Q 4: Rydberg Atoms, Ions, and Molecules (joint session Q/MO)

Time: Monday 11:00–12:45 Location: HS I

Q 4.1 Mon 11:00 HS I

Interfacing Rydberg atoms with an GHz electromechanical oscillator — •Julia Gamper, Cedric Wind, Valerie Mauth, Samuel Germer, Wolfgang Alt, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

Rydberg atoms exhibit strong electric dipole transitions over a large range of the electromagnetic spectrum which make them interesting for hybrid quantum systems bridging vastly different frequency regimes.

In this talk, I will present our approach to interfacing optically controlled Rydberg atoms with an electromechanical oscillator for cooling one of the vibrational modes of the oscillator to its quantum mechanical ground state by exchange of microwave photons with the atoms.

I will discuss the design of this hybrid system and present our progress on the construction. Our system consists of a 3D magneto-optical trap for loading rubidium atoms which are subsequently magnetically transported to the experimental region which is at cryogenic temperatures of 4K and includes a vibration-isolation system that reduces vibrations below 25nm.

As a first step towards our envisioned hybrid system, we plan to trap the rubidium atoms with a superconducting wire trap on a chip with an integrated microwave resonator to drive microwave transitions of the Rydberg atoms close to the cryogenic surface.

Q 4.2 Mon 11:15 HS I

Magic wavelength traps for collective Rydberg excitations — •Daniil Svirskiy[1], Lukas Ahlheit[1], Chris Nill[2], Jan de Haan[1], Nina Stiesdal[1], Wolfgang Alt[1], Igor Lesanovsky[2], and Sebastian Hofferberth[1] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Institute of Theoretical Physics, University of Tübingen, Germany

Storage of optical photons as collective excitation in an ultracold atomic medium is one of the possible candidates for the realization of a quantum memory. However, photon storage times are limited by various decoherence mechanisms, including thermal atomic motion and inhomogeneous differential light shifts between atoms sharing the excitation. The latter can be suppressed by magic trapping, which equalizes the AC Stark shifts for the ground and excited levels of the atom.

In this talk, I present our implementation of a magic trap for ultracold Rydberg atoms. We conduct photon storage and retrieval measurements for two different trapping geometries: a magic lattice and a running wave trap with different trap wavelengths. Our experiments demonstrate that both the longitudinal standing wave and the radial trap shape impact the magic condition. This difference arises from the Rydberg electron wavefunction extending over a significant region of the trap potential and contributing a ponderomotive part to the trap potential. We investigate how this part scales with principle quantum number n and determine the optimal magic lattice wavelength for each Rydberg state.

Q 4.3 Mon 11:30 HS I

Avoided-Crossing Rydberg Facilitation with Phonon Coupling in 1D Lattices — •Daniel Brady and Michael Fleischhauer — RPTU Kaiserslautern, Kaiserslautern, Germany

Rydberg anti-blockade (facilitation) offers one of the most promising mechanisms for realizing robust neutral-atom quantum gates. However, concomitant with the strong dipolar interactions between Rydberg atoms (spins) are mechanical forces coupling Rydberg atoms to high motional states (phonons) in their respective tweezer traps. This has so far kept experimental realizations of quantum gates with facilitation out of reach. Recently, Rydberg excitations have been created by coupling to an avoided-crossing potential in an experimental setting. This approximately harmonic potential alters the nature of the spin-phonon coupling and therefore might offer a method of realizing quantum gates.

For a chain of atoms trapped in tweezer arrays under the facilitation constraint, we numerically simulate the dynamics of the spin-phonon coupling. In particular we investigate how the motional degrees of freedom affect the spreading dynamics of Rydberg excitations.

Q 4.4 Mon 11:45 HS I

Electronically Excited Cold Rydberg Ion Crystals — •Marion Mallweger[1], Natalia Kuk[1], Harry Parke[1], Ivo Straka[1], Robin Thomm[1], Vinay Shankar[1], Weibin Li[3], Igor Lesanovsky[2,3], and Markus Hennrich[1] — [1]Stockholm University, Stockholm, Sweden — [2]Institut für Theoretische Physik, Universität Tübingen, Germany — [3]School of Physics and Astronomy, University of Nottingham, United Kingdom

Trapped Rydberg ions harness two advantages: a well defined confinement through the charge of the ion and strong interactions through its large principle quantum number. In the experiments presented here a trapped strontium ion was excited from the metastable 4D to Rydberg states. While for the ground state of the ion, the polarizability is negligible, for Rydberg ions it increases as $\sim n^7$. Thus, the high polarizability of the Rydberg state with respect to the ground state leads to a change in radial confinement during the Rydberg excitation. For an ion crystal, this change can be enough to cause a structural phase transition from a linear configuration in the lower-lying electronic states to a zigzag configuration in the Rydberg state. We explore and characterize this electronic state dependent structural phase transition. We investigate this effect via spectroscopy scans of the Rydberg resonance with varying radial confinement close to the transition point of the zigzag crystal configuration. By tuning the polarizability, the change in radial trap confinement and therefore the transition point can be tuned. This enables a novel method for studying molecular phenomena with ions in the well-isolated environment of a Paul trap.

Q 4.5 Mon 12:00 HS I

Ultralong-Range Ytterbium Rydberg Molecules — •Tangi Legrand, Florian Pausewang, Xin Wang, Ludwig Müller, Eduardo Uruñuela, Wolfgang Alt, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

An ultralong-range Rydberg molecule forms through the interaction between a ground-state atom and the electron of a highly excited Rydberg atom, leading to molecular states characterized by extreme spatial extension, large dipole moments and long lifetimes.

In this work, we present the spectroscopic characterization of such molecules in a dense and ultracold ytterbium (Yb) gas. Using two-photon excitation, we probe the molecular binding energies and map out the vibrational spectra. By applying low-energy quantum scattering techniques to the observed binding energies, we can extract the electron-neutral atom s-wave scattering length. Our data enables precise benchmarking of Yb model wavefunctions derived from multichannel quantum defect theory, offering a robust validation for the accuracy of theoretical descriptions of Rydberg (molecular) states.

We also present our apparatus featuring a two-chamber compact design comprising a dispenser-loaded 2D MOT and a two-color 3D MOT allowing narrow-linewidth cooling. After loading into an optical trap, we reach $T < 10\,\mu$K at atomic densities of $10^{13}\,\mathrm{cm}^{-3}$. By consecutive evaporation we reach $T \approx 200\,$nK. Electrodes around the atomic cloud allow electric field background compensation, field ionization of Rydberg atoms and molecules, and their delivery to a microchannel plate.

Q 4.6 Mon 12:15 HS I

Roughening dynamics of quantum interfaces — Wladislaw Krinitsin[1,2], •Niklas Tausendpfund[1,3], Matteo Rizzi[1,3], Markus Heyl[4], and Markus Schmitt[1,2] — [1]Institute of Quantum Control (PGI-8), Forschungszentrum Jülich, Jülich, Germany — [2]Faculty of Informatics and Data Science, University of Regensburg, Regensburg, Germany — [3]Institute for Theoretical Physics, University of Cologne, Köln, Germany — [4]Center for Electronic Correlations and Magnetism, University of Augsburg, Augsburg, Germany

The roughening transition, known from three-dimensional classical spin systems, describes how fluctuations of interfaces transition from being bounded to being extensive when crossing the characteristic roughening temperature. We explore signatures of such phenomena in the dynamics of domain walls in the two dimensional quantum Ising model, where we observe pre-thermal steady states in their evolution well beyond the perturbative limit using Tree Tensor Networks. We formulate an effective model of the interface, which captures qualitative features of a roughening transition. Most notably, it exhibits a Berezinskii Kosterlitz Thouless quantum phase transition from smooth to rough interfaces, whose signatures extend to finite temperatures.

These findings can be related to the observed slow thermalization in the full model, opening the way to a better understanding of prethermalization effects in interface dynamics, which can be easily implemented and tested in experimental setups such as Rydberg atom experiments.

Q 4.7 Mon 12:30 HS I

Control thermalization in one dimensional Floquet driven Rydberg atom chain — •Weibin Li[1], Yunhui He[2], and Jianming Zhao[2] — [1]University of Nottingham, Nottingham, UK — [2]Shanxi University, Taiyuan, China

We study Floquet thermalization of a one dimensional disorder-free Rydberg atom chain. The stroboscopic dynamics of the finite Rydberg atom chain is numerically solved. We show that the Floquet thermalization results from the emergence of an effective multi-body interaction across the atom chain. We characterize the properties of the thermalization using level spacing statistics and entanglement entropy. The dependence of the Floquet thermalization on the driving period and laser detuning is examined. The scaling with the system size and dependence on the initial state are explored. Our results can be readily observed in the current Rydberg atom array experiments.