# TT 37: Matter At Low Temperature: Quantum Liquids, Bose-Einstein Condensates, Ultra-cold Atoms, ... 2

Time: Thursday 9:30–13:00 Location: H 3005

TT 37.1 Thu 9:30 H 3005

**Superposition of BEC and a first-order phase transition in a repulsive Bose gas** — •Michael Maennel[1], Klaus Morawetz[1,2], and Pavel Lipavsky[3,4] — [1]Department Physical Engineering, Münster University of Applied Science, 48565 Steinfurt, Germany — [2]International Institute of Physics, Universidade Federal do Rio grande do Norte, 59.072-970 Natal-RN, Brazil — [3]Institute of Physics, Academy of Sciences, Cukrovarnická 10, 16253 Prague 6, Czech Republic — [4]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 12116 Prague 2, Czech Republic

We investigate a Bose gas with finite-range interaction using a scheme to eliminate self-interaction in the T-matrix approximation. In this way the corrected T-matrix becomes suitable to calculate properties below the critical temperature, without the use of anomalous functions. In the vicinity of the onset of Bose-Einstein condensation (BEC) chemical potential and pressure show a van-der-Waals like behavior indicating a first-order phase transition although there is no long-range attraction. Furthermore for sufficiently strong interaction the equation of state becomes multivalued near the BEC transition. For a Hatree-Fock or Hartree-Fock-Bogoliubov approximation such a multivalued region can be avoided by a Maxwell construction. However, for the T-matrix approximation there remains a multivalued region even after a Maxwell construction.

TT 37.2 Thu 9:45 H 3005

**Dissipative and Finite Temperature Dynamics using Vidals Superoperator Renormalization** — •Lars Bonnes and Andreas Läuchli — Institut für Theoretische Physik, Universität Innsbruck, Österreich

The study of dynamical properties of quantum systems has gained new momentum through the progress made in the preparation of and control of low dimensional quantum system in ultra cold atomic and molecular gases. Matrix product state bases methods such as the density matrix renormalization group have proven invaluable for the numerical study of the ground-state properties as well as the (non- equilibrium) dynamics of one dimensional systems. Using the superoperator renormalization algorithm by Zwolak and Vidal [**PRL** 93, 207205 (2004)], one has access to the full dynamics of a density matrix such that one can incorporate not only non-zero temperatures but also dissipative dynamics given by a Lindblad equation.

We present results on finite-temperature quench dynamics as well as the dissipative dynamics of a Bose- Hubbard model using an efficient quantum number enabled implemention. We then address question of ballistic versus diffusive spreading of correlations and the entanglement properties of the finite-temperature states.

TT 37.3 Thu 10:00 H 3005

**Interacting Bosonic Quantum Ratchets** — •Karen Rodriguez and Achim Rosch — Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany

We study the Hamiltonian quantum ratchet dynamics of cold Bosons loaded on optical lattices. Under the influence of time-periodic space-dependent hopping and local potential, the relevant symmetries are broken leading the system to develop unidirectional transport in long term evolutions. By means of the Floquet theory and the Gutwiller wave function, we analyze the transport problem and the crucial role of the interactions on the ratchet average dc-current.

TT 37.4 Thu 10:15 H 3005

**Floquet states of many-body quantum systems** — •Sergey Denisov, Armin Seibert, Alexey Vladimir Ponomarev, and Peter Hänggi — Institut für Physik, Universität Augsburg, Universitätsstr. 1, D-86135 Augsburg

Periodic driving of a quantum many-body system could provide an access to a multitude of new-non-equilibrium states, essentially different from those a system exhibits at equilibrium. However, the field of ac-driven many-body quantum systems is a little-explored area, mainly for two reasons. First, until recently there were enough exciting problems to study at the equilibrium corner. Second, even under equilibrium conditions, a typical many-body system is a hard nut to crack due to the exponential growth of the number of system states with the number of quantum entities it contains. We discuss the possible directions to take in order to get insight into the evolution of ac-driven many-body quantum systems, outline the obstacles and possible means to overcome them. Our approach is based on the Floquet operator formalism and density-matrix renormalization group (DMRG) methods.

TT 37.5 Thu 10:30 H 3005

**Doublon dynamics in the one dimensional extended Hubbard model** — •Felix Hofmann and Michael Potthoff — I. Institut für Theoretische Physik, Universität Hamburg, Germany

The existence of repulsively bound states within the Hubbard model has been known since the early work of Hubbard. Here, their time evolution is calculated numerically exact in few-particle subspaces using the Lanczos method and will give insight into their propagation und stability properties. In general, nonvanishing couplings of the extended model, describing dipolar cold gases, cause a renormalization of the hopping parameter. An internal vibrational degree of freedom is accessible in the case of equal couplings and allows for a free propagation of repulsively bound pairs. In an effective description they will be subjected to a nearest-neighbor interaction, which will not give rise to a quantum-droplet phase unlike in the bosonic case [1]. In agreement with Fermi's golden rule, a power law decay will take place on short time scales until the probability for finding a repulsively bound state in the system approaches a constant value. Already moderate coupling strengths will lead to a high stability which even increases in the presence of more particles in the system, which is also confirmed by calculations for the half-filled system [2]. This establishes the possibilty of the experimental observation of repulsively bound pairs.

[1] D. Petrosyan et al., Phys. Rev. A 76, 033606 (2007).
[2] K. A. Al-Hassanieh et al., Phys. Rev. Lett. 100, 166403 (2008).

TT 37.6 Thu 10:45 H 3005

**Noise properties of periodic driven quantum systems** — •Vicente Leyton[1], Vittorio Peano[2], and Michael Thorwart[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstraße 9, 20355 Hamburg — [2]Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA

The Lax formula for two-time correlations combined with the Floquet formalism is used for the study of the noise properties of periodically driven nonlinear oscillators in contact with a dissipative environment. In particular, we consider the case of the quantum Duffing oscillator, where its non-equidistant energy spectrum leads to multiphoton transitions induced by the external driving at external frequencies close to the fundamental oscillator frequency. We consider the regime of weak coupling, in which the contact with the environment induces dissipative ransitions between nearest neighbour levels only. In addition to the dissipative dynamics, when the driving is at resonance with some multiphoton transition, Rabi oscillations between the states involved in the multiphoton transition are induced. We study the fluctuations of the number of photons pumped into the system when the multiphoton Rabi dynamics is faster than dissipative processes. We find a rich structure in the noise power spectrum including side-peaks associated to the multiphoton transitions. Moreover, we can extract information on the dissipative rate for resonant dynamical tunnelling in the dynamically induced bistable quasienergy landscape. The procedure presented here is extendible to other nonlinear systems like the driven Jaynes-Cummings model.

TT 37.7 Thu 11:00 H 3005

**Localized phase structures growing out of quantum fluctuations in two tunnel-coupled atomic condensates** — •Clemens Neuenhahn[1], Anatoli Polkovnikov[2], and Florian Marquardt[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Institute for Theoretical Physics II, Staudtstr. 7, 91058 Erlangen, Germany — [2]Department of Physics, Boston University, 590 Commonwealth Avenue, Boston, Massachusetts 02215, USA

We investigate the relative phase between two weakly interacting 1D condensates of bosonic atoms after suddenly switching on the tunnel-coupling. The following phase dynamics is governed by the quantum sine-Gordon equation. In the semiclassical limit of weak interactions, we observe the parametric amplification of zero-point quantum fluctuations leading to the formation of breathers with a finite lifetime. The typical lifetime and density of the these 'quasibreathers' are derived employing exact solutions of the classical sine-Gordon equation. Both quantities (density and lifetime) depend crucially on the initial, overall relative phase between the condensates, which is considered as a tunable parameter.

**15 min. break.**

TT 37.8 Thu 11:30 H 3005

**Damping of Bloch Oscillations in the Hubbard Model** — •Martin Eckstein[1] and Philipp Werner[2] — [1]Max Planck Research Department for Structural Dynamics, University of Hamburg, Centre for Free Electron Laser Science, Hamburg, Germany — [2]Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland

Using nonequilibrium dynamical mean-field theory (DMFT), we study the isolated Hubbard model in a static electric field in the limit of weak interactions. Linear response behavior is established at long times, but only if the interaction exceeds a critical value, below which the system exhibits an ac-type response with Bloch oscillations [1]. The transition from ac to dc response is defined in terms of the universal long-time behavior of the system, which does not depend on the initial condition. In order to understand whether these phenomena can be observed in experiments with ultracold gases, one has to estimate the importance of the inhomogeneous confining trap. This is done within a realspace DMFT approach.

[1] M. Eckstein and Ph. Werner, Phys. Rev. Lett. 107, 186406 (2011).

TT 37.9 Thu 11:45 H 3005

**New approach to many-body non equilibrium dynamics: functional renormalization group master equation** — •Johannes Hick[1], Thomas Kloss[2], and Peter Kopietz[1] — [1]Institut für Theoretische Physik, Goethe Universität Frankfurt am Main, Germany — [2]Laboratoire de Physique et Modélisation des Milieux Condensé, CNRS and Université Joseph Fourier, Grenoble, France

We use a functional renormalization group (FRG) approach to study the non-equilibrium time evolution of non-interacting bosons which are coupled to a phonon bath. We show that with a suitable cutoff procedure the resulting FRG flow equation for the distribution function resembles a master equation whose scale-dependent transition rates are determined by a system of FRG flow equations. We compare numerical results of this FRG master equation approach with perturbative results based on a conventional Boltzmann equation.

TT 37.10 Thu 12:00 H 3005

**Polaron to molecule transition in strongly interacting Fermi gases** — •Tilman Enss and Richard Schmidt — TU München, Germany

A light impurity in a Fermi sea undergoes a transition from a polaron to a molecular bound state for increasing interaction. We develop a new method to compute the spectral functions of the polaron and molecule in a unified framework based on the functional renormalization group with full self-energy feedback. We discuss the energy spectra and decay widths of the attractive and repulsive polaron branches as well as the molecular bound state. The decay follows a characteristic power-law scaling near the transition, showing that the transition is of first order.

TT 37.11 Thu 12:15 H 3005

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

An impressive progress on experimental side has led to great interest in non-equilibrium dynamics. Thus we investigate the behavior of fermionic systems after a quench, i.e., a sudden change in the intrinsic parameters. We focus on interaction quenches and study the momentum distribution of 1D and 2D Hubbard models, where the interaction between particles is suddenly turned on.

In our approach we find surprising correspondence between results for the 1D model and the $D = \infty$ DMFT results in the case of large interaction strengths.

The technique used is a semi-analytic approach based on the Heisenberg equations of motion [1]. We aim at a description of the behavior in the prethermalization regime, i.e., on short and intermediate time scales. Besides the momentum distribution the method allows for a discussion of other observables for various dopings.

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

TT 37.12 Thu 12:30 H 3005

**Bosonic spectral functions in the dynamical mean-field theory calculated with a 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, Faculty of Physics, University of Warsaw, ul. Hoza 69, PL-00-681 Warszawa, Poland

With the use of a strong-coupling solver for the bosonic dynamical mean-field theory (B-DMFT)[1] we investigate the evolution of spectral functions across the phase transition from the Mott-insulating to the superfluid phase in the Bose-Hubbard model. The B-DMFT provides a comprehensive and thermodynamically consistent description of correlated lattice bosons. Within the B-DMFT normal and Bose-Einstein condensed bosons are treated on equal footing. In the B-DMFT the bosonic lattice problem is replaced by a single site coupled to two bosonic baths corresponding to normal and condensed bosons, respectively. This yields a set of equations which have to be solved self-consistently. The use of a strong-coupling solver allows us to compute the spectral functions in different transition scenarios (density driven vs. interaction driven transition).

[1] K. Byczuk and D. Vollhardt, Phys. Rev. B 77, 235106 (2008)

TT 37.13 Thu 12:45 H 3005

**Non-adiabatic ramps in quantum many-particle systems** — •Masud Haque — Max Planck Institute for Physics of Complex Systems

A change of system parameter can be neither truly instantaneous nor truly adiabatic in real life. For several quantum many-particle systems, I will consider non-equilibrium dynamics induced by finite-rate ramps. The ramp rate extrapolates between an instantaneous quench and an adiabatic sweep. I will characterize the deviation from adiabaticity through the excess energy or "heating" of the system.

For cold-atom systems in a harmonic trapping potential, I will show that the non-adiabatic heating in finite-time ramps has universal features common to a wide range of systems.