TT 37: MLT: Quantum Liquids, Bose-Einstein Condensates, Ultra-cold Atoms, ...

Time: Wednesday 14:00–18:00 Location: HSZ 105

TT 37.1 Wed 14:00 HSZ 105

Stroboscopic observation of quantum many-body dynamics — •Stefan Kessler[1], Andreas Holzner[2], Ian McCulloch[3], Jan von Delft[2], and Florian Marquardt[1,4] — [1]Institute for Theoretical Physics, Friedrich-Alexander-Universiät Erlangen-Nürnberg, Erlangen, Germany — [2]Physics Department, ASC, CeNS, Ludwig-Maximilians-Universität München, München, Germany — [3]School of Physical Sciences, University of Queensland, Brisbane, Australia — [4]Max Planck Institute for the Science of Light, Erlangen, Germany

In recent experiments single-site resolved observation of cold atoms in optical lattices has been demonstrated. Thus it is possible to take a snapshot of a quantum many-body system, which opens a new way of observing its real-time dynamics. This inspired us to address the question how an interacting quantum-many body system evolves in time when the positions of the atoms are frequently observed. Using time-dependent DMRG we obtain the time evolution of the full many-body wave function, that is then periodically projected in order to simulate realizations of stroboscopic measurements. For the example of a 1-D chain of spin-polarized fermions with nearest-neighbor interaction, we find regimes for which many-particle configurations are stabilized and destabilized depending on the interaction strength and the time between observations. This model can be experimentally realized in optical latices with 2-species fermions in the insulating phase. We also discuss the possibility of observing just a single site and thus requiring only partial information about the many-body system. This leads to new effects that are not related to the usual quantum Zeno physics.

TT 37.2 Wed 14:15 HSZ 105

Breakdown of diffusion and negative absolute temperatures for ultracold atoms in optical lattices — •Stephan Mandt, Akos Rapp, David Rasch, and Achim Rosch — Institute of Theoretical Physics, University of Cologne, Germany

The last years have seen dramatic progress in the control of quantum gases in optical lattices, which allows to study out-of-equilibrium dynamics and transport properties in strongly correlated systems. We investigate the breakdown of diffusion in the transport of fermionic atoms on a lattice described by a homogeneous Hubbard model, based on an experiment by the group of Immanuel Bloch on an expanding cloud. We observe a crossover from diffusive behavior in the center of the cloud to a ballistic motion of atoms in its outer regions: While the cloud's shape remains round in the diffusive regime, it obtains a square shape when the motion becomes ballistic. Surprisingly, the system exhibits a strong feedback from the ballistic on the diffusive regions characterized by a universal loss rate of particles obeying singular diffusion equations.

In the second part we suggest and model a dynamical process in which an atomic gas with a negative absolute temperature can be created by inverting the sign of the harmonic trap. Due to the finite bandwidth of the lattice, which gives both an upper and a lower bound to the kinetic energy, the system still gets trapped even by the inverted potential, but equilibrates to a negative absolute temperature. We analyze the time scales needed to equilibrate to $T < 0$ and study the amount of heat generated by this non-equilibrium process.

TT 37.3 Wed 14:30 HSZ 105

The Quantum Kinetic Theory of Collisionless Superfluid Internal Convection — •Lukas Gilz and James Anglin — TU Kaiserslautern, Kaiserslautern, Germany

When a superfluid is heated locally, condensate and non-condensate fractions flow in opposite directions. As if to rebut the 19th century conclusion that cold is merely absence of heat, condensate flows like a flux of cold, from cooler regions to hotter. Wereas this phenomenon of "superfluid internal convection" is usually described within Landau's phenomenological two fluid model, we obtain a more fundamental picture of internal convection by extending a standard master equation formulation of quantum kinetic theory to include two reservoirs of different temperatures. We find that internal convection occurs even in collisionless regimes and that coherent scattering is essential to the observation of a condensate flow. Besides computing estimates of particle-, energy- and entropy flow, we propose an experimental approach by which this behavior can be observed in trapped ultracold Bose gases.

TT 37.4 Wed 14:45 HSZ 105

Ginzburg-Landau theory for the Jaynes-Cummings-Hubbard model — •Christian Nietner[1], Axel Pelster[2], Gernot Schaller[1], and Tobias Brandes[1] — [1]ITP, TU Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]FB Physik, Uni Duisburg-Essen, Lotharstr. 1, 47048 Duisburg, Germany

We develop a Ginzburg-Landau theory for the Jaynes-Cummings-Hubbard model, which describes the thermodynamics of photons evolving in an infinite lattice of cavities each filled with a two-level atom. Following Ref. [1], we calculate the effective action in first order of the hopping term. With this we reproduce at first the finite-temperature mean-field result of Refs. [2,3] for the quantum phase boundary between a Mott-insulating and a superfluid phase of polaritons. Subsequently, we investigate the excitation spectra in both the Mott phase and the superfluid phase. We find that our results for the energy gap and the effective masses of the particle and hole excitations in the superfluid phase are in good quantitative agreement with Ref. [4]. We determine the sound velocity of polaritons as a function of the detuning between the cavity mode and the two-level system. Finally, we outline how to obtain finite-size corrections to these results.

[1] B. Bradlyn, F. E. A. dos Santos, and A. Pelster, Phys. Rev. A **79**, 013615 (2009).
[2] J. Koch and K. L. Hur, Phys. Rev. A **80**, 023811 (2009).
[3] S. Schmidt and G. Blatter, Phys. Rev. Lett. **103**, 086403 (2009).
[4] S. Schmidt and G. Blatter, Phys. Rev. Lett. **104**, 216402 (2010).

TT 37.5 Wed 15:00 HSZ 105

Mott-insulator and superfluid phases in the bosonic dynamical mean-field theory with the strong coupling impurity solver — •Anna Kauch[1], Krzysztof Byczuk[2], and Dieter Vollhardt[1] — [1]Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, D-86135 Augsburg, Germany — [2]Institute of Theoretical Physics, University of Warsaw, ul. Hoza 69, PL-00-681 Warszawa, Poland

We investigate the phase diagram of correlated lattice bosons using the bosonic dynamical mean field theory (BDMFT). The BDMFT, formulated by Byczuk and Vollhardt (Phys. Rev. B 77, 235106 (2008)), is a comprehensive and thermodynamically consistent approximation in which the normal and condensed bosons are treated on equal footing. Within BDMFT the lattice bosonic problem is replaced by a single impurity coupled to two bosonic baths (corresponding to normal and condensed bosons, respectively). The resulting set of equations, the so-called "impurity problem", has to be solved self-consistently. Our approach is the strong coupling expansion within which the phase transition between the Mott-insulating superfluid phases can be described. Different thermodynamical quantities (particle density, compressibility, order parameter) as well as the bosonic density of states are investigated across the transition line.

15 min. break

TT 37.6 Wed 15:30 HSZ 105

Functional renormalization group approach to interacting bosons at zero temperature — •Andreas Sinner[1], Nils Hasselmann[2], and Peter Kopietz[3] — [1]Universität Augsburg, Germany — [2]Universidade Federal do Rio Grande do Norte, Brazil — [3]Universität Frankfurt, Germany

We investigate the single-particle spectral density of interacting bosons within the non-perturbative functional renormalization group technique. The flow equations for a Bose gas are derived and solved within a truncation scheme which allows to extract the complete frequency and momentum structure of the normal and anomalous self-energies. Both the asymptotic small momentum regime, where perturbation regime fails, as well as the perturbative regime at larger momenta are well described within a single unified approach. The self-energies do not exhibit any infrared divergences, satisfy the U(1) symmetry constraints, and are in accordance with the exact relation which states that the anomalous self-energy vanishes at zero momentum and zero frequency. From the self-energies we extract the single-particle spectral density of the two-dimensional Bose gas. The dispersion is found to be of the Bogoliubov form and shows the crossover from linear Goldstone modes to the quadratic behavior of quasi-free bosons. The damping of the quasiparticles is found to be in accordance with the standard Beliaev damping.

TT 37.7 Wed 15:45 HSZ 105

Detecting the Amplitude Mode of Strongly Interacting Lattice Bosons by Bragg Scattering — •Ulf Bissbort[1], Yongqiang Li[1], Sören Götze[2], Jannes Heinze[2], Jasper S. Krauser[2], Malte Weinberg[2], Christoph Becker[2], Klaus Sengstock[2], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Johann Wolfgang Goethe Universität, 60438 Frankfurt/Main — [2]Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg

We report the first detection of the Higgs-type amplitude mode using Bragg spectroscopy in a strongly interacting condensate of ultracold atoms in an optical lattice. By the comparison of our experimental data with a spatially resolved, time-dependent dynamic Gutzwiller calculation, we obtain good quantitative agreement. This allows for a clear identification of the amplitude mode, showing that it can be detected with full momentum resolution by going beyond the linear response regime. A systematic shift of the sound and amplitude modes' resonance frequencies due to the finite Bragg beam intensity is observed. Within an extended Bogoliubov-de Gennes approach, an extensive quasi-particle analysis of the dynamical processes during the spectroscopic measurement is presented.

TT 37.8 Wed 16:00 HSZ 105

Bose-Einstein condensation at finite momentum and magnon condensation in thin film ferromagnets — •Johannes Hick, Francesca Sauli, Andreas Kreisel, and Peter Kopietz — Institut für Theoretische Physik, Universität Frankfurt, Max-von-Laue Strasse 1, 60438 Frankfurt, Germany

We use the Gross-Pitaevskii equation to determine the spatial structure of the condensate density of interacting bosons whose energy dispersion $\epsilon_{\boldsymbol{k}}$ has two degenerate minima at finite wave-vectors $\pm\boldsymbol{q}$. We show that in general the Fourier transform of the condensate density has finite amplitudes for all integer multiples of $\boldsymbol{q}$. If the interaction is such that many Fourier components contribute, the Bose condensate is localized at the sites of a one-dimensional lattice with spacing $2\pi/|\boldsymbol{q}|$; in this case Bose-Einstein condensation resembles the transition from a liquid to a crystalline solid. We use our results to investigate the spatial structure of the Bose condensate formed by magnons in thin films of yttrium-iron garnet .

TT 37.9 Wed 16:15 HSZ 105

Correlated Bosons beyond Pairwise Interactions - Dimersuperfluid in Two Dimensions — •Lars Bonnes and Stefan Wessel — Institut für Theoretische Physik III, Pfaffenwaldring 57, 70550 Stuttgart, Germany

We consider ultra-cold atoms loaded into a two-dimensional optical lattice with strong three-body losses, i.e. three bosons sharing one lattice site scatter inelastically and dissipate from the system. This process dynamically stabilizes a three-body on-site repulsion in analogy to the quantum Zeno effect. The system studied here is described by a Bose-Hubbard model on a square lattice with on-site attraction. The maximal number of particles per lattice site is restricted to two in order to take the three-body repulsion into account. Field theoretical considerations and numerical simulations using Matrix Product States in one dimension suggest the existence of a dimer superfluid phase for small tunneling rates that is effectively described by the condensation of pairs bosons and the absence of an atomic condensate. In this work we explore the ground state and finite-temperature phase diagram for our model using large-scale quantum Monte-Carlo simulations. Our main emphasis is the detection of the dimer superfluid phase and we address the issue of extrapolating our finite-temperature data to the thermodyanmic limit at T=0. We address the numerical issues i.e., fat-tailed distributions in the condensate density and demonstrate how we are able to overcome this issue by adding a term that couples lineary to the order parameter leading to a system with arbitrary long-range pair-hopping processes.

TT 37.10 Wed 16:30 HSZ 105

Dipolar bosons in coupled one-dimensional tubes — •Marianne Bauer and Meera Parish — Cavendish Laboratory, JJ Thompson Avenue, Cambridge, CB3 0HE, United Kingdom

Dipolar bosons in one-dimensional optical lattices are known to exhibit interesting phenomena. The phase diagram of such a system forms a complete devil's staircase in the classical limit of zero intersite hopping [1]. Including hopping leads to a competition of the crystalline Mott phases with a superfluid of defects [2]. However, a central question is how this behaviour survives as we perturb away from one dimension. Here, we provide an important step in this direction by considering the case of two coupled one-dimensional tubes. We find that the coupling between tubes can affect the types of defects appearing within the Mott phases, thus changing the region in chemical potential over which each filling fraction is stable. We also investigate how the Mott lobes vary with respect to intertube distance. Finally, we discuss the implications of our results for cold-atom experiments.

[1] P. Bak and P. Bruinsma, Phys. Rev. Lett. **49**, 249 (1982)
[2] F. J. Burnell, M. M. Parish, N. R. Cooper and S. L. Sondhi, Phys. Rev. B, **80**, 174519 (2009)

15 min. break

TT 37.11 Wed 17:00 HSZ 105

Thermodynamics of the 3D Hubbard model on approach to the Néel transition — •Sebastian Fuchs[1], Emanuel Gull[2], Lode Pollet[3,4], Evgeny Burovski[5,6], Evgeny Kozik[4], Thomas Pruschke[1], and Matthias Troyer[4] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, 37077 Göttingen, Germany — [2]Department of Physics, Columbia University, New York, NY 10027, USA — [3]Physics Department, Harvard University, Cambridge, Massachusetts 02138, USA — [4]Theoretische Physik, ETH Zürich, 8093 Zürich, Switzerland — [5]LPTMS, CNRS and Université Paris-Sud, 91405 Orsay, France — [6]Department of Physics, Lancaster University, Lancaster, LA1 4YB, UK

We study the thermodynamic properties of the 3D Hubbard model for temperatures down to the Néel temperature using cluster dynamical mean-field theory [1]. In particular we calculate the energy, entropy, density, double occupancy and nearest-neighbor spin correlations as a function of chemical potential, temperature and repulsion strength. To make contact with cold-gas experiments, we also compute properties of the system subject to an external trap in the local density approximation. We find that an entropy per particle $S/N \approx 0.65(6)$ at $U/t = 8$ is sufficient to achieve a Néel state in the center of the trap, substantially higher than the entropy required in a homogeneous system. Precursors to antiferromagnetism can clearly be observed in nearest-neighbor spin correlators [2].

[1] T. Maier *et al.*, Rev. Mod. Phys. 77, 1027 (2005)
[2] S. Fuchs *et al.*, arXiv:1009.2759v1 (2010)

TT 37.12 Wed 17:15 HSZ 105

Localization of correlated fermions in optical lattices with speckle disorder — •Denis Semmler[1], Julia Wernsdorfer[1], Ulf Bissbort[1], Krzysztof Byczuk[2,3], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, 60438 Frankfurt am Main, Germany — [2]Institute of Theoretical Physics, Warsaw University, ul. Hoża 69, 00-681 Warszawa, Poland — [3]Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute for Physics, University of Augsburg, 86135 Augsburg, Germany

Strongly correlated fermions in three- and two-dimensional optical lattices with experimentally realistic speckle disorder are investigated. We extend and apply the statistical dynamical mean-field theory, which treats local correlations non-perturbatively, to incorporate on-site and hopping-type randomness on equal footing. Localization due to disorder is detected via the probability distribution function of the local density of states. We obtain a complete paramagnetic ground state phase diagram for experimentally realistic parameters and find a strong suppression of the correlation-induced metal insulator transition due to disorder [1]. Our results indicate that the Anderson-Mott and the Mott insulator are not continuously connected due to the specific character of speckle disorder.

[1] D. Semmler, J. Wernsdorfer, U. Bissbort, K. Byczuk, and W. Hofstetter, arXiv:1009.3438.

TT 37.13 Wed 17:30 HSZ 105

BCS-BEC crossover of a spin-imbalanced Fermi gas in one dimension — •Fabian Heidrich-Meisner[1], Adrian Feiguin[2], Ulrich Schollwöck[1], and Wilhelm Zwerger[3] — [1]LMU Munich, Germany — [2]University of Wyoming, Laramie, USA — [3]TU Munich, Germany

We present a numerical study of the one-dimensional BCS-BEC crossover of a spin-imbalanced Fermi gas [1]. The crossover is described

by the Bose-Fermi resonance model in a real space representation. Our main interest is in the behavior of the s-wave pair correlations, which, in the BCS limit, are of the Fulde-Ferrell-Larkin-Ovchinnikov type, while in the BEC limit, a superfluid of diatomic molecules forms that exhibits quasi-condensation at zero momentum. We use the density matrix renormalization group method to compute the phase diagram as a function of the detuning of the molecular level and the polarization. As a main result, we show that FFLO-like correlations disappear well below full polarization close to the resonance. The critical polarization depends on both the detuning and the filling.

[1] Heidrich-Meisner, Feiguin, Schollwöck, Zwerger Phys. Rev. A 81, 023629 (2010).

TT 37.14 Wed 17:45 HSZ 105

Relaxation of fermionic quantum systems after an interaction quench — •Simone A. Hamerla and Götz S. Uhrig — Technische Universität Dortmund, Lehrstuhl für Theoretische Physik I, 44221 Dortmund, Germany

The impressive progress on experimental side in the context of fermionic atoms in optical lattices and especially the tunability of the interaction strength has led to new interest in the dynamics of quantum systems out of equilibrium.

We study the time evolution of fermionic systems after a quench, i.e. a sudden change in the intrinsic parameters of the system. In this context interaction quenches, where the interaction between particles is suddenly turned on, are of special interest.

In this setup we do not focus on the long time behavior of the system, which determines the thermalization but on short times after the quench, the so called prethermalization. The relaxation of the system is studied by the use of a semi-analytic approach based on the Heisenberg equations of motion [1]. This higher order equation of motion approach enables us to study the momentum distribution and other quantities of the system after the quench.

[1] G.S. Uhrig Phys. Rev. A 80, 061602(R)