TT 69: Other Low Temperature Topics: Cold Atomic Gases

Time: Wednesday 15:00–19:00 Location: A 053

TT 69.1 Wed 15:00 A 053

Strongly Correlated Phases and Ferromagnetic Phases of Fermions in an Optical Flux Lattice Model — •Simon Davenport and Nigel Cooper — Cavendish Laboratory, 19 J J Thomson Avenue, Cambridge, CB3 0HE

We study a theoretical model of a 2-dimensional ultracold atomic gas subject to an "optical flux lattice": a particular laser configuration where Raman-dressed atoms experience a strong effective magnetic field, which can lead to a bandstructure of narrow energy bands with non-zero Chern numbers. In this optical flux lattice we place spin-1/2 fermions that interact via a Feshbach-resonance induced contact interaction, coupling spin-up and spin-down particles. Atoms restricted to the lowest band are described by an effective model of spinless fermions with a tunable interaction coupling states in a momentum-dependent manner across the Brillouin zone. This non-local interaction is due to the Raman coupling between spin-up and spin-down levels. We present a summary of results from a detailed exact diagonalization study of the effective lowest band model. In particular we offer evidence indicating the presence of strongly correlated phases and ferromagnetic phases.

TT 69.2 Wed 15:15 A 053

Ground states for the Bose-Hubbard model with flat bands — •Petra Pudleiner[1] and Andreas Mielke[2] — [1]Institute of Physics, Johannes Gutenberg University, Mainz, Germany — [2]Institute for Theoretical Physics, Ruprecht-Karls University, Heidelberg, Germany

Flat band systems have been studied intensively in experiment and theory. They are a prototype for strongly correlated systems. Especially for bosons in a flat band, several interesting questions arise: What is the nature of the ground state? Are there regions in phase space where one can see a Bose transition?

The Bose-Hubbard model is used to visualize low energies on two-dimensional lattices which exhibit a lowest flat energy band. Up to the critical lattice filling constant, an eigenstate of the aforementioned band can be constructed by means of the charge density wave (CDW) as many-body ground state. Huber and Altman [1] explored ground states in the vicinity of the critical filling on the kagome lattice via a mean-field calculation; however, by restricting the calculation to a weakly interacting Hamiltonian.

The purpose of this talk is, firstly, to present similar results which are obtained by transferring their methods to the checkerboard lattice and, secondly, to demonstrate initial steps to extend to strong interactions. In this regard, one boson is added to the well-known ground state. The distribution of this additional particle seems to be localized, in contrast to the weakly interacting limit; here we observe a Bose condensation.

[1] S. Huber and E. Altman, PRB 82, 184502 (2010)

TT 69.3 Wed 15:30 A 053

Many-Body Anderson Localization of BECs in the Bose-Hubbard Model — •Roman Katzer[1], Cord Müller[2], and Johann Kroha[1] — [1]Universität Bonn — [2]Université de Nice, France

We have developed the transport theory for a Bose gas in the disordered Bose-Hubbard model in the regime of strong interactions, i.e. in the vicinity of the Mott lobes of vanishing Bose-Einstein condensate (BEC) amplitude. In contrast to previous approaches, we consider the Bose glass *not* as a state with vanishing averaged BEC amplitude with finite compressibility, but as the phase with *finite* average BEC amplitude but vanishing superfluid transport due to many-body Anderson localization of the interacting BEC wave functions and their many-body excitations. The theory is based on a calculation of the local many-body ground and excited states within a stochastic mean-field theory, treating the on-site Hubbard interaction exactly by diagonalizing the local part of the Bose-Hubbard Hamitonian in Fock space. Non-local effects of the interaction are neglected, analogous to Dynamical Mean-Field Theory. The transport theory for these hopping many-body states, including quantum interference processes ("Cooperons") is formulated as a generalization of the self-consistent theory of Anderson localization. The theory describes semiquantitatively the Mott localized phase ("Mott lobes"), the superfluid phase and the Bose glass phase as well as the respective phase transitions. In particular, the theory obeys the theorem of inclusions which states that in a disordered system there is no direct transition from the Mott phase to the superfluid phase.

TT 69.4 Wed 15:45 A 053

Thermalization of a Quenched Bose-Josephson Junction. — •Anna Posazhennikova[1], Mauricio Trujillo-Martinez[2], and Johann Kroha[2] — [1]Royal Holloway University of London, UK — [2]Universitaet Bonn, Germany

The experimental realization and control of quantum systems isolated from the environment, in ultracold atomic gases relaunched the interest in the fundamental non-equilibrium problem of how a finite system approaches thermal equilibrium. Despite intensive research there is still no conclusive answer to this question. We investigate theoretically how a quenched Bose-Josephson junction, where the Josephson coupling is switched on instantaneously, approaches its stationary state. We use the field theoretical approach for bosons out of equilibrium in a trap with discrete levels, developed by us previously [1,2]. In this approach the operators for Bose-Einstein condensate (BEC) particles are treated on mean-field level, while excitations of the Bose gas in higher trap levels are treated fully quantum-mechanically. This leads to coupled equations of motion for the BEC amplitudes (Gross-Pitaevskii equation) and the quasiparticle propagators. The inelastic quasiparticle collisions responsible for the system relaxation during the time-dependent evolution are described within self-consistent second-order approximation.

[1] M. Trujillo-Martinez, A. Posazhennikova, J. Kroha,
Phys. Rev. Lett. 103, 105302 (2009).
[2] M. Trujillo-Martinez, A. Posazhennikova, J. Kroha,
New J. Phys. in press; arXiv:1406.5536v2.

TT 69.5 Wed 16:00 A 053

Non-Equilibrium Expansion Dynamics in the 2D Bose-Hubbard Model — Mauricio Trujillo-Martinez[1], •Anna Posazhennikova[2], and Johann Kroha[1] — [1]Universität Bonn — [2]Royal Holloway University of London, UK

We study the temporal expansion of an ultracold Bose gas in the 2D Bose-Hubbard model, where initially all bosons are put in one central site of the lattice. The time evolution of interacting many-body systems in more than one dimension has been a challenge for numerically exact methods. We therefore use the recently developed semi-analytical method for time evolution of Bose systems [1] where the many-body Hamiltonian is represented in an appropriate, local eigenbasis and the corresponding field operators are separated into classical (BEC) and quantum mechanical parts. As consequence, the classical Gross-Pitaevskii BEC dynamics is coupled to the quantum fluctuations. After a quench, i.e. after a sudden switch of the lattice nearest neighbor hopping, the bosons spead over the lattice in a nontrivial way. The low-density part at the rim of the bosonic cloud spreads ballistically, while the spread of the high-density part in the center of the cloud is inhibited by interaction-induced self-trapping effects, characteristic for lattice dynamics. As a result, the bosonic cloud separates spatially into a ballisic fore-runner and a nearly self-trapped central part. The expansion velocity of the fore-runner is consistent with the Lieb-Robinson limit.

[1] M. Trujillo-Martinez, A. Posazhennikova, J. Kroha,
Phys. Rev. Lett. 103, 105302 (2009);
New J. Phys. in press; arXiv:1406.5536v2.

TT 69.6 Wed 16:15 A 053

Relaxation of oscillations in a mass-imbalanced mixture of trapped ultracold Fermi gases — •Robert Bamler and Achim Rosch — University of Cologne, Germany

We present theoretical results on the center-of-mass oscillations of a mixture of two ultracold Fermi gases trapped in a harmonic potential. We investigate the dependency of the relaxation time on the mass difference and on the strength of the scattering between the two fermion species.

Ultracold atomic gases allow for the study of many-particle systems under highly controllable conditions. As interactions with the environment can be reduced to negligible amounts, these systems can be used to study the dynamics far from equilibrium and, in particular, the relaxation towards equilibrium due to collisions between the system's constituents.

We consider a mixture of two species of fermionic atoms in a harmonic trap. If both atom species have the same mass, then the center-of-mass oscillation of the atomic cloud around its equilibrium position is undamped even in the presence of interactions between the atoms. Moreover, Kohn's theorem states that the oscillation frequency is independent of the interaction strength. The situation changes if the two atomic species have slightly different masses. In this case, inter-species collisions lead to finite relaxation times for the two oscillatory modes and, with growing interaction strength, a merging of the two oscillatory modes. We study this transition quantitatively by investigating the memory matrix of the macroscopic coordinates.

TT 69.7 Wed 16:30 A 053

Directed motion of doublons and holes in periodically driven Mott insulators — •Maximilian Genske and Achim Rosch — Institut für Theoretische Physik, Universität zu Köln, D-50937 Cologne, Germany

Periodically driven systems can lead to a directed motion of particles. We investigate this ratchet effect for a bosonic Mott insulator where both a staggered hopping and a staggered local potential vary periodically in time. If driving frequencies are smaller than the interaction strength and the density of excitations is small, one obtains effectively a one-particle quantum ratchet describing the motion of doubly occupied sites (doublons) and empty sites (holes). Such a simple quantum machine can be used to manipulate the excitations of the Mott insulator. For suitably chosen parameters, for example, holes and doublons move in opposite directions. To investigate whether the periodic driving can be used to move particles "uphill", i.e., against an external force, we study the influence of a linear potential $-gx$. For long times, transport is only possible when the driving frequency ω and the external force g are commensurate, $n_0 g = m_0\omega$, with $\frac{n_0}{2}, m_0 \in \mathbb{Z}$. Ultimately, increasing the density of excitations leads to a breakdown of the one-particle picture. As an outlook, we thus discuss how interaction effects can be described by Floquet-Boltzmann equations.

TT 69.8 Wed 16:45 A 053

Tight binding models for ultracold atoms using maximally localized Wannier functions — •Julen Ibañez-Azpiroz[1], Asier Eiguren[2,3], Aitor Bergara[2,3], Giulio Pettini[4], and Michele Modugno[2,5] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, D-52425 Jülich, Germany — [2]Universidad del Pais Vasco, Bilbao, Spain — [3]Donostia International Physics Center, Spain — [4]Universita di Firenze and INFN, Italy — [5]Ikerbasque, Basque Foundation for Science, Spain

We discuss how to construct tight-binding models for weakly interacting ultracold atoms using maximally localized Wannier functions (MLWFs) [1]. The resulting models are shown to accurately describe the properties of the continuous systems with the use of few tunneling coefficients. First we work out a simple honeycomb lattice model directly related to the graphene physics [2]. Next we generalize the approach for including a vector potential and analyze a possible implementation of the Haldane model. We show that the commonly employed Peierls substitution does not yield a reasonable description of the effect of the vector potential on the tunneling coefficients [3], which in turn affects the topological phase diagram.

JIA acknowledges support from Helmholtz Gemeinschaft Deutscher-Young Investigators Group Program No. VH-NG- 717 (Functional Nanoscale Structure and Probe Simulation Laboratory).

[1] N. Marzari and D. Vanderbilt Phys. Rev. B 56, 12847 (1997)
[2] J. Ibañez-Azpiroz et al., Phys. Rev. A 87, 011602(R) (2013)
[3] J. Ibañez-Azpiroz et al., Phys. Rev. A 90, 033609 (2014)

15 min. break.

TT 69.9 Wed 17:15 A 053

Dimensional crossover and cold-atom realization of topological Mott insulators — Mathias S Scheurer[1], Stephan Rachel[2], and •Peter P Orth[1] — [1]Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Institute for Theoretical Physics, TU Dresden, 01062 Dresden, Germany

Interacting cold-atomic gases in optical lattices offer an experimental approach to outstanding problems of many body physics. One important example is the interplay of interaction and topology which promises to generate a variety of exotic phases such as the fractionalized Chern insulator or the topological Mott insulator. Both theoretically understanding these states of matter and finding suitable systems that host them have proven to be challenging problems. Here we propose a cold-atom setup where Hubbard on-site interactions give rise to spin liquid-like phases: weak and strong topological Mott insulators. They represent the celebrated paradigm of an interacting and topological quantum state with fractionalized spinon excitations that inherit the topology of the non-interacting system. Our proposal shall help to pave the way for a controlled experimental investigation of this exotic state of matter in optical lattices. Furthermore, it allows for the investigation of a dimensional crossover from a two- dimensional quantum spin Hall insulating phase to a three-dimensional strong topological insulator by tuning the hopping between the layers.

TT 69.10 Wed 17:30 A 053

Second order interaction corrections to the Fermi surface and the quasiparticle properties of dipolar fermions in three dimensions — •Jan Krieg, Philipp Lange, and Peter Kopietz — Institut für Theoretische Physik, Universität Frankfurt, Germany

We have calculated the renormalized Fermi surface and the quasiparticle properties in the Fermi liquid phase of three-dimensional dipolar fermions to second order in the dipole-dipole interaction. Using parameters relevant to an ultracold gas of Erbium atoms, we have found that the second order corrections typically renormalize the Hartree-Fock results by less than one percent. On the other hand, if we use the second order correction to the compressibility to estimate the regime of stability of the system, the point of instability is already reached for a significantly smaller interaction strength than in the Hartree-Fock approximation.

TT 69.11 Wed 17:45 A 053

Artificial gauge fields in extra dimensions — •Julius Ruseckas[1], Gediminas Juzeliunas[1], Ian Spielman[2,3], Alessio Celi[4], Pietro Massignan[4], Nathan Goldman[5], and Maciej Lewenstein[4,6] — [1]Institute of Theoretical Physics and Astronomy, Vilnius University, A. Goštauto 12, Vilnius, LT-01108 Lithuania — [2]Joint Quantum Institute, University of Maryland, College Park, Maryland 20742-4111, USA — [3]National Institute of Standards and Technology, Gaithersburg, Maryland 20899, USA — [4]ICFO-Institut de Ciencies Fotoniques, Mediterranean Technology Park, E- 08860 Castelldefels (Barcelona), Spain — [5]Laboratoire Kastler Brossel, CNRS, UPMC, ENS, 24 rue Lhomond, F- 75005 Paris, France — [6]ICREA-Institucio Catalana de Recerca i Estudis Avancats, E-08010 Barcelona, Spain

We demonstrate [1] that one can engineer a two-dimensional lattice with nonzero synthetic magnetic flux using atoms in a standard one-dimensional optical lattice. The additional dimension appears due to laser-assisted transitions between the atomic sub-levels in the ground state manifold. A distinctive feature of the proposed scheme is the sharp boundaries in the extra dimension, a feature that is difficult to implement for the atoms in optical lattices in the real-space. The boundaries of the extra dimension can be closed down using additional laser-assisted transitions. which leads to a remarkably simple realisation of the fractional (Hofstadter butterfly-type) spectrum.

[1] A. Celi, P. Massignan, J. Ruseckas, N. Goldman, I. B. Spielman, G. Juzeliunas, and M. Lewenstein,
Phys. Rev. Lett. 112, 043001 (2014).

TT 69.12 Wed 18:00 A 053

Phase Space Interactions and Exchange Quasienergy — •Lingzhen Guo[1,2], Modan Liu[1,3], and Michael Marthaler[1] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, SE-41296 Göteborg, Sweden — [3]Department of Physics, Beijing Normal University, Beijing 100875, China

In this work, we investigate the dynamics of many interacting atoms trapped in a one dimensional (1D) harmonic potential and driven by laser beams. By going to a rotating frame, we transform the one dimensional (spatial)interaction potential to a two dimensional potential in phase space, which only depends on the phase space distance under rotating wave approximation (RWA). The *phase space interaction potentials*, describing the interaction between slow evolution modes of interacting particles under RWA, are created by exchanging their fast oscillating modes. We quantize the phase space interactions and apply it to the study of driven multistable systems. We propose the concept of *exchange quasienergy* and calculate it for the system of two driven half-spin fermions, which is the difference of quasienergies between the singlet and triplet states. In theory, our work provides a new mechanism of creating interactions by exchanging not intermediate bosons but the interacting particles themselves. In experiments, the novel effects related to exchange quasienergy can be directly measured and may bring a new way to manipulate entangled states of atoms.

TT 69.13 Wed 18:15 A 053

B-DMFT with strong-coupling solver for inhomogeneous systems — Anna Kauch[1], •Jaromir Panas[2], Dieter Vollhardt[3], and Krzysztof Byczuk[2] — [1]Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, 18221 Praha, Czech Republic — [2]Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warszawa, Poland — [3]Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, 86135 Augsburg, Germany

We employ bosonic dynamical mean-field theory (B-DMFT) [1] with a strong-coupling impurity solver [2] to compute the particle density and condensate fraction of strongly interacting, inhomogeneous Bose systems. We apply the method to bosons in optical lattices with inhomogeneities due to the trapping potential and impurities. The influence of these inhomogeneities on the transition between the Mott insulating phase and the Bose-Einstein condensate is discussed.

[1] K. Byczuk and D. Vollhardt, Phys. Rev. B 77, 235106 (2008).
[2] A. Kauch, K. Byczuk, and D. Vollhardt,
Phys. Rev. B 85, 205115 (2012).

TT 69.14 Wed 18:30 A 053

Anderson and Mott transitions in the presence of spin-dependent disorder — •Jan Skoliomwski[1], Krzysztof Byczuk[1], and Dieter Vollhardt[2] — [1]Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, ul. Pasteura 5, PL-02-093 Warszawa, Poland — [2]Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, D-86135, Augsburg, Germany

Recent experiments with ultra-cold atoms in optical lattices [1] have caused us to investigate the phase diagram of correlated lattice fermions in the presence of spin-dependent disorder [2,3]. To this end we solved the Anderson-Hubbard model with a spin-dependent random potential within the dynamical mean-field theory, using the geometrically averaged local density of states to make the theory sensitive to Anderson localization [4]. The paramagnetic ground state phase diagram was determined. Spin-dependent disorder is seen to destabilize the metallic solution, in contrast to the usual case of spin-independent disorder [5]. For strong disorder above the critical point for the Mott transition novel spin-dependent localized phases are found.

[1] D. McKay and B. DeMarco, New J. Phys. 12, 055013 (2010).
[2] K. Makuch et al., New J. Phys. 15, 045031 (2013).
[3] R. Nanguneri et al., Phys. Rev. B 85, 134506 (2012).
[4] V. Dobrosavljevic et al., Europhys. Lett. 62, 76 (2003).
[5] K. Byczuket al., Phys. Rev. Lett. 94, 056404 (2005).

TT 69.15 Wed 18:45 A 053

Dirac cones merging transition and geometric phase in Stuckelberg interferometer with cold atoms — •Lih-King Lim — MPI PKS, Dresden, Germany — Institut d'Optique, Palaiseau, France

Dirac cones in the energy spectrum lies at the heart of many interests in studying two-dimensional crystals such as graphene or MoS_2. Besides its unusual density-of-states, a Dirac cone possesses geometric information hidden in the wavefunction, e.g., Berry phase and mass. The latter determines the type of topological state of matter. Thanks to recent progresses in engineering two-dimensional topological band structure with cold atoms, we study a Stuckelberg interferometer realized via Bloch-oscillations-type experiment. The paths that bring Bloch waves to interfere are made of the two energy levels in between a pair of Dirac cones. We show that the interference pattern contains an extra phase shift that has a geometric origin, in the form of an open path Berry phase of the wavefunction. It is revealed in the final inter-band transition probability and hence, it is a gauge invariant quantity. This phase can serve as a robust bulk probe for topological band structures realized with artificial crystals.

[1] L.-K. Lim, J.N. Fuchs, G. Montambaux,
Phys. Rev. Lett. 112, 155302 (2014).