Q 7: Ultracold Plasmas and Rydberg Systems

Time: Monday 10:30–12:15 Location: S SR 211 Maschb.

Q 7.1 Mon 10:30 S SR 211 Maschb.

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

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons enables the realization of optical nonlinearities which can modify light on the level of individual photons. This approach forms the basis of a growing Rydberg quantum optics toolbox, which already contains photonic logic building-blocks such as single-photon sources, switches, transistors, and photonic two-qubit gates.

For an optical medium smaller than a single Rydberg blockade volume, a large number of individual atoms behave as a single Rydberg "superatom" which can be efficiently coupled to few-photon probe pulses. The strongly enhanced collective coupling and the highly directed collective emission of this system realizes an analogue to waveguide-QED systems, which enables the study of coherent emitter-photon interaction in free-space [1]. In this talk, we present our recent investigation of intrinsic three-photon correlations mediated by a single superatom [2]. We also present our steps towards the formation of multiple superatoms coupled to a single probe-mode to realize a cascaded system of quantum emitters.

[1] A. Paris-Mandoki et al., Phys. Rev. X 7, 41010 (2017)
[2] N. Stiesdal et al., Phys. Rev. Lett. 121, 103601 (2018)

Q 7.2 Mon 10:45 S SR 211 Maschb.

Multi-photon correlations by interaction with collective Rydberg clouds — •Kevin Kleinbeck and Hans Peter Büchler — University of Stuttgart, Institute for theoretical Physics 3, Stuttgart

Exploiting the Rydberg blockade mechanism, a cold atomic cloud turns into a single effective emitter with collectively enhanced coupling to a focused photonic mode. Verified by experimental results, we give a model Hamiltonian and show that these "Rydberg superatoms" can imprint multi-particle correlations onto initially uncorrelated photons. Especially, we discuss the underlying mechanism for two-photon correlations and show the existence of three-photon correlations even in the connected part of the three-body correlation function.

Q 7.3 Mon 11:00 S SR 211 Maschb.

Experimental Observation of a Resonantly Enhanced Optical Nonlinearity in a Rydberg Gas — •Annika Tebben[1], Clément Hainaut[1], Valentin Walther[2], Yongchang Zhang[2], André Salzinger[1], Renato Ferracini Alves[1], Nithiwadee Thaicharoen[1], Gerhard Zürn[1], Thomas Pohl[2], and Matthias Weidemüller[1,3] — [1]Physikalisches Institut, Ruprecht-Karls Universität Heidelberg, Im Neuenheimer Feld 226, 69129 Heidelberg, Germany — [2]Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK 8000 Aarhus C, Denmark — [3]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

Large optical nonlinearities can be reached by coupling light to a strongly interacting Rydberg gas under conditions of electromagnetically induced transparency (EIT). For understanding the nonlinear, nonlocal response in such a medium, investigating the crossover from a non-interacting to an interacting Rydberg gas in the regime of low optical depth per blockade radius is crucial. In this work, we theoretically develop and experimentally observe the existence of a resonant enhancement of the nonlinear response in this regime. The effect can be modelled only if the intermediate state of the atomic three-level system, which is typically adiabatically eliminated, is explicitly included in the theoretical description. We report on the experimental investigation of this resonance effect and its implications on the absorption and refraction of the propagating probe field.

Q 7.4 Mon 11:15 S SR 211 Maschb.

New ultracold Ytterbium experiment for Rydberg quantum optics — •Philipp Lunt, Aksel Nielsen, Mohammad Noaman, Simon Ball, and Sebastian Hofferberth — University of Southern Denmark, Odense, Denmark

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons enables the realization of optical nonlinearities which can modify light on the level of individual photons.

Here, we present our new experiment to study the interactions between a large number of photons converted into Rydberg polaritons simultaneously propagating through a medium with extremely high atomic density. It is proposed to achieve this aim by exploiting the properties of Ytterbium, an alkaline-earth-like element. In a nutshell, these properties consist of an ultraviolet probe wavelength, access to narrow inter-combination lines for efficient Doppler cooling and access to triple magical wavelengths. As consequence, we expect a high optical depth per blockade volume and long coherence times for stopped or slow polaritons.

This talk will discuss the status of the experiment apparatus for this novel system and the progress towards Ytterbium quantum optics. In particular, we will discuss our complete laser setup, which achieves sub-100Hz linewidths for 395nm, 399nm and 556nm lasers locked to a high-finesse cavity.

Q 7.5 Mon 11:30 S SR 211 Maschb.

Interactions and Scattering Dynamics among Rydberg Polaritons in multi-mode optical cavities — •Jan Kumlin[1], Hadiseh Alaeian[2], and Hans Peter Büchler[1] — [1]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany — [2]5th Institute of Physics and Center for Integrated Quantum Science and Technology, University of Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany

Polaritons are quasi-particles resulting from the strong coupling of matter and photon states, whose dynamical properties stem from the photonic part and whose interaction properties originate from their matter part. While the small mass of the photons inside a cavity allows for observing quantum effects at higher temperatures, even up to the room temperature, the interaction allows for creating collective many-body effects. Due to their weak interactions, exciton-polaritons have been only studied in the weakly interacting mean field limit and the realization of a strongly correlated many-system has remained elusive so far. In this talk we discuss a new quasi-particle called cavity-Rydberg polariton, a quantum superposition of a Rydberg state and a cavity mode. Due to the strong interaction inherited by the Rydberg atoms, cavity-Rydberg polaritons are one of the best candidates to realize a strongly interacting system for studying quantum many-body physics with photons.

Q 7.6 Mon 11:45 S SR 211 Maschb.

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 develop a theory to describe the propagation of a light pulse through a lattice of Rydberg atoms using the polariton picture. A system of three-level atoms is coupled with a space-dependent probe and control field. A Bose-Hubbard-like model for the dark state polariton is obtained after a transformation in the Wannier basis. The analysis is done with the variational principle[1] which allows for the investigation of larger system sizes, long-range jumps, dissipative processes and also an implementation of the Rydberg blockade radius. We show the evolution of the output intensity and the dark state polariton occupation probability. The results are the first step towards the study of the behavior of the dark state polariton inside a lattice.

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

Q 7.7 Mon 12:00 S SR 211 Maschb.

Strong correlations and dissipative dynamics in quantum many-body systems — •Seyedjavad Kazemi and Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

The combination of strong correlations and dissipative dynamics in a quantum many-body system presents a severe challenge to their theoretical descriptions, as many methods for equilibrium systems cannot be applied. We build on the variational principle for dissipative quantum many-body systems [1] and extend the method to important questions in the context of strongly interacting spin systems. As a first step, we analyse the non-equilibrium steady state of Rydberg atoms with strong long-range interactions, where we find a dissipative variant of the Rydberg blockade in the pair correlation function. In addition, we investigate the interplay between driving strength and dimensionality.

[1] H. Weimer, Variational Principle for Steady States of Dissipative Quantum Many-Body Systems, Phys. Rev. Lett. 114, 040402 (2015).