Q 20: Ultracold plasmas and Rydberg atoms

Time: Monday 16:30–18:45 Location: E 415

Group Report Q 20.1 Mon 16:30 E 415

Steady-state crystallization of Rydberg excitations in optically driven atomic ensembles — •Michael Höning[1], Dominik Muth[1], David Petrosyan[2], and Michael Fleischhauer[1] — [1]Fachbereich Physik und Landesforschungszentrum OPTIMAS, TU Kaiserslautern — [2]Institute of Electronic Structure and Laser, FORTH, GR-71110 Heraklion, Crete, Greece

We study the emergence of many-body correlations in strongly-interacting, driven dissipative systems. Specifically, we examine resonant optical excitations of Rydberg states of atoms interacting via long-range van der Waals potential employing exact numerical methods such as t-DMRG and semiclassical Monte-Carlo simulations. In a one-dimensional lattice of atoms with nearly complete blockade of simultaneous excitation at the adjacent sites, we find that, under appropriate (dark-state) driving, the atoms can develop finite-range crystalline order of Rydberg excitations. At higher atomic densities, all atoms within the blockade radius form "superatoms", each accommodating at most one Rydberg excitation. Under strong uniform driving, the saturation of superatoms leads to quasi-crystallization of Rydberg excitations whose correlations exhibit damped spatial oscillations. The behavior of the system can be approximated by an analytically soluble model based on a "hard-rod" interatomic potential.

Q 20.2 Mon 17:00 E 415

Spontaneous avalanche ionization of a strongly blockaded Rydberg gas — •Christoph S. Hofmann, Martin Robert-de Saint-Vincent, Hanna Schempp, Georg Günter, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg

We report the sudden and spontaneous evolution of an initially correlated gas of repulsively interacting Rydberg atoms to an ultracold plasma [1]. Under continuous laser coupling we create a Rydberg ensemble in the strong blockade regime, which at longer times undergoes an ionization avalanche. By combining optical imaging and ion detection, we access the full information on the dynamical evolution of the system, including the rapid increase in the number of ions and a sudden depletion of the Rydberg and ground state densities. Rydberg–Rydberg interactions are observed to strongly affect the dynamics of plasma formation. We use a coupled rate-equation model to describe our data and to reveal that the initial correlations of the Rydberg ensemble should persist through the avalanche. The latter would mitigate disorder-induced-heating [2], and offer a route to enter new strongly-coupled regimes.

[1] M. Robert-de Saint-Vincent *et al.* arXiv:1209.4728 (2012)
[2] M. Murillo PRL **87** 115003 (2001)

Q 20.3 Mon 17:15 E 415

Light propagation in strongly interacting Rydberg gases — •Martin Gärttner and Jörg Evers — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

Electromagnetically induced transparency in Rydberg gases has proven a valuable tool for applications in non-linear optics. Recently, single photons and other non-classical states of light have been produced using light propagation through strongly interacting Rydberg gases. We present a model describing the propagation of a weak probe beam in the presence of a strong coupling beam, coupling to a strongly interacting Rydberg level. Our model is based on the rate equation ansatz [1,2] and includes the attenuation of the probe beam. We test our model by comparing to experimental results of the group of M. Weidemüller [3] covering a large range of atomic densities and to other state of the art models. We find that all properties but the excitation statistics are described well by the rate equation model, indicating that quantum correlations in the light field should be taken into account.

[1] C. Ates et *al.*, Phys. Rev. A 76, 013413 (2007)
[2] K. P. Heeg et *al.*, arXiv:1202.2779 (2012)
[3] C. Hofmann et *al.*, arXiv:1211.7265 (2012)

Q 20.4 Mon 17:30 E 415

Optical imaging of Rydberg atoms in dense atomic gases — •Georg Günter, Hanna Schempp, Martin Robert-de Saint-Vincent, Stephan Helmrich, Vladislav Gavryusev, Christoph Hofmann, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg

We experimentally investigate a new all-optical method to image Rydberg atoms embedded in dense atomic gases [1]. The method exploits strong interactions between the Rydberg atoms and highly polarizable excited states of the surrounding gas. The resulting level-shifts of the excited states are mapped via electromagnetically induced transparency on a strong optical transition, leading to absorption for many atoms surrounding each Rydberg impurity in an otherwise transparent gas. Using this novel technique we show single shot images of small numbers of Rydberg atoms. Furthermore we characterize the time resolution and state-selectivity of the method. This makes it a promising tool for dynamical studies of strongly correlated many-body states as well as transport phenomena in Rydberg aggregates.

[1] G. Günter et al Phys.Rev.Lett. 108, 013002 (2012)

Q 20.5 Mon 17:45 E 415

Crystallization of photons via light storage in Rydberg gases — Johannes Otterbach[1,2], •Matthias Moos[1], Dominik Muth[1], and Michael Fleischhauer[1] — [1]Fachbereich Physik and Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Department of Physics, Harvard University, Cambridge, MA 02138, USA

Light exciting atoms to Rydberg states under conditions of electromagnetically induced transparency (EIT) can be described in terms of slow-light Rydberg-polaritons. The strong interaction mediated by the Rydberg atoms can give rise to crystallization of photons, i.e., to density waves with long-range power-law correlations. In an 1D setting the low-energy physics can be described by a Luttinger liquid model. When the corresponding Luttinger parameter K becomes smaller than $1/2$, the density wave dominates the correlations marking the onset of crystallization. We calculate the K parameter by DMRG simulations and compare it to analytic approximations. We find that under typical slow-light conditions K is much larger than $1/2$ and thus no crystalline order can emerge. However, storing the polaritons in a stationary spin wave by switching off the control laser the effective mass and thus the kinetic energy vanish and K approaches zero. If the storage is done sufficiently adiabatic, long range crystalline order can be generated. We analyze the dynamics of this build-up in terms of a time-dependent Luttinger theory and derive conditions for an optimal storage scenario.

Q 20.6 Mon 18:00 E 415

Binding by dissipation — •Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover

I will demonstrate how dissipative forces can act as a binding mechanism between two strongly interacting particles, even when the interaction potential is purely repulsive [1]. The bound state arises as a quasi-stationary state of the dynamical evolution of the system. This method also carries the potential to serve as a cooling mechanism for strongly interacting quantum gases. Finally, I will discuss a possible experimental realization with ultracold Rydberg atoms.

[1] M. Lemeshko, H. Weimer, arXiv:1211.4035 (2012).

Q 20.7 Mon 18:15 E 415

Rydberg Physics on the Millisecond Timescale — •Thomas Niederprüm, Tobias Massimo Weber, Torsten Manthey, Vera Guarrera, Giovanni Barontini, and Herwig Ott — Research Center Optimas, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

Several proposals have demonstrated that dressing ultracold atoms with highly excited Rydberg states can be an extremely powerful tool to tune the interactions among them. The changed interactions create a new equilibrium state for the system that is reached typically on a timescale of milliseconds. While the short time behavior of cold Rydberg gases, the so called frozen Rydberg gas, has been vastly studied in the past only little work has been done to understand the long time behavior of Rydberg excitations in cold atomic gases. This talk will give an overview on recent experiments in our group aiming to address this regime of Rydberg physics. The ionization of Rydberg atoms inside cold clouds turns out to be an important process in such experiments. Monitoring these ion signals and combining the Rydberg excitation with a Scanning Electron Microscope we are able to study blockade phenomena in samples with dimensions down to 500 nm inside of optical lattices. Furthermore the influence of high energetic electrons on the excitation of Rydberg atoms inside a BEC is reported.

Q 20.8 Mon 18:30 E 415

Sub-Poissonian statistics of Rydberg-interacting dark-state polaritons — •Hanna Schempp[1], Christoph S. Hofmann[1], Georg Günter[1], Martin Robert-de-Saint-Vincent[1], Martin Gärttner[2,3], Jörg Evers[2], Shannon Whitlock[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut , Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [3]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

Interfacing light and matter at the quantum level is at the heart of modern atomic and optical physics and enables new quantum technologies involving the manipulation of single photons and atoms. A prototypical atom-light interface is electromagnetically induced transparency, in which quantum interference gives rise to hybrid states of photons and atoms called dark-state polaritons. We have observed individual dark-state polaritons as they propagate through an ultracold atomic gas involving Rydberg states [1]. Strong long-range interactions between Rydberg atoms give rise to an effective interaction blockade for dark-state polaritons, which results in large optical nonlinearities and modified polariton number statistics. The observed statistical fluctuations drop well below the quantum noise limit indicating that photon correlations modified by the strong interactions have a significant back-action on the Rydberg atom statistics.

[1] C.S. Hofmann et al., arXiv:1211.7265