TT 7: Cold Atomic Gases

Time: Monday 10:15–13:00 Location: H18

TT 7.1 Mon 10:15 H18

Dimensional phase transition from 1D behavior to a 3D Bose-Einstein condensate — Denis Morath, Dominik Strassel, Axel Pelster, and •Sebastian Eggert — Department of Physics and Research Center Optimas, University Kaiserslautern, 67663 Kaiserslautern, Germany

The emergence of new properties from low-dimensional building blocks is a universal theme in different areas in physics. The investigation of transitions between isolated and coupled low-dimensional systems promises to reveal new phenomena and exotic phases. Interacting 1D bosons, which are coupled in a two-dimensional array, are maybe the most fundamental example of a system which illustrates the concept of a dimensional phase transition. However, recent experiments using ultracold gases have shown a surprising discrepancy between theory and experiment [1] and it is far from obvious if the power laws from the underlying 1D theory can predict the transition temperature and order parameter correctly for all interaction strengths. Using a combination of large-scale Quantum Monte-Carlo simulations and chain mean-field calculations, we show that the behavior of the ordering temperature as a function of inter-chain coupling strength does not follow a universal powerlaw, but also depends strongly on the filling.

[1] A. Vogler, R. Labouvie, G. Barontini, S. Eggert, V. Guarrera, and H. Ott, PRL **113**, 215301 (2014)

TT 7.2 Mon 10:30 H18

Interacting bosons on a two-leg ladder in the presence of gauge fields — Marie Piraud[1], Sebastian Greschner[2], •Fabian Heidrich-Meisner[1], Ian McCulloch[3], Temo Vekua[2], and Ulrich Schollwoeck[1] — [1]LMU Munich, Germany — [2]University of Hanover, Germany — [3]University of Queensland, Australia

We present the phase diagram of the Bose-Hubbard model on a two-leg ladder geometry in the presence of a homogeneous flux per plaquette, motivated by recent quantum gas experiments [1,2] that studied the regime of weak interactions. Based on extensive density matrix renormalization group simulations and a bosonization analysis, we explore the parameter space and calculate experimentally accessible observables. For hardcore bosons, the phase diagram comprises Meissner and vortex phases atop either superfluids or Mott insulators, depending on filling [4]. For moderate interactions, vortex lattices form at certain commensurate vortex densities. Very interestingly, the breaking of lattice translations in the vortex lattice phases can lead to a spontaneous reversal of the circulation direction of the chiral current [5].

[1] M. Atala et al., Nature Phys. **10**, 588 (2014)
[2] M. Mancini et al., Science **349**, 1510 (2015)
[3] B. K. Stuhl et al. Science **349**, 1514 (2015)
[4] M. Piraud et al., PRB **91**, 140406(R) (2015)
[5] S. Greschner et al., PRL **115**, 190402 (2015)

TT 7.3 Mon 10:45 H18

Sudden expansion and domain-wall melting of strongly interacting bosons in 2D optical lattices and on multileg ladders — •Johannes Hauschild[1], Frank Pollmann[1], and Fabian Heidrich-Meisner[2] — [1]Max Planck Institute for the Physics of Complex Systems, D-01187 Dresden, Germany — [2]Department of Physics and Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität München, D-80333 München, Germany

We numerically investigate the expansion of clouds of hard-core bosons in a 2D square lattice using a matrix-product state based method. This non-equilibrium setup is induced by quenching the trapping potential to zero and is specifically motivated by recent experiments [1]. As the anisotropy of the amplitudes J_x and J_y for hopping in different spatial directions is varied from 1D to 2D, we observe a crossover from a fast ballistic expansion in the 1D limit $J_x \gg J_y$ to much slower dynamics in the isotropic 2D limit. We further compare the expansion of a cloud on multileg ladders and long cylinders with the melting of a domain wall and discuss the scenario of a condensation at finite momenta [2].

In addition, we study the domain-wall melting in the presence of a random on-site chemical potential. Tuning the inter-chain coupling J_y allows then to study the transition from an Anderson insulator in 1D to a many-body localized state in 2D.

[1] J. P. Ronzheimer et al., PRL **110**, 205301 (2013)
[2] J. Hauschild et al., PRA **92**, 053629 (2015)

TT 7.4 Mon 11:00 H18

Bosonic Self-Energy Functional Theory with Symmetry Breaking — •Dario Hügel[1], Philipp Werner[2], Lode Pollet[1], and Hugo U. R. Strand[2] — [1]Department of Physics, Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, Ludwig-Maximilians-Universität München, Theresienstrasse 37, 80333 Munich, Germany — [2]Department of Physics, University of Fribourg, 1700 Fribourg, Switzerland

We derive a non-perturbative variational self-energy functional for symmetry-broken bosonic systems from the corresponding Baym-Kadanoff functional. The local physics of the Bose-Hubbard model in three dimensions, as well as its thermodynamical properties in two dimensions, can be accurately reproduced by searching for the stationary points of such a functional with respect to just three scalar variational parameters: a symmetry-breaking field, and the normal and anomalous components of an imaginary-time independent hybridization function. We further show how bosonic dynamical mean-field theory follows naturally from the self-energy functional when extending the formalism to an imaginary-time-dependent hybridization function, while the mean-field approximation is obtained when neglecting the contributions of non-condensed bosons.

The simplicity of the method makes studying more complex lattice boson systems tractable. In particular, it can be generalized to systems with synthetic gauge fields and spin-orbit interactions, where path integral Monte Carlo methods fail due to the notorious sign problem.

TT 7.5 Mon 11:15 H18

DMFT + NRG study of the SU(N) Fermi-Hubbard model — •Seung-Sup B. Lee, Jan von Delft, and Andreas Weichselbaum — Physics Department, Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, Ludwig-Maximilians-Universität München, 80333 München, Germany

The SU(N) Fermi-Hubbard model, involving N flavors of fermions that interact fully symmetrically, has recently gained experimental relevance in the context of ultracold Ytterbium atoms in optical lattice, where the value of N can be changed controllably up to $N = 6$. The SU(2) Fermi-Hubbard model is well-known to exhibit a Mott metal-insulator transition, but a quantitative analysis of its SU(N)-symmetric counterpart has been limited so far to $N \leq 3$ or half-filling. Here we study the Mott transition of SU(N) Fermi-Hubbard model (up to $N = 6$) with dynamical mean-field theory (DMFT) using the numerical renormalization group (NRG) as impurity solver. By exploiting non-Abelian symmetry, the NRG yields the local spectral function efficiently with high spectral resolution over a wide range of system parameters, such as the interaction strength, chemical potential, and temperature.

15 min. break

TT 7.6 Mon 11:45 H18

Beyond the Hubbard bands in strongly correlated lattice bosons — •Hugo U. R. Strand[1], Martin Eckstein[2], and Philipp Werner[1] — [1]University of Fribourg, 1700 Fribourg, Switzerland — [2]Max Planck Research Department for Structural Dynamics, University of Hamburg-CFEL, 22761 Hamburg, Germany

We study the dynamics of the Bose-Hubbard model in- and out-of-equilibrium, using the real-time extension [1] of bosonic dynamical mean-field theory (BDMFT) [2] in combination with a Nambu strong-coupling impurity solver. Building on our previous study on quench dynamics [1], yielding qualitative agreement with cold-atom experiments [3], we here focus on theoretically reproducing and understanding cold-atom spectroscopy experiments [4, 5] in the strong-coupling limit. We perform non-equilibrium BDMFT interaction-modulation spectroscopy calculations, qualitatively reproducing experimental results, and explain the observed spectra by analyzing the structure of the equilibrium single-particle spectral function and the interaction-susceptibility. In particular, we discuss the nontrivial temperature dependence of the second resonance [6].

[1] Strand, Eckstein, Werner, PRX **5**, 011038 (2015)
[2] Anders, Werner, Troyer, Sigrist, Pollet, PRL **109**, 206401 (2012)

[3] Greiner, Mandel, Hansch, Bloch, Nature **419**, 51 (2002)
[4] Stöferle, Moritz, Schori, Köhl, Esslinger, PRL **92**, 130403 (2004)
[5] Clément, Fabbri, Fallani, Fort, Inguscio, PRL **102**, 155301 (2009)
[6] Strand, Eckstein, Werner, PRA **92**, 063602 (2015)

TT 7.7 Mon 12:00 H18

Competition between spin-selective localization and antiferromagnetism of correlated lattice fermions — •Jan Skolimowski[1], Dieter Vollhardt[2], and Krzysztof Byczuk[1] — [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

Following our recent investigation of the paramagnetic ground state of correlated lattice fermions subjected to spin-dependent randomness [1], we study the magnetic ground state phase diagram of the Anderson-Hubbard model with spin-dependent disorder. The model is solved on a bipartite lattice within the dynamical mean-field theory with geometrically averaged local density of states, which makes our approach sensitive to Anderson localization and magnetic long range order. We determined the phase diagram which shows four phases: antiferromagnetic insulator, paramagnetic metal, and two distinct antiferromagnetic spin-selective localized phases. Our results show that antiferromagnetism (AF) is suppressed more strongly at weak spin-dependent disorder, whereas for large disorder strengths AF is sustained for all interaction strengths.

[1] J. Skolimowski, D. Vollhardt, K. Byczuk, PRB **92**, 094202 (2015)

TT 7.8 Mon 12:15 H18

Study of the Bose-Hubbard model with infinite-range interaction — •Jaromir Panas[1], Anna Kauch[2], and Krzysztof Byczuk[1] — [1]Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warszawa, Poland — [2]Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, 18221 Praha, Czech Republic

In relation to a recent experiment [1] we study the Bose-Hubbard model with an infinite-range interaction creating a staggered order. To this end we employ the bosonic dynamical mean-field theory (B-DMFT) [2] with a self-consistent, mean-field correction responsible for the exact treatment of an infinite-range interaction. The B-DMFT method is generalized to a system on a bipartite lattice. A self-consistent equation that includes effects of long-range ordering is presented. Comparison with experiment is achieved through a phase diagram. We find four distinct phases thus obtaining qualitative agreement with experimental results.

[1] R. Landig, L. Hruby, N. Dogra, M. Landini, R. Mottl, T. Donner, and T. Esslinger, arXiv:1511.00007.
[2] K. Byczuk, and D. Vollhardt, PRB **77**, 235106 (2008).

TT 7.9 Mon 12:30 H18

Semiclassical quantisation for a bosonic atom-molecule conversion system — Eva-Maria Graefe, •Alexander Rush, and Maria Graney — Imperial College, London, United Kingdom

In this talk I will consider a simple two state quantum model of atom-molecule conversion in cold atom systems, where bosonic atoms can combine into diatomic molecules and vice versa. The many-particle system can be expressed in terms of the generators of a deformed SU(2) algebra, and the mean-field dynamics takes place on a deformed version of the Bloch sphere resembling a teardrop, with a cusp singularity. I will demonstrate the mean-field and many-particle correspondence, showing how semiclassical methods can be used to recover features such as the many-particle spectrum from the mean-field description.

TT 7.10 Mon 12:45 H18

Frustrated magnetism with soft-shoulder potentials and cluster liquids — •Tao Ying[1,2], Marcello Dalmonte[3,4], and Guido Pupillo[1] — [1]IPCMS (UMR 7504) and ISIS (UMR 7006), University of Strasbourg and CNRS, 67000 Strasbourg, France — [2]Institute for Theoretical Solid State Physics, RWTH Aachen University, 52056 Aachen, Germany — [3]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [4]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria

Cold bosonic atoms in optical lattices with finite-range soft-shoulder potentials (i.e., soft-core potentials with an additional hard-core on-site interaction) can cause cluster formation, which provides a natural source of frustration that leads to infinite ground state degeneracies, and hence to exotic quantum phenomena. Using quantum Monte Carlo simulations, we study the Bose-Hubbard model on a square lattice with soft-shoulder potentials V of finite-range $r_c = 2\sqrt{2}a$, where a denotes the lattice spacing. Upon increasing V/t, the model exhibits a superfluid to cluster liquid transition, where in the latter phase, the correlation functions such as the momentum distribution shows a distinct shape compared to the normal liquid. We also study the nature of the correlations and winding number histograms at the quantum critical point.