively entangled N-qubit states like W- and GHZ-states by measurement. We point out the presented examples can be realized using currently available experimental setups.

TT 41.14 Thu 17:45 HSZ 105

Meissner effect in atom chips containing superconducting microstructures — •Daniel Cano, Brian Kasch, Helge Hattermann, Reinhold Kleiner, Claus Zimmermann, Dieter Koelle, and József Fortágh — Physikalisches Institut & Center for Collective-Quantum Phenomena, Universität Tübingen, Germany

Superconducting microstructures for trapping and manipulating ultracold quantum gases are expected to provide intriguing physical scenarios in which atomic physics and superconductor science converge. In this study, we investigate the impact of the Meissner effect on magnetic microtraps generated by superconducting microstructures. Both numerical simulations and experiments demonstrate that the Meissner effect shortens the distance between the microtrap and the superconducting surface, reduces the radial magnetic-field gradients and lowers the trap depth. Simulations based on the London theory have been carried out to calculate the supercurrent densities in thin-film microstructures. Experiments were done in a recently-built apparatus that loads ultracold ^{87}Rb atomic clouds into a magnetic microtrap generated by a superconducting Nb wire with circular cross section. By monitoring the position of the atomic cloud, we observe how the Meissner effect changes the microtrap parameters. Measurements of the trap position reveal a complete exclusion of the magnetic field from the superconducting wire for $T < 6\,\mathrm{K}$. For higher T, the magnetic field partially penetrates the superconducting wire and the microtrap parameters become more similar to those expected for a normal-conducting wire.

[1] D. Cano *et al.*, Phys. Rev. Lett. **101**, 183006 (2008)

TT 41.15 Thu 18:00 HSZ 105

Propagation of a wave packet in the presence of random scattering and nonlinearity — •Georg Schwiete[1,2] and Alexander Finkel'stein[1,2] — [1]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, 76100, Israel — [2]Department of Physics, Texas A&M University, College Station, TX 77843-4242, US

We address the problem of propagation of an injected wave-packet in a random potential in the presence of nonlinear interactions in two spatial dimensions. This problem is relevant for studies of Anderson localization in photonic lattices or for the expansion of Bose-Einstein condensates in the presence of disorder. Our starting point is the Gross-Pitaevskii equation (nonlinear Schroedinger equation) with a disorder potential. We derive a system of coupled equations that describes the spreading of the average density.

TT 41.16 Thu 18:15 HSZ 105

Quantum Dynamics of Optomechanical Systems — •Max Ludwig, Björn Kubala, and Florian Marquardt — Department of Physics, Arnold Sommerfeld Center for Theoretical

Physics, and Center for NanoScience, Ludwig-Maximilians-Universität München,Theresienstr 37, D-80333 München, Germany

A generic optomechanical system consists of a driven optical cavity and a movable mirror attached to a cantilever. Recently, a new kind of optomechanical system has been realized by replacing the cantilever by a cloud of cold atoms located inside a cavity.

A common feature of optomechanical systems is the instability they can exhibit towards a regime where the mechanical oscillator settles into self-sustained oscillations. We analyze the quantum dynamics of these self-sustained oscillations using a master equation approach applied to the coupled system consisting of the cavity mode and the mechanical oscillation. When a suitable "quantum parameter" is sent to zero, these results converge towards the predictions of the classical theory of the instability. By contrast, for a large value of the quantum parameter the system is strongly influenced by quantum fluctuations.

Optomechanical systems involving the motion of ultracold atoms exhibit very large values of the quantum parameter and are hence expected to show substantial quantum effects. We discuss some prospects that open up for such kind of setups.

TT 41.17 Thu 18:30 HSZ 105

Solids and Supersolids of Three-Body Interacting Polar Molecules on an Optical Lattice — Kai P. Schmidt[1], Julien Dorier[2], and •Andreas Läuchli[3] — [1]Lehrstuhl für theoretische Physik I, TU Dortmund, Dortmund, Germany — [2]CTMC, EPFL, Lausanne, Switzerland — [3]MPI für Physik komplexer Systeme, Dresden, Germany

We study the physics of cold polar molecules loaded into an optical lattice in the regime of strong three-body interactions, as put forward recently by Büchler et al. [Nature Phys. 3, 726 (2007)]. To this end, quantum Monte Carlo simulations, exact diagonalization, and a semiclassical approach are used to explore hard-core bosons on the 2D square lattice which interact solely by long-ranged three-body terms. The resulting phase diagram shows a sequence of solid and supersolid phases. Our findings are directly relevant for future experimental implementations and open a new route towards the discovery of a lattice supersolid phase in experiment.

TT 41.18 Thu 18:45 HSZ 105

Phase Diagram of Polar Molecules with Three-Body Interactions — •Lars Bonnes, Stefan Wessel, and Hans-Peter Büchler — Institut für theoretische Physik III, Universität Stuttgart

Motivated by a recent proposal on using polar molecules in optical lattices driven by microwave fields to induce strong three-body interactions (H. P. Büchler et al., Nature Physics 3, 726 (2007)), we analyze the quantum phase diagram of the boson Hubbard model with dominant nearest neighbor three-body repulsions using quantum Monte Carlo simulations. In particular, we consider the case of a honeycomb-lattice in the hard-core limit. In contrast to previously studied cases of the chain and the square lattice, three-body repulsions on the honeycomb lattice exhibit clear characteristics of strongly frustrated interactions, giving rise to macroscopically degenerate classical regions and quantum state selections via order-by-disorder phenomena. We discuss the nature of the emerging insulating phases at several unconventional lattice fillings, and compare to effective low-energy descriptions, such as in terms of quantum dimer models.