Q 37: SYRA: Ultracold Rydberg Atoms and Molecules 3

Time: Thursday 10:30–13:00 Location: V7.03

Q 37.1 Thu 10:30 V7.03

Interaction enhanced imaging of individual Rydberg atoms in dense gases — •Martin Robert-de-Saint-Vincent, Georg Günter, Christoph S. Hofmann, Hanna Schempp, Henning Labuhn, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg

Neutral atoms in Rydberg states are highly-polarisable particles, which can experience quantum effects and interactions over macroscopic distances. Many-body systems of Rydberg atoms offer a unique opportunity to create and investigate strong correlations in ultra-cold atomic gases [1]. Until recently, Rydberg ensembles have mostly been studied via field-ionization and subsequent ion detection, typically providing ensemble properties. Here, we present an all-optical method to image individual Rydberg atoms embedded within dense gases of ground state atoms [2]. The scheme exploits interaction-induced shifts on highly polarizable excited states of probe atoms, which can be spatially resolved via an electromagnetically induced transparency resonance. Using a realistic model, we show that individual Rydberg atoms can be imaged with enhanced sensitivity and high resolution despite photon shot noise and atomic density fluctuations. This scheme could be extended to other impurities such as ions, and is ideally suited to studies of spatially-correlated many-body systems.

[1] Pohl et al., PRL 104, 043002 (2010)
[2] G. Günter et al., arXiv:1106.5443v1 (2011), to be published in PRL

Q 37.2 Thu 10:45 V7.03

Rydberg Atom Spectroscopy in Electric Fields — •Atreju Tauschinsky, Richard Newell, Vanessa Leung, Ben van Linden van den Heuvell, and Robert Spreeuw — Institute of Physics, University of Amsterdam, Amsterdam, Netherlands

We study rubidium Rydberg states in static and oscillating electric fields using Electromagnetically Induced Transparency (EIT) in the 5s-5p-nℓ system for $n \geq 28$ and $\ell = 0 \ldots 2$. We present high-precision Doppler free measurements of DC Stark shifts in a room temperature vapour cell which are in excellent agreement with theoretical calculations. These measurements clearly show that the assumption of quadratically shifting energy levels where the shift is determined by the polarizability of the state is valid only for very small fields, less than 5% of the Inglis-Teller Limit.

We furthermore investigate the behaviour of Rydberg states in superposed AC and DC electric fields and observe populated sidebands of very high order. We present a model, based on generalized Bessel functions for the sideband population induced by oscillating fields in arbitrarily stark-shifting levels and compare the results of this model to our measurements.

Atreju Tauschinsky *et al.* Spatially resolved excitation of Rydberg atoms and surface effects on an atom chip. Phys. Rev. A **81**, 063411 (2010)

C. S. E. van Ditzhuizen *et al.* Observation of Stückelberg oscillations in dipole-dipole interactions. Phys. Rev. A **80**, 063407 (2009)

Q 37.3 Thu 11:00 V7.03

Coherent spectroscopy involving Rydberg states in electrically contacted microcells — •Renate Daschner, Ralf Ritter, Daniel Barredo, Harald Kübler, Robert Löw, and Tilman Pfau — Universität Stuttgart

Micron sized glass cells filled with atomic vapor are promising candidates for quantum devices based on the Rydberg blockade. Due to the strong interaction between two Rydberg atoms, only one Rydberg excitation is possible within a certain volume characterized by the blockade radius (typically few microns). This effect also provides a nonlinearity that is an essential tool for proposals to entangle mesoscopic ensembles and to realize single photon sources. Measurements show, that coherent Rydberg excitation in thermal vapor and micron-sized cells is possible [1].

The large DC Stark shift of Rydberg atoms provides a possibility to induce transmission or absorption in the medium. To address individual cells one needs electrical contact of the cells. This can be done by coating the inside of glass cells for example with a metal. We show first measurements in coated electrically contacted cells where we can shift the signal by more than one linewidth with a DC electric field.

[1] Kübler, H., Shaffer, J. P., Baluktsian, T., Löw, R. & Pfau, T. Coherent excitation of Rydberg atoms in micrometre-sized atomic vapour cells, Nature Photon. 4, 112-116 (2010)

Q 37.4 Thu 11:15 V7.03

Measurement of the Rydberg ionization current in thermal vapor cells — •Daniel Barredo, Renate Daschner, Harald Kübler, Ralf Ritter, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Germany

Rydberg atoms confined in atomic vapor cells are promising candidates for the realization of single photon sources and quantum optical devices [1].To date, most information about the behavior of the Rydberg ensembles in thermal vapors has been extracted by absorptive measurements, e.g. EIT. However, to access directly quantities, like the population of the excited states, new methods are needed. In this task, the detection of the Rydberg ionization current provides a complementary and direct insight in the atomic processes.

We show measurements of the Rydberg-ion current in thermal vapor cells equipped with field plates.

[1] Kübler, H., Shaffer, J.P., Baluktsian, T., Löw, R. and Pfau, T. Coherent excitation of Rydberg atoms in micrometre-sized atomic vapour cells, *Nature Photon.* **4**, 112-116 (2010).

Q 37.5 Thu 11:30 V7.03

Scaling laws and correlations in finite Rydberg gases — •Martin Gärttner[1,2], Thomas Gasenzer[2], and Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, D-69120 Heidelberg

We study the coherent dynamics of a finite laser-driven cloud of ultracold Rydberg atoms by calculating the time evolution from the full many body Hamiltonian. Using the frozen gas approximation and treating the atoms as effective two level systems, we are mainly interested in the spatially resolved properties of the gas in its thermalized state. Even for resonant coupling to the Rydberg state, the pair correlation function shows a pronounced structure. It turns out that a simple estimation of the blockade radius predicts the position of the first maximum of the $g^{(2)}$-function quite well. However, we show that algebraic scaling laws as predicted in [1] are modified by finite size effects which serves as a test of the validity of the super atom picture. At positive detuning crystalline structures are observed even without using chirped laser pulses [2], which can be explained by resonant excitation processes and finite size effects.

[1] H. Weimer *et al.*, Phys. Rev. Lett. 101, 250601 (2008)
[2] T. Pohl *et al.*, Phys. Rev. Lett. 104, 043002 (2010)

Q 37.6 Thu 11:45 V7.03

Coherence on Förster resonances between Rydberg atoms — •Alexander Krupp, Johannes Nipper, Jonathan Balewski, Robert Löw, and Tilman Pfau — 5.Physikalisches Institut, Universität Stuttgart

Förster resonances are non-radiative dipole-dipole interactions between oscillating dipoles. Especially in biochemistry these resonances play a crucial role and describe the energy transfer process between two chromophores, parts of molecules which are responsible for their colors. In our work these resonances occur between a pair of Rydberg atoms, creating strong interactions between the atoms.

We report on studies of Förster resonances between Rydberg atoms in an ultra-cold atomic cloud of ^{87}Rb. By applying a small electric field we tune dipole coupled pair states into resonance, giving rise to Förster resonances. Via a Ramsey-type atom interferometer we can resolve several resonances at distinct electric field strengths. We study the coherence of the system at and close to the resonances and we observe a change in phase and visibility of the Ramsey fringes on resonance. The individual resonances are expected to exhibit different angular dependencies, opening the possibility to tune not only the interaction strength but also the angular dependence of the pair state potentials by an external electric field. In summary, we now have a tool to coherently tune interactions between Rydberg atoms. In further studies Rydberg atoms could be used as a model system to simulate energy transfer processes in bio-molecules.

Q 37.7 Thu 12:00 V7.03

Collective and quasiparticle excitations in 2D dipolar gases — •Alexey Filinov und Michael Bonitz — Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität, Leibnizstr. 15, D-24098 Kiel, Germany

The Berezinskii-Kosterlitz-Thouless transition in dipolar atomic, molecular and indirect exciton systems has been recently studied by path integral Monte Carlo simulations [1,2]. Here, we complement these analyses by the spectral densities of the longitudinal collective and single particle (SP) excitations by computing the dynamic structure factor, $S(q,\omega)$, and the SP spectral function, $A(q,\omega)$, across the superfluid to normal fluid transition. The SP spectrum has been worked out by evaluation of the one-particle Matsubara Green's function together with a stochastic optimization method for the reconstruction of $A(q,\omega)$ from imaginary times. We discuss the coupling of both spectra in the *superfluid phase*. We observe sharp resonances due to the quasi-condensate. The excitations in the normal phase are shifted to higher energies and significantly damped beyond the acoustic branch. Our results generalize previous zero-temperature analyses based on variational many-body wavefunctions [2,3]. The underlying physics of excitations and the role of the condensate is not easily extracted from such calculations. Moreover, at finite temperatures the use of the variational approach becomes problematic as the excitation damping becomes significant.

[1] A. Filinov et al., PRL 105, 070401(2010); [2] J. Böning et al., PRB 84, 075130(2011); [3] F. Mazzanti et al., PRL 102, 110405(2009); [4] D. Hufnagl et al., PRL 107, 065303(2011)

Q 37.8 Thu 12:15 V7.03

Crystallization of Rydberg excitations in continuously driven atomic ensembles — •David Petrosyan[1,2] and Michael Fleischhauer[1] — [1]Fachbereich Physik, Technische Universitaet Kaiserslautern, D-67663 Kaiserslautern — [2]Institute of Electronic Structure and Laser, FORTH, GR-71110 Heraklion, Crete, Greece

We study resonant optical excitations of dense atomic ensembles to the strongly interacting Rydberg states. We show that in the steady state of strong continuous driving the correlations of Rydberg excitation probabilities exhibit damped spatial oscillations reminiscent of the density waves of a finite temperature Luttinger-liquid with Luttinger parameter $K << 1/2$. For very strong driving, the period of the spatial oscillations saturates to a value corresponding to one collective Rydberg excitation (superatom) per blockade distance. After sudden switching off of the coupling lasers, the Rydberg quasi-crystal can survive for tens or hundreds of microseconds, it can be detected in situ by spatially-resolved Rydberg state ionization or adiabatically converted into a train of single-photon pulses.

Q 37.9 Thu 12:30 V7.03

Nonlocal Nonlinear Optics in cold Rydberg Gases — •Sevilay Sevinçli[1,2], Nils Henkel[1], Cenap Ates[1], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden,Germany — [2]Department of Physics and Astronomy, Aarhus University, 8000 Aarhus C, Denmark

Electromagnetically induced transparency (EIT) provides remarkable possibilities for nonlinear optics by enabling ultraslow group velocities and storage of light. The combination of EIT and interacting Rydberg gases has recently attracted considerable theoretical and experimental interest, as it holds promise for realizing extremely large nonlinearities by exploiting the exaggerated interactions between Rydberg atoms.

We present an analytical theory of the nonlinear response of cold Rydberg gases. This yields simple expressions for the third order susceptibilities which are in excellent agreement with recent measurements. It is further found that the nonlinear susceptibility is not only drastically enhanced but also highly nonlocal in nature, corresponding to long-range photon-photon interactions. Considering the propagation of light in such a Rydberg-EIT medium, this gives rise to a wealth of nonlinear wave phenomena, including soliton formation or modulation instabilities of strongly interacting light fields.

Q 37.10 Thu 12:45 V7.03

Collective interactions in Rydberg-dressed Bose-Einstein condensates — •Nils Henkel and Thomas Pohl — Max Planck Institute for the Physics of Complex Systems, Dresden

We investigate a Bose-Einstein condensate where atoms are dressed to high Rydberg states with strong van der Waals interactions. Solving exactly the internal many-body state dynamics, we show that this leads to effective ground state interactions with genuine many-body character. In the limit of large laser detunings, two-body interactions dominate [1,2] while many-body interactions become relevant in the strong-driving limit, i.e. in the limit of large laser intensities or weak detunings. We study the effects of these higher order interactions and show that nonlocal phenomena found for binary interactions are still also observable in the presence of strong collective, i.e. genuine many-body, interactions.

[1] N. Henkel, R. Nath and T. Pohl, Phys. Rev. Lett. **104** 195302
[2] F. Maucher et al., Phys. Rev. Lett. **106** 170401