Q 70: Quantum gases: Lattices IV

Time: Friday 16:30–18:30 Location: UDL HS2002

Q 70.1 Fri 16:30 UDL HS2002

Towards ultracold gasses in a periodically driven hexagonal lattice — •Lucia Duca[1,2], Tracy Li[1,2], Martin Reitter[1,2], Monika Schleier-Smith[3], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, München, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Stanford University, Stanford, CA, United States

Confining cold atoms in an optical lattice realizes a highly tunable system for simulating condensed matter phenomena in a clean and well controlled environment. Particularly interesting is the application of optical lattices to the studies of topologically distinct classes of physical system. Such properties can arise in cold atoms subjected to periodically driven optical lattices [1]. In our case we focus on cold atoms in a hexagonal lattice, which implements the graphene band structure. The effect of the drive is to induce the opening of a gap at the Dirac points in the energy spectrum, thereby introducing topological properties, similarly to what has been demonstrated with irradiated photonic crystals [2]. Here we present the current status of an apparatus for studying cold gasses in a hexagonal lattice and the latest experimental results.

[1] T. Kitagawa et al., Phys. Rev. B 82, 235114 (2010).
[2] M. C. Rechtsman et al., Nature 496, 196 (2013).

Q 70.2 Fri 16:45 UDL HS2002

Dimerized Mott insulators in driven hexagonal optical lattices — •Ole Jürgensen, Dirk-Sören Lühmann, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg

We numerically study driven optical honeycomb lattices and find dimerized insulator phases with fractional filling. These incompressible insulating phases are characterized by an interaction-driven localization of particles to individual dimers and a coherent superposition within the dimers. We calculate the ground state phase diagrams and the excitation spectra using an accurate cluster mean-field method as well as perturbation theory employing an effective model. Probing the fundamental excitations of the dimerized Mott insulator allows the distinction from normal Mott insulating phases. By computing finite lattices with large diameters the influence of the experimental confinement is discussed in detail.

Q 70.3 Fri 17:00 UDL HS2002

Transport phenomena in fastly driven lattices — •Alexander Itin — Center for optical quantum technologies, Hamburg University, Germany — Space Research Institute, Moscow, Russia

I present analysis of several systems related to driven lattices. Firstlly, directed transport in a fastly driven classical periodic potential is considered [1]. Using canonical perturbation theory, general expressions are derived for the drift velocity in arbitrary potential and force. I extend this scheme to solve GP equation in a shaken lattice, as realized in a recent Hamburg experiment [2]. This gives interesting new insight into the system, allowing to interpretate subtle features in experimental results. I consider then fully quantum systems, Bose- and Fermi-Hubbard models, in the presence of high-frequency driving. A method inspired by classical canonical perturbation theory is developed to derive effective Hamiltonians of these systems. I demonstrate that the presented method [4] has some advantages to recent studies based on flow equation method [3]. One of the possible application of results is coherent light-control of solids [5]. I also analyze recent Hamburg experiments with ultracold atoms in amplitude-modulated optical lattices [6], which build quantum simulator of the phenomenon of photoconductivity. I extend my semiclassical analysis [6] to interacting mixtures of gases. [1] A.P.Itin, A.I.Neishtadt, Phys.Rev.E 86, 016206 (2012). [2] J.Struck et.al, Phys. Rev. Lett. 108, 225304 (2012). [3] A. Verdeny et. al., Phys. Rev. Lett. 111, 175301 (2013). [4] A.P.Itin, arxiv:1213.xxx (2013). [5] A.Subedi et.al, arxiv::1311.0544 (2013). [6] J.Heinze et.al, Phys. Rev. Lett. 110 (2013).

Q 70.4 Fri 17:15 UDL HS2002

Collective Phenomena in an Array of Trapped Atoms Strongly Coupled to a Nanophotonic Waveguide — •Hashem Zoubi — Max-Planck Institute for the Physics of Complex Systems, Dresden, Germany

A lattice of trapped atoms strongly coupled to a one-dimensional nanophotonic waveguide is investigated in exploiting the concept of polariton as the system natural collective eigenstate. We apply a bosonization procedure, which was presented separately by P. W. Anderson and V. M. Agranovich, to transform excitation spin-half operators into interacting bosons, and which shown here to confirm the hard-core boson model. We derive polariton-polariton kinematic interactions and study them by solving the scattering problem. In using the excitation-photon detuning as a control parameter, we examine the regime in which polaritons behave as weakly interacting photons, and propose the system for realizing superfluidity of photons. We implement the kinematic interaction as a mechanism for nonlinear optical processes that provide an observation tool for the system properties, e.g. the interaction strength produces a blue shift in pump-probe experiments.

[1] H. Zoubi, and H. Ritsch, New J. Phys. 12, 103014 (2010).
[2] H. Zoubi, and H. Ritsch, Advances in Atomic, Molecular, and Optical Physics 62, 171, (Eds.: E. Arimondo, P. Berman, C. Lin), (Elsevier, 2013).
[3] H. Zoubi, Europhys. Lett. 100, 24002 (2012).
[4] H. Zoubi, arXiv:1310.6241 (2013).

Q 70.5 Fri 17:30 UDL HS2002

Cavity QED in the Recoil Resolved Regime — •Jens Klinder, Hans Kessler, Matthias Wolke, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

We are experimentally exploring the light matter interaction of a Bose-Einstein condensate (BEC) with the light mode of an ultrahigh finesse optical cavity ($F \approx 340\,000$). The key feature of our cavity is the small intracavity field decay rate ($\kappa/2\pi \approx 4.5\,\mathrm{kHz}$), which is half the spectral width of the transmission resonances. Most importantly, this decay rate is smaller than twice the recoil frequency ($\omega_{\mathrm{rec}}/2\pi \approx 3.55\,\mathrm{kHz}$) or rather the spectral linewidth is smaller than the frequency change of a photon in a single backscattering event. Together with a Purcell factor of $\eta \approx 40 \gg 1$, this leads to a unique situation where each atom can backscatter only a single photon, because the kinetic energy transfer required for further backscattering is not resonantly supported by the cavity. With our setup we were able to demonstrate targeted heating and cooling of atoms on a sub-recoil energy scale at densities on the order of $10^{14}\,\mathrm{cm}^{-3}$ incompatible with conventional laser cooling which relies on the scattering of near resonant photons [1].

Furthermore, the inaccessibility of higher momentum states leaves us with a true two level system interacting with our narrowband cavity. This model system gives us the opportunity to investigate novel aspects of light matter interaction like exotic quantum phase transitions or attractors in cavity optomechanics.

[1] M. Wolke, J. Klinner, H. Keßler, and A. Hemmerich, Science 337, 75 (2012)

Q 70.6 Fri 17:45 UDL HS2002

Exploring the driven-dissipative Dicke phase transition — •Renate Landig, Rafael Mottl, Lorenz Hruby, Ferdinand Brennecke, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, Switzerland

We experimentally study the driven-dissipative Dicke quantum phase transition, realized by coupling the external degree of freedom of a Bose-Einstein condensate to the light field in a high-finesse optical cavity. By monitoring the cavity output field we are able to observe in real-time the diverging atomic density fluctuations while approaching the critical point. The observed critical behavior deviates from the expectation for the closed Dicke model and is in quantitative agreement with the enhanced fluctuation spectrum of the driven-dissipative system. Using a heterodyne detection setup, we spectroscopically resolve the cavity output field. This enables us to separately determine the quasiparticle excitation spectrum and its damping rate, and gives insight into the many-body state and its temperature.

Q 70.7 Fri 18:00 UDL HS2002

Quantum simulation of relativistic fields interacting with artificial gravity in 2D bichromatic optical lattices — •Nikodem Szpak — Fakultät für Physik, Universität Duisburg-Essen

We present our latest results on the possibilities of quantum simulation of relativistic fields in 2-dimensional bichromatic optical lattices. Geometry and relative strength of the laser beams define the properties of the effective quantum field and set the mass-gap of its ground-state excitations (particles and antiparticles). Local static or time-dependent amplitude and/or phase modulations can then introduce effective curved geometry and gravitational potential. The last can be used for simulation of gravitational lensing or interaction with strong gravitational waves – beyond the range of any direct experiments.

Q 70.8 Fri 18:15 UDL HS2002

Veselago lensing with ultracold atoms in an optical lattice
— •Martin Leder, Christopher Grossert, and Martin Weitz — Institute of Applied Physics, University of Bonn, Germany

In 1968 Veselago pointed out that electromagnetic wave theory allows for materials with a negative index of refraction, in which most known optical phenomena would be reversed [1]. A slab of such a material can focus light by negative refraction, an imaging technique strikingly different from conventional positive refractive index optics, where curved surfaces bend the rays to form an image of an object. Veselago lensing has also been proposed for electrons in graphene material [2] and cold atoms in dark state media [3], but so far no experimental realization has been reported. Here we demonstrate Veselago lensing for matter waves, using ultracold atoms in an optical lattice. A relativistic, i.e. photon-like, dispersion relation for rubidium atoms is realized with a bichromatic optical lattice potential. We rely on a Raman π-pulse technique to transfer atoms between two different branches of the dispersion relation, converting a spatially diverging atom flow to a spatially converging one, and resulting in a focusing completely analogous to the effect described by Veselago for light waves. We study negative refraction and Veselago lensing both in a one-dimensional geometry and perform a ray-tracing simulation of a two-dimensional Veselago lens.

[1] Veselago, V.G., Sov. Phys. Usp. **10**, 509 (1968).
[2] Cheianov, V.V. et al., Science **315**, 1252 (2007).
[3] Juzeliūnas, G. et al., Phys. Rev. A **77**, 011802 (2008).