Q 24: Ultracold plasmas and Rydberg systems II (with A)

Time: Tuesday 14:30–16:30 Location: f303

Q 24.1 Tue 14:30 f303

Dynamically probing ultracold lattice gases via Rydberg molecules — •Oliver Thomas[1,2], Torsten Manthey[1], Thomas Niederprüm[1], Tanita Eichert[1], Philipp Geppert[1], and Herwig Ott[1] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

Rydberg Molecules have been an ongoing field of interest since their first theoretical prediction and experimental realization in ultra cold gases nearly 7 years ago. Since then great progress, theoretically and experimentally, has been made in understanding these exotic states, in which one or more ground state atoms are bound in the electronic wave function of an highly excited Rydberg state by a Fermi contact type interaction.

We show that the excitation of long-range Rydberg molecules can be used to probe position- and time-sensitive the occupation of sites in an ultra-cold many body system, by using the natural decay of the excited molecular state into an ion as a continuous probe. We use this technique to dynamically probe the occupation in a many body quantum system when crossing the superfluid to Mott insulator transition. With the technique of scanning electron microscopy, we also show the position sensitiveness of the used scheme, depleting only atoms located in the inner region of the prepared many body system.

Q 24.2 Tue 14:45 f303

Pumping squeezed states of a micro-mechanical oscillator with Rydberg atoms. — •Robin Stevenson[1], Jiri Minar[1], Sebastian Hofferberth[2], and Igor Lesanovsky[1] — [1]School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, United Kingdom — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

We investigate a system comprising of a stream of Rydberg atoms passing close by a micro-mechanical oscillator. We show in the situation where the atomic transition is resonant with a single-phonon transition of the oscillator, this system is equivalent to a micromaser, realised for example by atoms passing one by one through a cavity. This in principle allows the observation of a lasing transition and the creation of coherent states.

Furthermore, we demonstrate that when the atoms are on resonance with a two-phonon transition of the oscillator we can generate nonclassical states in the oscillator. In the small interaction limit, the oscillator is driven towards coherent superpositions of coherent states with opposite sign. In the presence of thermal coupling the oscillator is driven towards squeezed states that can have variance lower than the vacuum state. Finally, we discuss experimental parameters and explore whether the non-classical states discussed here are achievable with current technology.

Q 24.3 Tue 15:00 f303

Optimal preparation of the crystalline states and the GHZ states on Rydberg many-body systems — •Jian Cui[1], Rick van Bijnen[2], Thomas Pohl[2], Simone Montangero[1], and Tommaso Calarco[1] — [1]Institute for Complex Quantum Systems, Ulm, Germany — [2]Max-Planck-Institute for the Physics of Complex Systems, Dresden, Germany

Rydberg atoms, characterized by their exaggerated strong and long-range interactions, serve as one of the most promising candidate platforms for quantum simulators. The finite lifetimes of Rydberg atoms set the duration limits within which experiments have to be performed. To identify the dynamics satisfying this lifetime condition based on the current experimental technologies in Rydberg many-body systems, however, turns out to be highly nontrivial. Presently, most methods in this regard rely on the adiabatic evolution, which is slow by definition. Here, we apply the methods from optimal control theory to solve this problem. Optimized control pulses for preparing the crystalline states and the GHZ states on the ultra-cold Rydberg atomic gases with much less time cost than the corresponding adiabatic schemes have been numerically identified. Besides the lifetimes, other realistic experimental constraints and imperfections including the lost of atoms, finite detuning and coupling strengths as well as the limited bandwidths of control pulses, among others, have been taken into account in deriving the results, so that they can be readily applied in real experiments.

Q 24.4 Tue 15:15 f303

Resolved quadrupole shifts of a single trapped Rydberg ion — •Gerard Higgins[1,2], Fabian Pokorny[1,2], Weibin Li[3], Christine Maier[2], Johannes Haag[2], Florian Kress[2], Quentin Bodart[1], Yves Colombe[2], Igor Lesanovsky[3], and Markus Hennrich[1,2] — [1]Stockholm University, Sweden — [2]Universität Innsbruck, Austria — [3]University of Nottingham, United Kingdom

Trapped Rydberg ions are a novel approach to quantum information processing, which joins the advanced quantum control of trapped ions with the strong dipolar interactions between Rydberg atoms [1-2]. The strong electric fields used for trapping Rydberg ions give rise to fundamental phenomena which are not usually observed in neutral Rydberg atom experiments. Here we present recent experimental results in which effects of the trap on a Rydberg ion were observed.

A single strontium ion was trapped in the center of the electric quadrupole field of a linear Paul trap and excited to Rydberg S- and D-states using two ultraviolet photons. The Rydberg ion was subjected to both the DC and the radio-frequency electric quadrupole fields of the trap as well as an applied magnetic field. The Rydberg states were split by the magnetic field due to the Zeeman effect, which explains the observed resonance structure of the excited Rydberg S-states. Rydberg D-states possess an electric quadrupole moment and couple to the gradients of the trapping fields, which has allowed effects of both the DC and RF trapping fields to be resolved in D-state resonances.

[1] M. Müller, et al., New J. Phys. **10**, 093009 (2008)
[2] T. Feldker, et al., Phys. Rev. Lett. **115**, 173001 (2015)

Q 24.5 Tue 15:30 f303

Rydberg-atom interfaces between photons and superconducting cavities — •Wildan Abdussalam, Daniel Viscor, and Thomas Pohl — Max Planck Institute for the Physics and Complex Systems, Dresden, Germany

Owing to their large polarisability Rydberg atoms hold promise for realising strong coupling between microwave photons and superconducting cavities. Yet, the very same property makes Rydberg states prone to surface noise which has thus far hampered efficient interfacing.

Here, we study the coupled dynamics of a single cavity photon and a strongly interacting ensemble of Rydberg atoms and show that available Rydberg-Rydberg atom interactions can be utilised to overcome this problem. Using realistic noise sources and accounting for additional decay of Rydberg states, we demonstrate that collective photon coupling to interacting Rydberg ensembles provides a promising to noise-resistant quantum interfaces.

Q 24.6 Tue 15:45 f303

Quantum state tomography of a nano-mechanical oscillator using Rydberg atoms — •Adrián Sanz Mora, Sebastian Wüster, and Jan-Michael Rost — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany

Rydberg atoms have proven to be an excellent tool to observe the quantum dynamical features of a microwave cavity mode[1]. Here we investigate their applicability to characterize instead the motional state of a nano-mechanical oscillator. Attaching a ferroelectric domain to the oscillator supplies it with a permanent electric dipole moment. Coupling between mechanical vibrations of such oscillator and a Rydberg transition dipole is thus enabled via an electric dipole-dipole interaction. Atomic Ramsey interference measurements of phase-shifts acquired by Rydberg atom-oscillator states in an off-resonance scenario provides a non-destructive detection of discrete mechanical quanta. Translations in phase space of the mechanical oscillator, required for its full tomographical reconstruction[2], are performed using the aforementioned coupling while the atoms are simultaneously driven by optical fields in an off-resonant Raman scenario. The Wigner function for a given initial motional state of the mechanical oscillator is recreated by applying several sequences of Ramsey measurements at many different sampling points in the phase space of the mechanical oscillator.

[1] S. Deléglise et al., *Nature* **455**, 510 (2008).
[2] M.R. Vanner et al., Ann. Phys. **527**, 15 (2014).

Q 24.7 Tue 16:00 f303

Decoherence dynamics in a single photon switch — •Callum Murray[1], Alexey Gorshkov[2], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]University of Maryland, Maryland, USA

In this talk, we will discuss the decoherence processes affecting the performance of a dissipative single photon switch. A device of this kind uses a single gate photon to block the transmission of many other target photons via conditional absorption, and has recently been demonstrated in a Rydberg EIT medium. However, the decoherence processes affecting the gate photon in this case are still not very well understood. In this talk, a complete characterisation of this decoherence will be presented along with the impact this has on the maximum achievable switch fidelity.

Q 24.8 Tue 16:15 f303

Experimental demonstration of Rydberg dressing in a many-body system — •Johannes Zeiher[1], Peter Schauss[1], Sebastian Hild[1], Antonio Rubio Abadal[1], Jae-Yoon Choi[1], Rick van Bijnen[2], Thomas Pohl[2], Immanuel Bloch[1,3], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Rydberg atoms offer the possibility to study long range interacting systems of ultracold atoms due to their strong van der Waals interactions. Admixture of a Rydberg state to a ground state, known as Rydberg dressing, allows for greatly increased experimental tunability of these interactions.Here we report on our results of the realization of Rydberg dressing in a many-body spin system. Starting from a two-dimensional spin-polarized Mott insulator state of rubidium-87, we optically couple one spin component to a Rydberg p-state on a single photon ultra-violet transition at 297 nm. Using Ramsey interferometry in the ground state manifold, we measure the spin-spin correlations induced by the long range interactions. To show the predicted versatility of Rydberg dressing, we realize an increased interaction range by selecting a different Rydberg state and experimentally study anisotropic interactions by tilting the quantization axis.