TT 30: Matter At Low Temperature: Quantum Liquids, Bose-Einstein Condensates, Ultra-cold Atoms, ... 1

Time: Wednesday 15:00–18:45 Location: H 3005

Invited Talk TT 30.1 Wed 15:00 H 3005

Bose-Einstein condensation of Photons — •Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

Bose-Einstein condensation, the macroscopic ground state accumulation of particles with integer spin (bosons) at low temperature and high density, has been observed in several physical systems, including cold atomic gases and solid state physics quasiparticles. However, the most omnipresent Bose gas, blackbody radiation (radiation in thermal equilibrium with the cavity walls), does not show this phase transition. The photon number here is not conserved (vanishing chemical potential), and at low temperatures photons disappear in the cavity walls instead of occupying the cavity ground state. In my talk, I will describe an experiment observing a Bose-Einstein condensation of photons in a dye-filled microscopic optical resonator [1]. The phase transition to a macroscopically occupied ground state occurs at room temperature. In my talk, I will begin with a general introduction and give an account of current work and future plans of the Bonn photon gas experiment.
[1] J. Klaers, J. Schmitt, F. Vewinger, and M. Weitz, Nature 468, 545 (2010).

TT 30.2 Wed 15:30 H 3005

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

Recent experiments have demonstrated single-site resolved observation of cold atoms in optical lattices. Thus, in the future it may be possible to take repeated snapshots of an interacting quantum many-body system during the course of its evolution. Here we address the impact of the resulting quantum (anti-)Zeno physics on the many-body dynamics. We use time-dependent DMRG to obtain the time evolution of the full wave function, that is then periodically projected in order to simulate realizations of stroboscopic measurements. For the example of a 1-D lattice of spinless fermions with nearest-neighbor interactions, we find regimes for which many-particle configurations are stabilized or destabilized, depending on the interaction strength and the time between observations. We show that similar effects are expected for other models, such as the 1-D Fermi- and Bose-Hubbard model.

TT 30.3 Wed 15:45 H 3005

Universal probes for antiferromagnetic correlations and entropy in cold fermions on optical lattices — •E.V. Gorelik[1], D. Rost[1], T. Paiva[2], R. Scalettar[3], A. Klümper[4], and N. Blümer[1] — [1]Institute of Physics, Johannes Gutenberg University, Mainz, Germany — [2]Instituto de Fisica, Universidade Federal do Rio de Janeiro, Brazil — [3]Department of Physics, UC Davis, USA — [4]University of Wuppertal, Germany

A major hurdle on the way of using ultracold fermionic atoms on optical lattices as "quantum simulators" of correlated solids is the verification of antiferromagnetic (AF) signatures. Current experimental efforts focus on nearest-neighbor (NN) spin correlation functions and on cooling below a central entropy per site of $s < \log(2)/2$.

Our calculations in the strong-coupling regime of the half-filled Hubbard model using DMFT, determinantal QMC, and Bethe ansatz [1] reveal AF signatures in the double occupancy, spin correlations, and kinetic energy already at $s \lesssim \log(2)$ with surprising universality regarding dimensionality, when viewed as a function of entropy (which is appropriate in the cold-atom context). Both the onset of next-nearest neighbor spin correlations and a minimum in the double occupancy clearly separate the AF Heisenberg regime (at $s \lesssim \log(2)$) from dominant charge physics and should be used experimentally to probe both the AF correlations and the entropy of the system.
[1] E. V. Gorelik, D. Rost, T. Paiva, R. Scalettar, A. Klümper, N. Blümer, arXiv:1105.3356

TT 30.4 Wed 16:00 H 3005

Constant forces induce negative absolute temperatures in optical lattices — •Stephan Mandt[1], Akos Rapp[2], and Achim Rosch[1] — [1]Institute for Theoretical Physics, University of Cologne, Germany — [2]Institute for Theoretical Physics, University of Hanover, Germany

Ultracold atoms in optical lattices offer a novel possibility to explore transport properties of model Hamiltonians, such as the Hubbard model for Fermions, in absence of impurities, lattice defects or phonons. The fact that the Hubbard model describes a thermally isolated system has got severe consequences on its transport properties: a cloud of interacting fermionic atoms in an optical lattice in presence of a gravitational potential, e.g., doesn't simply "fall downwards". Instead, we show that it diffuses symmetrically upwards and downwards, while its radius grows subdiffusively in time according to $R \propto t^{1/3}$. We also show that negative absolute temperatures naturally emerge in such a situation, and how equilibrated negative temperatures can be realized in optical lattices.

TT 30.5 Wed 16:15 H 3005

Ultracold atomic gases at negative absolute temperatures — •Akos Rapp — Institut f. Theoretische Physik, Leibniz Universität, Hannover, Deutchland

Ultracold atomic clouds are used to simulate a broad range of complex quantum systems with a high degree of experimental control. We will discuss that current techniques allow for a realization of an out-of-equilibrium situation where the system relaxes to a state with negative absolute temperature, T<0. Under these conditions, higher energy levels are more likely occupied than lower energy levels. As a consequence, bosonic atoms in an optical lattice condense at finite momenta, at the maxima instead of the minimum of the kinetic energy. A further interesting possibility of using T<0 is that one can experimentally reach new parameter regimes. This idea could be applied to simulate the SU(3) attractive Hubbard model with repulsively interacting atoms, which can prove useful to understand some puzzles of quantum chromodynamics.

TT 30.6 Wed 16:30 H 3005

Spin-1 Bosons in Optical Superlattices — •Andreas Wagner[1], Andreas Nunnenkamp[1], Eugene Demler[2], and Christoph Bruder[1] — [1]University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland — [2]Harvard University, Cambridge, MA 02138, USA

We examine spinor Bose-Einstein condensates in optical period-2 superlattices theoretically using a Bose-Hubbard Hamiltonian which takes spin effects into account. The system shows quantum phase transitions between Mott-insulating and superfluid phases. In particular, we study the spin-dependent effects on the phase diagram. Within the Mott phase the extended superlattice corresponds to an array of isolated double-well potentials. For these systems we study single-particle tunneling which occurs when one lattice site is ramped up relatively to a neighboring site [1]. Spin-dependent effects modify the tunneling events in a qualitative and a quantitative way. Depending on the asymmetry of the double well different types of magnetic order occur, making the system of spin-1 bosons in an optical superlattice a model for mesoscopic magnetism. Homogeneous and inhomogeneous magnetic fields are applied and the effects of the linear and the quadratic Zeeman shifts are examined.We also investigate the bipartite entanglement between the sites and construct states of maximal entanglement. The entanglement in our system is due to both orbital and spin degrees of freedom. We calculate the contribution of orbital and spin entanglement and show that the sum of these two terms gives a lower bound for the total entanglement.
[1] A. Wagner, C. Bruder, and E. Demler, arXiv:1110.1968

TT 30.7 Wed 16:45 H 3005

Interaction Effects in One-Dimensional Many-Body Bosonic Transport — •Arturo Argüelles, Julien Dujardin, and Peter Schlagheck — Université de Liège, Liège, Belgium

We calculate the transport properties of an ultracold gas of Bose-Einstein condensed atoms that is coupled from a magnetic trap into a one-dimensional waveguide[1,2]. A central aim of such guided atom lasers[1] is to study the role of atom-atom interaction in many-body transport processes across finite scattering regions within the waveguide resembling tunnel junctions and quantum dots. Our numerical approach to solve this many-body scattering problem is based on the Matrix Product State ansatz where we adapt absorbing boundary conditions and a external source of particles. We discuss the current, the density profiles and the transmission coefficient in the steady-state regime as functions of the interaction for varous scattering geometries.

[1] W. Guerin et al., PRL 97, 200402 (2006).
[2] T. Ernst et al., PRA 81, 013631 (2010).

15 min. break.

Invited Talk TT 30.8 Wed 17:15 H 3005

Topological superfluids confined in a regular nano-scale slab geometry — •John Saunders[1], Robert Bennett[1], Lev Levitin[1], Andrew Casey[1], Brian Cowan[1], Jeevak Parpia[2], Dietmar Drung[3], and Thomas Schurig[3] — [1]Department of Physics, Royal Holloway University of London, Egham, Surrey, TW20 0EX — [2]Department of Physics, Cornell University, Ithaca, NY 14853, USA — [3]Physikalisch-Technische Bundesanstalt, Abbestrasse 2-12, D-19587, Berlin, Germany

Superfluid 3He confined in a regular nano-fabricated slab geometry provides a model system for the investigation of surface and thin film effects in a p-wave superfluid. We have fabricated and cooled such samples to well below 1 mK for the first time, and investigated their NMR response, exploiting a SQUID NMR spectrometer of exquisite sensitivity. We have used NMR on a 650 nm thick superfluid slab to identify the profound effect of confinement on the relative stability of the A and B phases and to make quantitative measurements of the suppression and surface induced distortion of the order parameter.

In these systems the effective confinement length scale (slab thickness/superfluid coherence length) is the new tuning parameter. Increasing confinement should stabilize new p-wave superfluid states of matter, such as the quasi-2D gapped A phase or the planar phase. Nanofluidic samples of superfluid 3He promise a route to explore topological superfluids and their surface, edge and defect-bound excitations under well controlled conditions.

TT 30.9 Wed 17:45 H 3005

Supersolid phase transitions for hard-core bosons on a triangular lattice — •Xue-Feng Zhang[1,2], Raoul Dillenschneider[1], Yue Yu[2], and Sebastian Eggert[1] — [1]Department of Physics, University of Kaiserslautern, D-67663 Kaiserslautern, Germany — [2]Institute of Theoretical Physics, Chinese Academy of Sciences, P.O. Box 2735, Beijing 100190, China

Hard-core bosons on a triangular lattice with nearest-neighbor repulsion are a prototypical example of a system with supersolid behavior on a lattice. We show that in this model the physical origin of the supersolid phase can be understood quantitatively and analytically by constructing quasiparticle excitations of defects that are moving on an ordered background. The location of the solid to supersolid phase transition line is predicted from the effective model for both positive and negative (frustrated) hopping parameters. For positive hopping parameters the calculations agree very accurately with numerical quantum Monte Carlo simulations. The numerical results indicate that the supersolid to superfluid transition is first order.

TT 30.10 Wed 18:00 H 3005

Dislocation-induced superfluidity in a model supersolid — •Debajit Goswami[1], Kinjal Dasbiswas[2], Chi-Deuk Yoo[3], and Alan Dorsey[2] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]University of Florida, Gainesville, USA — [3]University of Minnesota, Minneapolis, USA

Motivated by recent experiments on the supersolid behavior of ^{4}He, we study the effect of an edge dislocation in promoting superfluidity in a Bose crystal. Using Landau theory, we couple the elastic strain field of the dislocation to the superfluid density, and use a linear analysis to show that superfluidity nucleates on the dislocation before occurring in the bulk of the solid. Moving beyond the linear analysis, we develop a systematic perturbation theory in the weakly nonlinear regime, and use this method to integrate out transverse degrees of freedom and derive a one-dimensional Landau equation for the superfluid order parameter. We then extend our analysis to a network of dislocation lines, and derive an XY model for the dislocation network by integrating over fluctuations in the order parameter. Our results show that the ordering temperature for the network has a sensitive dependence on the dislocation density, consistent with numerous experiments that find a clear connection between the sample quality and the supersolid response.

TT 30.11 Wed 18:15 H 3005

Half-Vortex Unbinding and Ising Transition in Two-Dimensional Superfluids — •Lars Bonnes[1,2] and Stefan Wessel[3] — [1]Institut für Theoretische Physik, Universität Innsbruck, Österreich — [2]Institut für Theoretische Physik III, Universität Stuttgart — [3]Institut für Theoretische Festkörperphysik, RWTH Aachen

We analyze the thermodynamics of the atomic and (nematic) pair superfluids appearing in the attractive two-dimensional Bose-Hubbard model with a three-body hard-core constraint that has been derived as an effective model for cold atoms subject to strong three-body losses in optical lattices. We show that the thermal disintegration of the pair superfluidity is governed by the proliferation of fractional half-vortices leading to an unconventional Berezinskii-Kosterlitz-Thousless transition. In addition to the (conventional) Berezinskii-Kosterlitz-Thousless transition out of the atomic superfluid, we furthermore identify a direct thermal phase transition separating the pair and the atomic superfluid phases, and show that this transition is continuous with critical scaling exponents consistent with those of the two-dimensional Ising universality class. Our results make a direct connection between the partial loss of quasi long-range order at the Ising transition between the two superfluids and the parity selection of the atomic winding number fluctuations that distinguish the atomic and pair superfluid.

TT 30.12 Wed 18:30 H 3005

Interaction of helium-3 impurities with point defects and deformation fileds in solid helium-4. — •Yaroslav Lutsyshyn — Institut für Physik, Universität Rostock, 18051 Rostock, Germany

Interaction between defects and impurities is widely believed to be at the root of a wide range of effects which had been observed in recent years in hcp solid helium-4. In particular, several theories place special role on the dislocation network pinning by helium-3 impurities.

We will report quantum Monte Carlo simulations of a helium-3 impurity in crystalline helium-4. Calculations are performed with the diffusion Monte Carlo method. This is a first principles approach which allows to obtain exact ground state of many-body bosonic systems. The results show that while vacancies are attracted to the impurity, the vacancy-He3 pair is not bound at low density. Additional impurity properties are extracted by simulating it in a strained crystal. Motion in the elastic deformation field can be used to describe the long-range interaction of helium-3 with various lattice defects, especially the dislocation lines.