Q 24: Quantum Gases: Opt. Lattice 1

Time: Wednesday 10:30–13:00 Location: HSZ 02

Q 24.1 Wed 10:30 HSZ 02

Studying Quantum Many-Particle Systems on the Single-Atom Level — •M. Endres, C. Weitenberg, J. Sherson, M. Cheneau, P. Schauss, T. Fukuhara, I. Bloch, and S. Kuhr — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

The reliable detection of single quantum particles has revolutionized the field of quantum optics and quantum information processing. For several years, researchers have aspired to extend such detection possibilities to larger-scale, strongly correlated quantum systems.

We report on fluorescence imaging of bosonic Mott insulators in an optical lattice with single-atom and single-site resolution[1]. From our images, we fully reconstruct the atom distribution on the lattice and identify individual excitations with high fidelity.

Furthermore we will present progress towards in-situ thermometry and the detection of coherent particle-hole excitations across the superfluid-to-Mott-insulator transition.

We plan to use our detection technique to study one dimensional quantum systems. In the Tonks-Girardeau regime, their strongly interacting nature can be revealed by the density-density correlation function, which should show a distinct anti-bunching of the particles.

[1] J. Sherson et al., Nature 467, 68 (2010)

Q 24.2 Wed 10:45 HSZ 02

A mulitband ground-state superfluid — •Parvis Soltan-Panahi, Julian Struck, Dirk-Sören Lühmann, Andreas Bick, Wiebke Plenkers, Rodolphe Le Targat, Patrick Windpassinger, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Superfluid bosonic atoms confined in a 3D optical lattice are usually very well described by a single quasi-momentum state in the lowest Bloch band (s-band). In this regime, interaction effects are small and can mostly be treated at a mean-field level.

Here, we report on the experimental realization of an interaction induced mixing of the s- and p-band states in a shallow, spin-dependent hexagonal lattice in the superfluid regime. This novel phase occurs for a certain class of spin-mixtures and can be unambiguously determined by a clear reduction of the six-fold rotational symmetry to a three-fold symmetry of the many-body state in momentum space. Remarkably, the fully correlated two-particle interaction plays here the major role, which is usually only observed in strongly interacting systems.

We theoretically describe this novel mulit-band superfluid ground-state phase as a second-order quantum phase transition. This is characterized by a twisted quantum mechanical phase between s- and p-band superfluid fractions, which leads to the very characteristic momentum spectrum of the different spin-components.

Q 24.3 Wed 11:00 HSZ 02

Adiabatic generation of a Heisenberg antiferromagnet in an optical lattice — •Michael Lubasch[1], Valentin Murg[2], Mari-Carmen Bañuls[1], Juan Ignacio Cirac[1], Ulrich Schneider[3], and Immanuel Bloch[1,3] — [1]Max Planck Institute of Quantum Optics, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany — [2]University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria — [3]Ludwig-Maximilians-University Munich, Faculty of Physics, Schellingstrasse 4, 80799 Munich, Germany

Ultracold fermions in optical lattices hold the potential to be employed as a true quantum simulator of the Hubbard model and as such give us insight into high-T_c superconductivity. However, a main obstacle is still the low temperatures needed for the validity of the Hubbard model description.

Whereas a fermionic Mott state has already been realized in an optical lattice (R. Joerdens *et al.*, Nature **455**, 204 (2008); U. Schneider *et al.*, Science **322**, 1520 (2008)), the next challenge is the demonstration of magnetic order, present in an underlying Heisenberg antiferromagnet. However, a direct construction of this state is difficult because even lower temperatures are needed.

Alternatively, we may try to generate the antiferromagnetic state by means of adiabatic evolution from an easily preparable initial state. We numerically simulate our proposal via Matrix Product States (MPS) in 1D and Projected Entangled Pair States (PEPS) in 2D. We discuss the resulting time scales for the adiabatic evolution, the effect of defects in the initial state and the importance of a harmonic trap.

Q 24.4 Wed 11:15 HSZ 02

Complete devil's staircase and crystal–superfluid transitions in a dipolar XXZ spin chain: A trapped ion quantum simulation — •Philipp Hauke[1], Fernando M. Cucchietti[1], Mari-Carmen Bañuls[2], Alexander Müller-Hermes[2], J. Ignacio Cirac[2], and Maciej Lewenstein[1] — [1]ICFO – The Institute of Photonic Sciences, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Systems with long-range interactions show such intriguing properties as the accommodation of many meta-stable states, supersolid phases, and counterintuitive thermodynamics. On the downside, this increased complexity hinders theoretical studies, making a quantum simulator for long-range models highly desirable. In [1], we propose a trapped-ion quantum simulation of hard-core bosons on a chain with dipolar off-site interaction and tunneling, equivalent to a dipolar XXZ spin-1/2 chain. We explore the rich phase diagram of this model employing perturbative mean-field theory, exact diagonalization, and quasi-exact numerical techniques (density-matrix renormalization group and infinite time evolving block decimation). We find that the complete devil's staircase – an infinite sequence of crystal states existing at vanishing tunneling – spreads to a succession of lobes similar to the Mott-lobes of Bose–Hubbard models. Inside the insulating lobes there appears – opposed to models with nearest-neighbor tunneling – a *quasi-supersolid*, a phase with diagonal long-range and off-diagonal quasi–long-range order. [1] Hauke *et al.*, New J. Phys. **12** (2010) 113037

Q 24.5 Wed 11:30 HSZ 02

Towards Plaquettes in Optical Superlattice — •Marcos Atala[1,2], Monika Aildesburger[1], Yu-Ao Chen[1,2], Sylvain Nascimbene[1,2], Stefan Trotzky[1], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilian-Universität, Schellingstrasse 4, 80798 München, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Superimposing two optical lattice potentials differing in periodicity by a factor of two creates a superlattice structure. Together with two orthogonal lattices it provides a generic system to study isolated double well physics. By removing one of the orthogonal lattices one could extend the system from coupled quantum dots to coupled tubes, which allows us to extend the study of few-body physics to many-body physics. In addition, by adding another superlattice potential perpendicular to the first one, an array of plaquettes is created. In this talk we will discuss about recent progress in such a system.

Q 24.6 Wed 11:45 HSZ 02

Three-body losses and three-body correlations in one-dimensional systems — •Elmar Haller, Manfred J. Mark, Johann G. Danzl, Lukas Reichsöllner, Mohamed Rabie, Oliver Krieglsteiner, Andreas Klinger, and Hanns-Christoph Nägerl — Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, Technikerstrasse 25, A-6020 Innsbruck, Austria

We load a Bose-Einstein condensate of cesium atoms into an array of tube-like 1D traps generated by a 2D optical lattice potential, and we control the interaction strength by means of a 1D confinement-induced resonance [1]. Unlike for ultracold atoms in 3D geometry, which show a dramatic increase of three-body losses in the proximity of a Feshbach resonance, we observe a strong suppression of three-body losses in 1D. This suppression originates from a strong reduction of the three-body correlation function g_3 at close distances in 1D. We find a reduction of g_3 by several orders of magnitude for an increasing interaction parameter γ. The scaling of $g_3(\gamma)$ is compared to theoretical predictions [2] [1] E. Haller, *et al.*, Phys. Rev. Lett. **104** 153203 (2010).

[2] D. Gangardt, and G. Shlyapnikov, Phys. Rev. Lett. **90** 10401 (2003).

Q 24.7 Wed 12:00 HSZ 02

Scanning electron microscopy of ultracold atoms — •Peter Würtz, Andreas Vogler, Arne Ewerbeck, Matthias Scholl, Giovanni Barontini, Vera Guarrera, and Herwig Ott — TU Kaiserslautern

We have adapted a scanning electron microscope for the study of ultracold quantum gases. The technique allows for in situ imaging of single atoms with a resolution of better than 150 nm. Thus, it can readily be applied to study quantum gases in optical lattices. The dissipative interaction of the electron beam with the atoms can be used to selectively remove atoms. In this way, one can create arbitrary patterns of occupied lattice sites. We were able to measure temporal pair correlations in a thermal gas, which demonstrates the single atom sensitivity of our detection method. The system is also an interesting experimental platform to study electron-atom scattering processes and cold ion-atom collisions.

Q 24.8 Wed 12:15 HSZ 02

Emulating Frustrated Magnetism in Triangular Optical Lattices — •Julian Struck, Christoph Ölschläger, Christina Staarmann, Parvis Soltan-Panahi, Rodolphe Le Targat, Patrick Windpassinger, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany

We present the experimental realization of a quantum simulator for magnetism with ultracold quantum gases in optical lattices. It is possible to emulate magnetic interactions of a xy-model – interestingly with spinless bosons – by applying a time periodic acceleration to the lattice as proposed by Eckardt et al. [1]. Several different magnetic phases of this model have successfully been realized. The most interesting is the frustrated spiral phase which exhibits exotic properties like time-reversal and spontaneous symmetry breaking.

These first results open the perspective to extremely complex and yet not well understood phases like the spin-liquid in a quantum xy-model.

[1] A. Eckardt et al 2010 EPL 89 10010

Q 24.9 Wed 12:30 HSZ 02

The Dicke quantum phase transition in an optical cavity QED system — •Rafael Mottl[1], Kristian Baumann[1], Ferdinand Brennecke[1], Tobias Donner[1], Christine Guerlin[2], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Thales Research and Technology, 91767 Palaiseau Cedex, France

The collective interaction of an ensemble of atoms with an electromagnetic field mode is of fundamental interest. A conceptually important model describing such a system is the Dicke model for which the existence of a quantum phase transition was predicted years ago. We have achieved its first experimental realization in an open system in which a Bose-Einstein condensate is coupled to an optical high-finesse cavity. The interaction between the condensate atoms is mediated by the field of the optical cavity and is of infinite range. Starting in a superfluid state, the self-organized phase which emerges at the phase transition is of supersolid character.

We map out the phase diagram which agrees quantitatively with the Dicke model prediction. The spontaneous symmetry breaking occuring at the quantum phase transition leads to the development of two initially degenerate ground states which are observed by a phase-sensitive detection of light leaking out of the cavity. Investigating the excitation spectrum below threshold by Bragg spectroscopy, we identify a vanishing energy gap when approaching the critical point - a precursor of the quantum phase transition.

Q 24.10 Wed 12:45 HSZ 02

Hierarchy of correlations in the Bose–Hubbard–Model — Ralf Schützhold, Patrick Navez, and •Markus Pater — Fakultät für Physik, Universität Duisburg-Essen, Lotharstaße 1, D-47057 Duisburg, Germany

We study the Bose–Hubbard–Model in terms of reduced density matrices of one ($\hat{\rho}_\mu$), two ($\hat{\rho}_{\mu\nu}$) and more lattice sites.

By complete induction, we prove a hierarchy of correlations such as $\hat{\rho}^{\rm corr}_{\mu\nu} = \hat{\rho}_{\mu\nu} - \hat{\rho}_\mu \hat{\rho}_\nu$.

For large coordination numbers $Z \gg 1$, the two-point correlation $\hat{\rho}^{\rm corr}_{\mu\nu}$ is suppressed by $\hat{\rho}^{C}_{\mu\nu} = O\left(1/Z\right)$ while three-point correlators are suppressed by $O\left(1/Z^2\right)$ etc.

This facilitates a controlled analytical description of many–body quantum dynamics away from equilibrium.

We apply this approach to some physical example scenarios.