Q 36: Ultracold plasmas and Rydberg systems I (joint session Q/A)

Time: Wednesday 14:00–16:00 Location: f342

Q 36.1 Wed 14:00 f342

Free-space QED with Rydberg superatoms — •Nina Stiesdal, Hannes Busche, and Sebastian Hofferberth — University of Southern Denmark, Odense, Denmark

Rydberg quantum optics (RQO) allows to create strong optical nonlinearites at the level of individual photons by mapping the strong interactions between collective Rydberg excitations onto optical photons.

The strong interactions lead to a blockade effect such that an optical medium smaller than the blockaded volume only supports a single excitation creating a so-called Rydberg superatom. Due to the collective nature of the excitation, the superatom effectively represents a single emitter coupling strongly to few-photon probe fields with directional emission into the initial probe mode.

Here we discuss how we use Ryderg superatoms to study the dynamics of single two level systems strongly coupled to quantized propagating light fields, enabling e.g. the investigation of three-photon correlations mediated by a single quantum emitter.

We also show our experimental progress towards implementing a cascaded quantum system by interfacing multiple superatoms with a single probe mode.

Q 36.2 Wed 14:15 f342

Self-Induced Transparency in Room-Temperature Dense Rydberg Gases — •Zhengyang Bai[1,2], Weibin Li[1], and Guoxiang Huang[2] — [1]School of Physics and Astronomy, and Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham, NG7 2RD, UK — [2]State Key Laboratory of Precision Spectroscopy, East China Normal University, Shanghai 200062, China

Aggressively large Doppler effects is of the challenge to create static optical nonlinearities in atomic gases beyond ultracold temperatures. We show the creation of strong dispersive optical nonlinearities of nanosecond laser pulses in high number density atomic gases at room temperature. This is examined in a vapor cell setting where the laser light resonantly excites atoms to Rydberg P states through a single-photon transition. Using fast Rabi flopping and strong Rydberg atom interactions, both in the order of GHz, can overcome the Doppler effect as well as dephasing due to thermal collisions between Rydberg electrons and surrounding atoms. In this strong-driving regime both the light intensity and Rydberg interactions contribute to the generation of the optical nonlinearity. We show the emergence of a modified self-induced transparency (SIT) where the stable light propagation relies on the Rydberg interactions. We identify quantitatively that the SIT occurs at smaller (than 2π) pulse areas for higher Rydberg states. We furthermore demonstrate that a conditional optical phase gate can be implemented by harvesting strong Rydberg atom interactions and SIT.

Q 36.3 Wed 14:30 f342

Vanishing-polarizability states of trappd Rydberg ions — •Fabian Pokorny, Chi Zhang, Gerard Higgins, and Markus Hennrich — Department of Physics, Stockholm University, 10691 Stockholm, Sweden

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

Recently, we carried out a controlled-phase gate in a two-ion crystal with a gate time of 700ns and more than 70% entaglement fidelity [4]. In order to implement such a gate in large or even multidimensional ion crystals, Rydberg states with vanishing polarizability may be crucial to mitigate otherwise considerable line-broadening caused by phonon-dependent energy shifts of bare Rydberg states [4, 5]. Here we report the realization of microwave-dressed Rydberg states with vanishing polarizability. We observed negligible energy shifts even in presence of excess micro-motion and performed Rabi oscillations between low-lying electronic states and vanishing-polarizability Rydberg states with only Doppler cooling.

[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] C. Zhang, et al., arXiv:1908.11284 (2019)
[5] G. Higgins, et al., Phys. Rev. Lett. 123, 153602 (2019)

Q 36.4 Wed 14:45 f342

Strong spin-spin interactions and fast spin squeezing via Rydberg antiblockade dressing — •Weibin Li[1], Huaizhi Wu[1,2], and Shibiao Zheng[2] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, UK — [2]Fujian Key Laboratory of Quantum Information and Quantum Optics and Department of Physics, Fuzhou University, Fuzhou 350116, People's Republic of China

We propose an antiblockade Rydberg dressing (ARD) scheme with the atomic ground state optically dressed to two coupled Rydberg states. By tuning the laser frequency in proximity to the antiblockade resonance, we obtain an interaction potential where the Rydberg-dressed ground states experience weakly repulsive interactions at short distances, while undergo strongly attractive interaction at certain, larger distances. The dissipative dynamics of interacting atoms subjected to ARD can be effectively described by a dephasing process with both one-body and two-body losses. The ARD with significantly enhanced dressed interactions can be then applied for fast implementation of a spin-echo spin squeezing, and offers a new way for the study of complex collective dynamics and the simulation of many-body spin models.

Q 36.5 Wed 15:00 f342

Ultrafast electron cooling in an expanding ultracold plasma — •Tobias Kroker[1,2], Mario Neundorf[1,2], Klaus Sengstock[1,2], Markus Drescher[1,2], Philipp Wessels[1,2], and Juliette Simonet[1,2] — [1]Zentrum für Optische Quantentechnologien (ZOQ), Luruper Chaussee 149, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg

Local photoionization of a Bose-Einstein condensate with a femtosecond laser pulse provides access to an unprecedented regime of ultracold plasma. The accessible charge carrier density of $2{\cdot}10^{14}$ cm^{-3} enables the creation of micrometer-sized, strongly coupled plasma with an initial ion coupling parameter of $\Gamma = 4800$.

We create a tunable number of up to a few thousand charged particles by strong-field ionization of ^{87}Rb with an electron excess energy of 0.68 eV. Our dedicated experimental setup allows the measurement of the electronic kinetic energy distribution with meV resolution. We report on the direct observation of electron cooling from 5000 K to about 1 K in a few hundred nanoseconds.

The finite plasma size allows for charged particle tracing of the underlying plasma dynamics including mutual Coulomb coupling. The simulations are in excellent agreement with the measurements and provide access to the dynamics on sub-nanosecond timescales. We observe an ultrafast energy transfer of 50% of the excess energy from the electronic onto the ionic component within the first ten picoseconds.

Q 36.6 Wed 15:15 f342

Does a disordered Heisenberg spin system thermalize under explicit symmetry breaking? — •Titus Franz[1], Martin Gärttner[2], Adrien Signoles[3], Renato Ferracini Alves[1], André Salzinger[1], Annika Tebben[1], Sebastian Geier[1], David Grimshandl[1], Carlos Brandl[1], Clément Hainaut[1], Gerhard Zürn[1], and Matthias Weidemüller[1,4] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg — [3]Laboratoire Charles Fabry, Institut d'Optique Fraduate School, CNRS, Universite Paris-Saclay, 91127 Palaiseau cedex, France — [4]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

The far-from equilibrium dynamics of generic disordered systems is expected to show thermalization, but this process is yet not well understood and shows a rich phenomenology ranging from anomalously slow relaxation to the breakdown of thermalization. While this problem is notoriously difficult to study numerically, we can experimentally probe the relaxation dynamics in an isolated spin system realized by a frozen gas of Rydberg atoms. By breaking the symmetry of the Hamiltonian with an external field, we can identify characteristics of the long time magnetization, including a non-analytic behavior at zero field. These can be understood from mean field, perturbative, and spectral arguments. The emergence of these distinctive features allows to falsify whether the experiment satisfies Eigenstate Thermalization Hypothesis (ETH).

Q 36.7 Wed 15:30 f342

Quantum many-body dynamics of driven-dissipative Rydberg polaritons — •Tim Pistorius, Javad Kazemi, and Hendrik Weimer — Institut für theoretische Physik, Leibniz Universität Hannover, Deutschland

We study the propagation of Rydberg polaritons through an atomic medium in a one-dimensional optical lattice. We obtain an effective Hubbard model to describe the dark state polaritons under realistic assumptions. We analyse the driven-dissipative transport of polaritons through the system by considering a coherent drive on one side and by including the spontaneous emission of the metastable Rydberg state. Using a variational approch[1] to solve the many-body problem, we find strong antibunching of the outgoing photons despite the losses from the Rydberg state decay.

[1] H. Weimer, Phys. Rev. Lett. 114, 040402 (2015)

Q 36.8 Wed 15:45 f342

Distinguishability-induced quantum-to-classical transitions in many-body interference — •Christian Haen, Christoph Dittel, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Federal Republic of Germany

We study how partial particle distinguishability induces a transition from the quantum to the classical regime in interference scenarios of many, possibly interacting particles. By continuously tuning the particles' indistinguishability with respect to their internal degrees of freedom, we investigate the transition's statistical imprint – as revealed by interference visibilities [1] or the variance of on-site densities [2] – on the particles' dynamical evolution. Moreover, we assess the impact of a dynamical evolution of the internal degrees on the quantum-to-classical transition. Such internal dynamics may be induced by interactions with an environment and, thus, pave the way towards an open system theory of identical particles.

[1] C. Dittel, et al., arXiv, 1901.02810 (2019)
[2] T. Brünner, et al., *Phys. Rev. Lett.* **120**, 210401 (2018)