A 26: Ultra-cold plasmas and Rydberg systems (joint session A/Q)

Time: Thursday 14:00–15:45 Location: A-H1

A 26.1 Thu 14:00 A-H1

Ion-Rydberg interactions observed by a high-resolution ion microscope — •Moritz Berngruber, Nicolas Zuber, Viraatt Anasuri, Yiquan Zou, Florian Meinert, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Center for Integrated Quantum Science and Technology (IQST)

In this talk, we present the latest experimental results on spatially resolved ion-Rydberg-atom interaction studied with our high-resolution ion microscope. The apparatus provides a highly tunable magnification, ranging from 200 to over 1500, a spatial resolution better than 200 nm and a depth of field of more than 70 μm. These properties and the excellent electric field compensation enable the observation of ion-Rydberg-interaction in cold bulk quantum gases. The direct spatial imaging method allows for in-situ images of a new type of long-range Rydberg-atom-ion molecule in rubidium, which arises from a binding mechanism that is based on the interaction between the ionic charge and a flipping induced dipole of a Rydberg atom [1].
In addition, the ion microscope also allows for spectroscopic studies of the vibrational level structure. Moreover, the good temporal resolution of the detector enables the observation of dynamic phenomena during the interaction process which compared to traditional molecules are slowed down by many orders of magnitude.

[1] Zuber, N., et al. "Spatial imaging of a novel type of molecular ions." arXiv preprint arXiv:2111.02680 (2021).

A 26.2 Thu 14:15 A-H1

Chiral Rydberg States of Laser Cooled Atoms — •Stefan Aull[1], Steffen Giesen[2], Markus Debatin[1], Peter Zahariev[1,3], Robert Berger[2], and Kilian Singer[1] — [1]Institut für Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel — [2]Fb. 15 - Chemie, Hans-Meerwein-Straße 4, 35032 Marburg — [3]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

We propose a protocol for the preparation of chiral Rydberg states. It has been shown theoretically that using a suitable superposition of hydrogen wavefunctions, it is possible to construct an electron density and probability current distribution that has chiral nature. Following a well established procedure for circular Rydberg state generation and subsequent manipulation with taylored radio frequency pulses under the influence of a magnetic field, the necessary superposition with correspondingly set phases can be prepared. Enantio-selective excitation using photo-ionization circular dichroism is under theoretical and experimental development.

A 26.3 Thu 14:30 A-H1

Coherent delocalization in a frozen Rydberg gas — •Matthew Eiles, Ghassan Abumwis, Christopher Wächtler, and Alexander Eisfeld — Max Planck Institut für Physik komplexer Systeme, Nöthnitzer Str. 38 01187 Dresden

The long-range dipole-dipole interaction can create delocalized states due to the exchange of excitation between Rydberg atoms. We show that even in a random gas many of the single-exciton eigenstates are surprisingly delocalized, composed of roughly one quarter of the participating atoms. We identify two different types of eigenstates, one which stems from strongly-interacting clusters and one which extends over large delocalized networks, and show how to excite and distinguish them via appropriately tuned microwave pulses. The extent of delocalization can be enhanced by degeneracies in the atomic states which be controllably lifted using the Zeeman splitting provided by a magnetic field.

A 26.4 Thu 14:45 A-H1

From Highly Charged to Neutral Microplasma — •Mario Grossmann, Julian Fiedler, Jette Heyer, Markus Drescher, Klaus Sengstock, Philipp Wessels-Staarmann, and Juliette Simonet — The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg

By combining an ultracold quantum gas of ^{87}Rb with strong-field ionization in femtosecond laser pulses, we investigate the dynamics of highly charged to neutral microplasmas.
Our experimental setup enables us to detect ions and electrons separately and resolve their kinetic energies.
We locally ionize an ultracold target with densities of up to $10^{20}\mathrm{m}^{-3}$ within a micrometer sized focus. This allows creating initially strongly coupled plasmas with ion temperatures below 40 mK and a few hundred to thousand charged particles.
The excess energy of the electrons can be tuned via the wavelength of the ionizing laser pulse resulting in initial electron temperatures from 5800 K to 65 K. This directly impacts the neutrality of the plasma:
High excess energies yield a highly charged plasma with rapid electron cooling whereas low excess energies trigger a neutral plasma with greatly increased lifetimes. Below the ionization threshold we observe ultrafast excitation of Rydberg states.
The small number of particles permits us to compare our results to molecular dynamics simulations that grant access to the non-equilibrium plasma dynamics on picosecond timescales.

A 26.5 Thu 15:00 A-H1

Non-equilibrium Spin Dynamics using the Discrete Truncated Wigner Approximation — •Neethu Abraham[1,2] and Sebastian Wüster[1] — [1]Department of Physics, Indian Institute of Science Education and Research, Bhopal, Madhya Pradesh 462 066, India — [2]Department of Physics, Indian Institute of Science Education and Research, Tirupati, Andhra Pradesh 517 507, India

Approximate simulation methods play a crucial role in the efficient numerical computation of quantum dynamics in many body spin systems, since the exponentially increasing dimension of their Hilbert space cannot be treated exactly. We have investigated the realm of applicability of a very recently developed phase space method, based on the Monte Carlo sampling of the discrete Wigner function: the discrete truncated Wigner approximation (DTWA). Using the DTWA, we show that an aggregate of Rydberg atoms immersed in a background of detector atoms can serve as a quantum simulating platform for various many body physics problems. Decoherence in the excitation transport induced by the interactions with the background atoms can be controlled by altering the distance between the aggregate and detector atoms. This may allow for an experimental platform to examine energy transport subject to an environment.

We were also able to look at quench dynamics in condensed matter spin systems using essentially the same techniques due to the mathematical similarities between the Hamiltonians of these two systems. We explore the possible supremacy of DTWA over other methods, such as tDMRG, for the study of Domain Wall melting in a 2D spin lattice.

A 26.6 Thu 15:15 A-H1

Quantum simulations with circular Rydberg atoms — •Christian Hölzl, Aaron Götzelmann, Alexander Buhl, Achim Scholz, Moritz Wirth, and Florian Meinert — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, Germany

Highly excited low-l Rydberg atoms in configurable mircotrap arrays have recently proven highly versatile for studying quantum many-body spin systems with single particle control. I will report on the advances of a new project pursuing to harness high-l circular Rydberg atoms for quantum simulation. When stabilized against black body radiation (BBR) in a suitable cavity structure, circular Rydberg states promise orders of magnitude longer lifetimes compared to their low-l counterparts and thus provide an appealing potential to strongly boost coherence times in Rydberg-based interacting atom arrays. To maintain excellent high-NA optical access we exploit a novel approach using an indium tin oxide (ITO) capacitor, capable of surpressing the parasitic microwave BBR even in a non-cryogenic environment while beeing transparent to visible light.

A 26.7 Thu 15:30 A-H1

Phonon dressing of a facilitated one-dimensional Rydberg lattice gas — •Matteo Magoni, Paolo P. Mazza, and Igor Lesanovsky — Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We study the dynamics of a one-dimensional Rydberg lattice gas under facilitation conditions which implement a so-called kinetically constrained spin system. Here an atom can only be excited to a Rydberg state when one of its neighbours is already excited. Once two or more atoms are simultaneously excited mechanical forces emerge, which couple the internal electronic dynamics of this many-body system to the external vibrational degrees of freedom in the lattice. This electron-phonon coupling results in a so-called phonon dressing of many-body states which in turn impacts on the facilitation dynamics.

In our theoretical study we focus on a scenario in which all energy scales are sufficiently separated such that a perturbative treatment of the coupling between electronic and vibrational states is possible. This allows to analytically derive an effective Hamiltonian for the evolution of clusters of consecutive Rydberg excitations in the presence of phonon dressing [1]. We analyse the spectrum of this Hamiltonian and show, by employing Fano resonance theory, that the interaction between Rydberg excitations and lattice vibrations leads to the emergence of slowly decaying bound states that inhibit fast relaxation of certain initial states. We supplement our analysis by providing detailed experimental considerations on the validity of the approximations used.

[1] M. Magoni et al., arXiv: 2104.11160 (2021)