Q 8: Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)

Time: Monday 17:00–19:00 Location: HS 1010

Q 8.1 Mon 17:00 HS 1010

Time-reversal in a quantum many-body spin system — •Sebastian Geier[1], Adrian Braemer[1,2], Eduard Braun[1], Maximilian Müllenbach[1], Titus Franz[1], Martin Gärttner[1,2,3], Gerhard Zürn[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Physikalisches Institut, Im Neuenheimer Feld 226 — [3]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Time reversal in a macroscopic system is contradicting daily experience. Yet, with the precise control capabilities provided by modern quantum technology, the unitary evolution of a quantum system can be reversed, rendering it a powerful tool for scientific discovery and technological advancements. Here, we implement a time-reversal protocol in a dipolar interacting many-body spin system represented by Rydberg states in an atomic gas. By changing the states encoding the spin, we flip the sign of the interaction Hamiltonian, and demonstrate the reversal of the relaxation dynamics of the magnetization by letting a demagnetized many-body state evolve back-in-time into a magnetized state. We elucidate the role of atomic motion using the concept of a Loschmidt echo. Finally, by combining the approach with Floquet engineering, we demonstrate time reversal for a large family of spin models with different symmetries. Our method of state transfer is applicable across a wide range of quantum simulation platforms and has applications far beyond quantum many-body physics.

Q 8.2 Mon 17:15 HS 1010

Exploring the vibrational series of pure trilobite Rydberg molecules — •Markus Exner, Max Althön, Richard Blättner, and Herwig Ott — RPTU Kaiserslautern-Landau, Kaiserslautern, Deutschland

We report on the observation of two vibrational series of pure trilobite rubidium Rydberg molecules. These kinds of molecules consist of a Rydberg atom and a ground state atom. The binding mechanism is based on the scattering interaction between the Rydberg electron and the ground state atom. The trilobite molecules are created via three-photon photoassociation and lie energetically more than 15 GHz below the atomic 22F state. In agreement with theoretical calculations, we find an almost perfect harmonic oscillator behavior of six vibrational states. We show that these states can be used to measure electron-atom scattering lengths for low energies in order to benchmark current theoretical calculations. The molecules have extreme properties: their dipole moments are in the range of kilo-Debye and the electronic wave function is made up of high angular momentum states with only little admixture from the nearby 22F state. This high-l character of the trilobite molecules leads to an enlarged lifetime as compared to the 22F atomic state. Furthermore, our ion pulse spectrometer provides insights into the decay processes.

Q 8.3 Mon 17:30 HS 1010

Green's function treatment of Rydberg molecules with spin — •Matthew Eiles[1] and Chris Greene[2] — [1]Max Planck Institut für Physik komplexer Systeme, Nöthnitzer Str 38, 01187 Dresden Germany — [2]Department of Physics and Astronomy and Purdue Quantum Science and Engineering Institute, Purdue University, West Lafayette, Indiana 47907, USA

The determination of ultra-long-range molecular potential curves has been reformulated using the Coulomb Green's function to give a solution in terms of the roots of an analytical determinantal equation. For a system consisting of one Rydberg atom with a fine structure and a neutral perturbing ground state atom with hyperfine structure, the solution yields potential energy curves and wave functions in terms of the quantum defects of the Rydberg atom and the electron-perturber scattering phase shifts and hyperfine splittings. This method provides a promising alternative to the standard currently utilized method of diagonalization, which suffers from problematic convergence issues and nonuniqueness, and can potentially yield a more quantitative relationship between Rydberg molecule spectroscopy and electron-atom scattering phase shifts.

Q 8.4 Mon 17:45 HS 1010

Rydberg Atomtronic Devices — •Philip Kitson[1,2], Tobias Haug[1], Antonino La Magna[3], Oliver Morsch[4], and Luigi Amico[1,2,5] — [1]Technology Innovation Institute, Abu Dhabi, UAE — [2]Dipartimento di Fisica e Astronomia and INFN-Sezione di Catania, Catania, Italy — [3]CNR-IMM, Catania, Italy — [4]CNR-INO, Pisa, Italy — [5]Centre for Quantum Technologies, Singapore

Atomtronics realises circuits through the guidance of neutral ultra-cold atoms. However, a recent proposal in the field of atomtronics has been the integration of Rydberg atoms, whereby instead of transporting matter, the established flow is of Rydberg excitations. We take advantage of the blockade and anti-blockade phenomena, resulting from the large dipole moments of such atoms, to prevent or facilitate the flow of excitations throughout networks of Rydberg atoms. In our work, we capitalise on these ideas along with the use of specific atom detunings, in order to create a toolbox of Atomtronics devices. We first formulate a method to control the flow of excitations through a Rydberg network via a detuning upon a gate atom as an analogy to a switch. Second, we generate non-reciprocal flow by using certain conditions of the anti-blockade (the gate atom's detuning and position). Lastly, we devise Rydberg networks to conduct logical decisions. Employing the anti-blockade mechanism we create a classical AND gate and a NOT gate, whereby combining both, we produce a universal logic gate set.

Q 8.5 Mon 18:00 HS 1010

Spectral signatures of vibronic coupling in trapped cold atomic Rydberg systems — •Joseph William Peter Wilkinson[1], Weibin Li[2], and Igor Lesanovsky[1,2] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

Atoms and ions confined with electric and optical fields form the basis of many current quantum simulation and computing platforms. When excited to high-lying Rydberg states, long-ranged dipole interactions emerge which strongly couple the electronic and vibrational degrees of freedom through state-dependent forces. This vibronic coupling and the ensuing hybridization of internal and external degrees of freedom manifest through clear signatures in the many-body spectrum. In this talk, we briefly discuss the recent results in Ref. [1] wherein we consider the case of two trapped Rydberg ions that realize a quantum Rabi model due to the interaction between the relative vibrations and Rydberg states. We proceed to demonstrate that this hybridization can be probed by radio frequency spectroscopy and discuss observable spectral signatures at finite temperatures and for larger ion crystals.

[1]. J. W. P. Wilkinson, W. Li, and I. Lesanovsky, *Spectral signatures of vibronic coupling in trapped cold atomic Rydberg systems*, arXiv:2311.16998 (2023)

Q 8.6 Mon 18:15 HS 1010

Avalanche terahertz photon detection in a Rydberg tweezer array — •Chris Nill[1,2], Albert Cabot[1], Arno Trautmann[3], Christian Gross[3], and Igor Lesanovsky[1,4] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Institute for Applied Physics, University of Bonn, Wegelerstraße 8, 53115 Bonn, Germany — [3]Physikalisches Institut, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [4]School of Physics and Astronomy, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

We propose a protocol for the amplified detection of low-intensity terahertz radiation using Rydberg tweezer arrays [1]. The protocol offers single photon sensitivity together with a low dark count rate. It is split into two phases: during a sensing phase, it harnesses strong terahertz-range transitions between highly excited Rydberg states to capture individual terahertz photons. During an amplification phase, it exploits the Rydberg facilitation mechanism which converts a single terahertz photon into a substantial signal of Rydberg excitations. We discuss a concrete realization based on realistic atomic interaction parameters, develop a comprehensive theoretical model that incorporates the motion of trapped atoms, and study the many-body dynamics using tensor network methods.

[1] C. Nill et al., Avalanche terahertz photon detection in a Rydberg tweezer array, arXiv:2311.16365 (2023).

Q 8.7 Mon 18:30 HS 1010

Ultrafast excitation of dense Rydberg gases at the threshold to ultracold plasma — •Jette Heyer[1,2], Mario Grossmann[1,2], Julian Fiedler[1,2], Markus Drescher[1,2], Klaus Sengstock[1,2], Philipp Wessels-Staarmann[1,2], and Juliette Simonet[1,2] — [1]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [2]Center for Optical Quantum Technologies, University of Hamburg, Hamburg, Germany

Ultrashort laser pulses enable the local ionization of a quantum gas on femtosecond time scales. By tuning the central wavelength of a single laser pulse of 166 fs duration across the two-photon ionization threshold of ^{87}Rb, we investigate the transition from ultracold plasma to dense Rydberg gases.

Above this threshold, strong-field ionization triggers the formation of a highly charged ultracold plasma. Below the ionization threshold, we observe the ultrafast formation of dense Rydberg gases as the Rydberg blockade is bypassed by the large bandwidth of the femtosecond pulse. Charge-imbalanced microplasma dynamics prevent Rydberg recombination close to the threshold and leads to ionization of deeply bound Rydberg states even far below the threshold.

Our experimental setup allows us to directly detect the energy distribution of ions and electrons as well as Rydberg atoms. State of the art molecular dynamics simulations give us insight into the underlying dynamics of the many-body system, which is governed by long-range Coulomb interactions.

Q 8.8 Mon 18:45 HS 1010

Toward the demonstration of an avalanche THz photon detector with Rydberg atoms — •Fabio Bensch, Lea-Marina Steinert, Philip Osterholz, Shuanghong Tang, Arno Trautmann, and Christian Gross — Eberhard Karls Universität, Tübingen, Germany

Rydberg atoms confined within tweezers demonstrate unique capabilities in realizing strongly interacting and correlated many-body phenomena. The anti-blockade effect, notably, has proven to be an optimal tool for controlling non-linear avalanche Rydberg excitation in both disordered and ordered many-body systems. The integration of optical tweezers with advanced sorting algorithms enables the creation of defect-free arrays with highly precise geometry. In this context, we introduce a novel approach where the combination of defect-free arrays and avalanche facilitated excitation yields a straightforward and fuctional THz photon detector. This opens up an innovative utilization of Rydberg atoms to address the challenging issue of THz photon detection.