Q 71: Ultracold Plasmas and Rydberg Systems III (with A)

Time: Friday 11:00–12:45 Location: P/H2

Q 71.1 Fri 11:00 P/H2

Coherent manipulation of a superatom — •Johannes Zeiher[1], Peter Schauss[1], Sebastian Hild[1], Jae-yoon Choi[1], Tommaso Macri[1,2], Immanuel Bloch[1,3], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]QSTAR, Largo Enrico Fermi 2, 50125 Firenze, Italy — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Rydberg atoms offer the possibility to engineer long range interacting systems of ultracold atoms due to their strong van der Waals interactions. This can be harnessed to generate entangled states of many particles, which are of interest for metrology and quantum information applications. In our experiment, we start from a 2d Mott insulator of ground state atoms of rubidium-87. Using our recently developed single site addressing technique, we spatially control their shape and prepare samples with sub-shot noise atom number fluctuations. We optically excite Rydberg atoms and detect them in our optical lattice with submicron resolution. When the interaction energy becomes larger than the optical coupling bandwidth, the system is fully Rydberg blockaded and described as an effective two-level system, frequently called "superatom". We confirm the predicted collective $\sqrt{N}$ scaling of the optical coupling with the number of atoms from a single up to 180 particles. Furthermore, we demonstrate coherent manipulation of the superatom by performing Ramsey spectroscopy. We explore physics beyond the superatom description by detecting doubly excited states when the system size is on the order of the blockade radius.

Q 71.2 Fri 11:15 P/H2

Mesoscopic Rydberg-blockaded ensembles in the superatom regime and beyond — Tobias M. Weber, Michael Höning, Thomas Niederprüm, Torsten Manthey, •Oliver Thomas, Vera Guarrera, Michael Fleischhauer, Giovanni Barontini, and Herwig Ott — TU Kaiserslautern, Kaiserslautern, Germany

In recent years great progress has been made in understanding the collective behaviour introduced by Rydberg excitations in ultra cold gases. Because of their strong van der Waals interaction it is not possible to excite two Rydberg atoms resonantly within a blockade volume defined by the interaction strength and the excitation bandwidth. In dense atomic clouds hundreds of ground state atoms can be found within this volume, forming a so-called superatom. These strongly correlated ensembles show an increased excitation probability, described by an effective two-level system. Here we report on the controlled creation and characterization of an isolated mesoscopic superatom by means of accurate density engineering and excitation to Rydberg p-states [1]. Its variable size allows us to investigate the transition from a strongly confined effective two-level to an extended many-body system. By monitoring continuous laser-induced ionization we are able to determine the $g^2(\tau)$ correlation function and observe the expected anti bunching effect for resonant excitation, as well as bunching for off resonant coupling. The observed amplitudes and timescales can be described with an effective rate-equation model.

[1]: T. M. Weber et al, Creation, excitation and ionization of a mesoscopic superatom. arXiv:1407.3611

Q 71.3 Fri 11:30 P/H2

Excitation Energy Transfer in Ultra-Cold Rydberg Gase — •Torsten Scholak[1,2], Thomas Wellens[2], and Andreas Buchleitner[2,3] — [1]Department of Chemistry, University of Toronto, Toronto, Canada M5S 3H6 — [2]Physikalisches Institut der Albert-Ludwigs-Universität, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany — [3]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität, Albertstr. 19, D-79104 Freiburg, Germany

Ultra-cold gases of Rydberg atoms are one of the few many-body systems with tunable long-range interactions. This feature, along with their exceptional static and dynamic properties, as well as their versatility, has propelled them into the limelight. Now, with the advent of novel imaging methods capable of non-destructive monitoring of Rydberg excitations, Rydberg gases become an ideal testbed and a proving ground for theories of energy transport in complex systems, in particular, frustrated spin glasses, nitrogen-vacancy centers, and photosynthetic light-harvesting complexes. In this talk, we reveal how the nature of excitation energy transfer (EET) in the gas can be controlled via the dipole blockade effect [1]. For weak blockade, we predict transient localization of EET on small clusters of two or more atoms. For stronger blockade, EET will be significantly faster, because the excitations are efficiently migrated by delocalized states. We present our analysis of the ensemble-averaged mean-square displacement $\overline{\langle[\boldsymbol{r}(t)-\boldsymbol{r}(0)]^2\rangle}$ and a thorough study of the spatial distribution of the system's eigenstates.

[1] T. Scholak, T. Wellens, and A. Buchleitner, Phys. Rev. A , in press (2014), arXiv:1409.5625.

Q 71.4 Fri 11:45 P/H2

Resonant Rydberg dressing of two-electron atoms — •Christopher Gaul and Thomas Pohl — Max-Planck-Institut für Physik Komplexer Systeme, Nöthnitzer Str. 38, D-01187 Dresden

We study the emergence of effective atomic interactions from resonant laser excitation to high-lying, strongly interacting Rydberg states. Specifically, we consider two-electron atoms which permit two-photon coupling via a long-lived intermediate triplet state. Exploiting the formation of a dark state on resonance, we demonstrate that losses due to spontaneous decay can be greatly suppressed in this system. At the same time, the correlated Rydberg-excitation dynamics gives rise to significant effective interactions between two driven atoms.

Studying the resulting correlated steady state, we identify a two-body resonance, where induced light shifts balance with the Rydberg interaction and the laser detuning. Under strong driving, this resonance is shown to enable greatly enhanced effective interactions while keeping the corresponding decoherence rates at a very low level.

Compared to previous two-level schemes this new approach is found to yield much stronger interactions and shown to permit flexible tunability of the magnitude as well as the shape of the effective interaction potential. Potential applications will also be discussed.

Q 71.5 Fri 12:00 P/H2

Rydberg-Electron Assisted Molecule Formation in Ultracold Atomic Clouds — •Thomas Niederprüm, Torsten Manthey, Oliver Thomas, Tobias Weber, and Herwig Ott — Technische Universität, Kaiserslautern

The continuously improving level of experimental control allows for the realization of excitations to increasingly high principle quantum numbers inside of cold atomic clouds. As the size of a Rydberg atom as well as it's lifetime increases with the principal quantum number, it eventually enters a regime where it is likely to interact with the thermal ground state atoms surrounding it. At large distances this interaction is dominated by the scattering of the Rydberg electron with the ground state atom. At small internuclear separations however the 1/r4 - interaction between the ionic core of the Rydberg atom and the ground state atom is the leading contribution. The combined potential efficiently transports ground state atoms entering the Rydberg electrons wavefunction towards the ionic core. Approaching each other the ionic core and the ground state atom can undergo resonant dipole energy exchange and form an ionic Rb_2^+ molecule while the Rydberg electron gains the binding energy of the molecule and escapes. We report on the creation of such molecular ions in dense thermal clouds of ^{87}Rb under excitation to Rydberg p-States. Furthermore a systematic study on the density dependence of the molecule production for various principal quantum numbers enables us to obtain the effective cross section for the molecule formation process as well as it's scaling behavior.

Q 71.6 Fri 12:15 P/H2

Towards deterministic single-photon source via four-wave mixing in a thermal microcell — •Yi-Hsin Chen, Fabian Ripka, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Germany

Single-photon sources are the keys for photonic-based quantum security communication and information processing. One promising candidate to realize the deterministic single-photon source is based on the combination of four-wave-mixing (FWM) and Rydberg blockade effect. We propose that a single-photon source can be generated in a thermal vapor confined in a cell with micrometer scale, which is so-called microcell [1]. Similar to the studies of coherent Rydberg dynamics on nanosecond timescales [2] and van-der Waals interatomic interac-

tion [3] in three-level system, we implement a pulsed FWM scheme to observe both coherent dynamics and effects of dephasing due to Rydberg-Rydberg interaction [4]. Furthermore, we investigate the effects of the excitation volume by reducing the volume to below the Rydberg interaction range (few micrometers). We discuss prospects for the generation of non-classical light.

[1] M. M. Müller et al., PRA 87, 053412 (2013)
[2] Huber et al., PRL 107, 243001 (2011)
[3] Baluktsian et al., PRL 110, 123001 (2013)
[4] Huber et al., PRA 90, 053806 (2014)

Q 71.7 Fri 12:30 P/H2

Taking trapped strontium ions to a higher level — •Gerard Higgins[1], Fabian Pokorny[1], Christine Maier[2], Johannes Haag[1], Florian Kress[1], Yves Colombe[1], and Markus Hennrich[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria

Trapped Rydberg ions are a novel approach to quantum information processing [1]. By combining the high degree of control of trapped ion systems with long-range dipolar interactions of Rydberg ions [2], fast entanglement gates $\sim 1\mu$s may be realised in large ion crystals [3].

We are working towards exciting strontium ions, trapped in a linear Paul trap, to Rydberg states $26<n<60$ using a two-photon excitation scheme with 243nm and 304-309nm laser light.

We report on excitation using the UV lasers into higher levels, such as the intermediate state ($6P_{1/2}$) with 243nm laser light. We also present the overlapping of both Rydberg-excitation laser beams using a hydrogen-loaded photonic crystal fiber [4] and the focussing of both beams down to $\sim 10\mu$m onto trapped ions.

[1] M. Müller, et al., New J. Phys. **10**, 093009 (2008)
[2] D. Jaksch, et al., Phys. Rev. Lett. **85**, 2208 (2000)
[3] F. Schmidt-Kaler, et al., New J. Phys. **13**, 075014 (2011)
[4] Y. Colombe, et al., Opt. Express, **22**, 19783 (2014)