A 4: Ultracold Plasmas and Rydberg Systems I (joint session Q/A)

Time: Monday 10:30–12:15 Location: K 2.013

Group Report A 4.1 Mon 10:30 K 2.013

A Photon-Photon Quantum Gate Based on Rydberg Polaritons — •Steffen Schmidt-Eberle, Daniel Tiarks, Thomas Stolz, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Rydberg polaritons offer a unique way to create strong interactions for photons. We utilize these interactions to demonstrate a photon-photon quantum gate. To achieve this, a photonic control qubit is stored in a quantum memory consisting of a superposition of a ground state and a Rydberg state in an ultracold atomic gas. This qubit interacts with a photonic target qubit in the form of a propagating Rydberg polariton to generate a conditional pi phase shift, as in Ref. [1]. Finally, the control photon is retrieved. We measure two controlled-NOT truth tables and the two-photon state after an entangling-gate operation. This work is an important step toward applications in optical quantum information processing, such as deterministic photonic Bell-state detection which is crucial for quantum repeaters.

[1] D. Tiarks et al., Science Advances 2, 1600036 (2016).

A 4.2 Mon 11:00 K 2.013

Excitation blockade in highly Stark-shifted Rydberg states — •Raphael Nold, Markus Stecker, Lea Steinert, József Fortágh, and Andreas Günther — Center for Quantum Science, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen

We report on the observation of excitation blockade for strongly Stark-shifted Rydberg states. Therefore, we make use of the fact that even for electric fields above the classical ionization limit, there are long-living Rydberg states with small ionization rates. We have developed a detection scheme for controlled ionization and magnified imaging of those states with high spatial and temporal resolution by adiabatic transfer to a state with a suitable ionization rate. The detector consists of a high-resolution ion microscope for ground state and Rydberg atoms with magnifications up to 1000 and a spatial resolution in the 100nm regime. The blockade effect becomes evident in the spatial $g^{(2)}$ correlation function between individual detection events. We show that the strength of the blockade effect can be sensitively adjusted by small changes in the electric field strength. This opens up new perspectives for quantum simulation techniques.

A 4.3 Mon 11:15 K 2.013

Free-Space Quantum Electrodynamics with Rydberg Superatoms — •Simon Ball[1], Christoph Tresp[1], Nina Stiesdal[1], Asaf Paris-Mandoki[2], Jan Kumlin[3], Philipp Lunt[1], Christoph Braun[1], Hans Peter Büchler[3], and Sebastian Hofferberth[1] — [1]Department of Physics, Chemistry and Pharmacy, University of Southern Denmark, 5230 Odense, Denmark — [2]Instituto de Física, Universidad Nacional Autónoma de México, Mexico City 04510 Mexico — [3]Institut für Theoretische Physik III and Center for Integrated Quantum Science and Technology, Universität Stuttgart, 70569 Stuttgart, Germany

Achieving significant coupling between single photon and single atom in free space is challenging. Finding ways to increase the coupling strength has brought about cavity, circuit and more recently waveguide QED, where the electromagnetic wave is either trapped or transversely confined. We present the coherent interaction of a single Rydberg superatom interacting with a propagating, single mode, few-photon light field. Due to the collective nature of the excitation, the superatom inherits the light field's phase-relation and emits only in forward direction.[1] This property can be utilized to implement a dissipative spin chain, where the interaction between the individual spins is consecutively mediated by unidirectional travelling individual photons.

[1] A. Paris-Mandoki, C. Braun, J. Kumlin, C. Tresp, I. Mirgorodskiy, F. Christaller, H. P. Büchler, and S. Hofferberth, Phys. Rev. X 7, 41010 (2017).

A 4.4 Mon 11:30 K 2.013

On-demand single-photon source based on thermal rubidium — •Fabian Ripka, Florian Christaller, Hao Zhang, Harald Kübler, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut and IQST, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

Photonic quantum devices based on atomic vapors at room temperature combine the advantages of atomic vapors being intrinsically reproducable as well as semiconductor-based concepts being scalable and integrable. One key device in the field of quantum information are on-demand single-photon sources. A promising candidate for realization relies on the combination of two effects in atomic ensembles, namely four-wave mixing (FWM) and the Rydberg blockade effect, comparable to similar realizations using cold atoms [1].

Coherent dynamics to Rydberg states [2] and sufficient Rydberg interaction strengths [3] have already been demonstrated in thermal vapors. Additionally, time-resolved probing of collective Rydberg excitation has been performed [4], revealing a lifetime long enough for effective Rydberg-Rydberg interactions.

In the current state of the experiment, the Rydberg blockade sphere is larger than the excitation volume. We report on effects on the light statistics of the emitted photons we observed in the experiment.

[1] Y. O. Dudin et al., Science 336, 6083 (2012)
[2] Huber et al., PRL 107, 243001 (2011)
[3] Baluktsian et al., PRL 110, 123001 (2013)
[4] Ripka et al., Phys. Rev. A, 053429 (2016)

A 4.5 Mon 11:45 K 2.013

Imaging nonlocal photon interactions in a cold Rydberg gas — •Annika Tebben[1], Valentin Walther[3], Renato Ferracini Alves[1], Yongchang Zhang[3], Andre Salzinger[1], Clement Hainaut[1], Nithiwadee Thaicharoen[1], Gerhard Zürn[1], Thomas Pohl[3], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Ruprecht-Karls Universität Heidelberg, Im Neuenheimer Feld 226, 69129 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China — [3]Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK 8000 Aarhus C, Denmark

Rydberg interactions modify the transmission of a light field through a cold atomic gas under conditions of electromagnetically induced transparency (EIT).

In this work, we develop a theory for the nonlinear, nonlocal optical response in a such a medium, without employing the adiabatic elimination of the intermediate state. We find an enhancement of this response in the vicinity of the single-photon resonance due to resonant Rydberg dressing of the atoms. Simulations show that this enhancement can be observed experimentally in the transmission of the EIT probe beam.

A 4.6 Mon 12:00 K 2.013

Emergent universal dynamics for an atomic cloud coupled to an optical waveguide — •Jan Kumlin[1], Sebastian Hofferberth[2], and Hans Peter Büchler[1] — [1]Institut für Theoretische Physik III and Center for Integrated Quantum Science and Technology, Universität Stuttgart, 70569 Stuttgart, Germany — [2]Department of Physics, Chemistry and Pharmacy, University of Southern Denmark, 5230 Odense, Denmark

Motivated by recent experiments on strong coupling of a cloud of Rydberg atoms coupled to a propagating light field [1], we study the effect of interaction-induced dephasing in an atomic cloud of atoms coupled to an optical one-dimensional waveguide. The system's dynamics can then be described by dissipative terms characterising the collective emission of photons and coherent interaction due to the virtual exchange of photons. We show that the coherent exchange interaction gives rise to universal dynamics with coherent oscillations and dephasing on a time scale that grows with the number of atoms in the cloud. Further, we discuss a possible experimental setup to decouple coherent and dissipative dynamics in order to observe the universal dynamics.

[1] A. Paris-Mandoki, C. Braun, J. Kumlin, C. Tresp, I. Mirgorodskiy, F. Christaller, H. P. Büchler, and S. Hofferberth, Phys. Rev. X 7, 41010 (2017)