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Abstracts

(in alphabetic order of presenting author's last name)

Engineering collective light-matter interactions

Prof. Charles Adams, Durham University

Strong light-matter coupling -- without cavities -- requires a high optical depth such that any incident photon has a high probability of interacting. For a single dipole, optical depth (extinction) optimization is achieved by frequency matching and spatial mode matching of the incident light. [1] For many dipoles, optical depth maximisation becomes a complex many-body problem, where one may need to include the effects of the interactions between dipoles and the vector nature of the electromagnetic field. In general, for many dipoles, the light interacts with a collective mode, and one can exploit interactions to engineer the collective response as in Rydberg EIT [2] or using sub-wavelength arrays [3]. In this talk I will review the opportunities and challenges of such collective mode engineering.

[1] C. S. Adams and I. G. Hughes, Optics, OUP (2019).
[2] O. Firstenberg, C. S. Adams and S. Hofferberth, J. Phys. B 49, 152003 (2016).
[3] R. J. Bettles, S. A. Gardiner, and C. S. Adams, Phys. Rev. Lett. 116, 103602 (2016).

Driven dissipative dynamics in an open many body quantum system

Mr. Matteo Archimi, Department of Physics, University of Pisa

Understanding and probing phase transitions in nonequilibrium systems is an ongoing challenge in physics. A particular instance are phase transitions that occur between a nonfluctuating absorbing phase, e.g., an extinct population, and one in which the relevant order parameter, such as the population density, assumes a finite value. In this presentation I report the observation of signatures of such a nonequilibrium phase transition in an open driven quantum system. In our experiment, rubidium atoms in a quasi-one-dimensional cold disordered gas are laser excited to Rydberg states under so-called facilitation conditions. This conditional excitation process competes with spontaneous decay and leads to a crossover between a stationary state with no excitations and one with a finite number of excitations. We relate the underlying physics to that of an absorbing-state phase transition in the presence of a field (i.e., off-resonant excitation processes) which slightly offsets the system from criticality.

Rydberg spectroscopy in an atom-ion hybrid trap

Dr. Markus Deiss, Institute of Quantum Matter, Ulm University

Hybrid atom-ion traps are a key technology for intriguing applications such as cold chemistry, molecular physics and so on. The good controllability of both ionic and atomic states provides an opportunity for studying atom-ion interaction in a novel regime. Here, we demonstrate Rydberg spectroscopy of rubidium atoms within an atom-ion hybrid trap, where an optical dipole trap and a Paul trap are combined for simultaneous trapping of neutral and charged particles. This versatility allows for capturing ionized products following optical excitation of atoms towards Rydberg states. The trapped ions elastically collide with the rubidium atoms leading to atom loss, which gives rise to a high sensitivity for observing the underlying Rydberg excitation. In this presentation, we show results for spectroscopy of Rydberg states, including signatures for butterfly molecular bound states and avoided level crossings. We discuss our preliminary results on Stark maps. This work opens up a potential application of atom-ion hybrid traps to be used as a novel spectroscopic detection tool for investigating Rydberg phenomena.

Probing cold long-range collisions within an ion trap

Prof. Johannes Hecker Denschlag, University of Ulm

We report on experiments where we study cold collisions between neutral Rb atoms and between Rb atoms with Rb ions. During the collision, a Rb atom of the collision pair is optically excited towards a Rydberg state with the main quantum number n between n = 14 and n = 30. We observe a variety of different resonances which are linked to atomic and diatomic Rydberg states, some of which are linked to butterfly states. When these Rydberg states decay via ionization we trap the resulting ion in our trap where we can detect the resulting ions with unit probability. The resonance spectra vary quite strongly with the quantum number n. We present an update of our experimental and theoretical findings.

Thermal Rydberg Vapours for Terahertz Sensing and Imaging

Ms. Lucy Downes, Durham University

Terahertz (THz) radiation lies between the infrared and microwave regions, commonly defined as spanning the frequency range 0.1-10 THz. It has promising applications in many areas; from materials identification in security to non-destructive sub-surface imaging in medicine. However a lack of convenient detection methods mean there is far less technological exploitation of radiation in this region than elsewhere on the EM spectrum. Rydberg atoms have been used to perform electrometry of microwave and radio frequency fields, and the technique is well understood. Their well-defined properties eliminates the need for calibration and allows the measurements to be related directly to SI units. Alkali Rydberg atoms have atomic transitions spanning the THz gap making them promising for both electrometry and imaging applications. We show that a thermal Cesium Rydberg vapour can be used to perform THz electrometry across a range of frequencies. We also demonstrate a THz-to-optical converter using the same Rydberg system. By imaging visible fluorescence from the vapour we demonstrate 2D THz imaging at framerates of over 1 KHz with near diffraction-limited spatial resolution.

Coherence of the three-body Förster resonances in the interacting Rb Rydberg atoms

Dr. Vasiliy Entin, Rzhanov Institute of Semiconductor Physics SB RAS

Authors: V.M. Entin, E.A. Yakshina, D.B. Tretyakov, I.I. Beterov, I.I.Ryabtsev, P.Cheinet, P.Pillet

We have observed recently the Stark-tuned three-body Förster resonances at long-range interactions of a few cold Rb Rydberg atoms. The three-body resonance has a Borromean character and corresponds to a transition when the three interacting atoms change their states simultaneously. In our experiments with Rydberg atoms randomly positioned in a single interaction volume, we have found that the two-body and three-body resonances partially overlap due to the broadening of the two-body resonance. Here we analyze theoretically the conditions when the three-body resonance becomes narrower and better separated from the two-body resonance, if the three atoms are frozen in certain spatial configurations. We demonstrate coherent three-body interactions and the possibility to implement the three-qubit quantum gates and simulations.

Adiabatic flux insertion and growing of Laughlin states of cavity Rydberg polaritons"

Prof. Michael Fleischhauer, University of Kaiserslautern

Recently, the creation of a strong magnetic field in a photonic cavity system has been demonstrated [1]. Using this setup, we propose a scheme to adiabatically transfer flux quanta simultaneously to all cavity photons [2]. The flux transfer is achieved using external light fields with orbital angular momentum and a near-resonant dense atomic medium as a mediator. Furthermore, by coupling the cavity fields to a Rydberg state, strong photon-photon interactions can be realized and fractional quantum Hall states can be prepared. To this end, a growing protocol is discussed consisting of a sequence of flux insertion and subsequent single-photon insertion. Specifically, we discuss the growing of the $\nu = 1/2$ bosonic Laughlin state. First we adiabatically insert two photonic flux quanta, creating a two-quasihole excitation, and second we refill the hole with a single photon using the strong photon-photon interactions.
[1] N. Schine et al., Nature (London) 534, 671 (2016).
[2] P. A. Ivanov et al., Phys. Rev. A 98, 013847 (2018)

Microwave Spectroscopy of double Rydberg molecules

Prof. Thomas Gallagher, University of Virginia

There have been several proposal for the formation of macrodimers, molecules composed of two Rydberg atoms bound by long range interactions, and only recently have such molecules been observed. Here we describe microwave resonance transitions of pairs of cold Rydberg

atoms in a magneto optical trap. While it is unclear as to whether or not the atoms are bound, it is clear that the transitions can not occur in isolated atoms. Rather, they require the dipole-dipole interaction of a pair of atoms. We have observed transitions in which up to three microwave photons have been absorbed. A unified way of describing all of these microwave transitions is as Forster resonant energy transfers of Floquet states.

Coupling Rydberg atoms and superconducting resonators

Dr. Jens Grimmel, University of Tübingen

The creation of hybrid systems consisting of Rydberg atoms and coplanar superconducting resonators has been proposed to enable efficient state transfer between solid state systems and ultracold atoms. This type of systems could be used as an atomic quantum memory or for the implementation of new quantum gates. Due to the large dipole moment of Rydberg atoms, the coupling strength to the cavity is expected to be much larger than for ground state atoms. At the same time, Rydberg states are strongly affected by any detrimental fields, such as the electric field of adsorbates on the chipsurface, which lead to spatially inhomogeneous energy shifts. We report on the characterization of these fields, state selective detection of 87Rb Rydberg atoms and on the coupling between ultracold Rydberg atoms and a driven coplanar waveguide resonator on a superconducting atom chip.

Microscopy of ultracold Rydberg macrodimers

Dr. Christian Gross, Max-Planck Institute for Quantum Optics

Pairs of Rydberg atoms feature complex interaction potentials even at micrometer distance. In particular, attractive and repulsive pair potentials of the same symmetry may come close in energy, forming an avoided crossing at a distance much larger than the electronic wave function extend of the individual Rydberg atoms. The avoided crossing leads to a deep potential well, which supports multiple vibrational bound states. Here we report on the microscopic observation of such exotic Rydberg-Rydberg macrodimers using single site resolved imaging of an ultracold quantum gas in an optical lattice. We directly ``image'' the macrodimers as pairs of missing atoms and laser spectroscopy reveals the vibrational spectrum with high precision. We observe a strong dependence of the relative strength of the odd and even lines on the laser polarization and our local measurement reveals a clear spatial anisotropy of the excitation probability. Combining narrow line excitation to such Rydberg macrodimers with atomic motion in the lattice might be used to engineer many-body states stabilized through dissipation.

Excitation blockade in strongly Stark-shifted Rydberg systems

Dr. Andreas Günther, University of Tübingen

Long-range dipole-dipole interactions are among the main building blocks for Rydberg based quantum computers. Investigating these interactions in high electric fields becomes important for future chip-based systems, where electric fields are unavoidable.
We report on the observation of excitation blockade for strongly Stark-shifted Rydberg states. Therefore, we show that even at field regions above the classical ionization limit, there are long-living Rydberg states with small ionization rates, suitable for Rydberg excitation. At these high fields, small field adjustments on the order of 1V/cm allow for precise tuning of the dipole-dipole interaction strength and the Rydberg ionization rate. Based upon this, we have developed a detection scheme for high resolution imaging of individual Rydberg atoms. The detector consists of a high-resolution ion microscope 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 and can be sensitively adjusted by small changes in the electric field. This opens up new perspectives for quantum simulation techniques.

Interacting Rydberg Ions

Dr. Gerard Higgins, Stockholm University

Systems of trapped ions and systems of ultracold Rydberg atoms are used at the forefront of quantum physics research and they make strong contenders as platforms for quantum technologies. Trapped Rydberg ions are a new hybrid technology which has both the exquisite control of trapped ion systems and the strong interactions of Rydberg atoms.
We coherently excite two trapped strontium ions to Rydberg states using ultraviolet laser light. Microwave radiation is used to introduce large electric dipole moments to the Rydberg ions. We have observed strong dipole-dipole interactions (~1 MHz) between two Rydberg ions. Next we will use Rydberg interactions to carry out a fast (~1 us) two-qubit gate. Such gates may allow fast quantum gates to be carried out in large systems of trapped ions.

Dynamics of exciton-polaritons in a double-well potential

Dr. Panayotis Kalozoumis, University of Patras

We study strongly-interacting two-component exciton-polariton condensates in a double well potential. Due to the self- and cross-interactions of the two components, the system exhibits different regimes of strongly correlated Josephson oscillations of condensate, including fast Rabi-like oscillations, slow second-order oscillations. We also find interaction-induced self-trapping or its break up above critical value of the Josephson coupling.

Study of Rydberg blockade in thermal vapor

Mr. Dushmanta Kara, NISER Bhubaneswar

In this work, we present the experimental demonstration of Rydberg blockade in thermal atomic vapor where the atoms are not necessarily frozen. It has been observed that only the atoms moving with the same velocity collectively participate in the blockade process to form the super-atom. The interacting thermal vapor can be modeled using an approximate model of N-atoms moving within the same velocity class. An experiment is performed to measure Rydberg population in rubidium thermal vapor using optical heterodyne detection technique and a density-dependent suppression of Rydberg population as a signature of Rydberg blockade is observed in suitable experimental parameter regime. Further analysis of the experimental data using the approximate N-atom model verifies the scaling law for van der Waals interaction strength (C_6) with the principal quantum number of the Rydberg state with 5% error. Our result suggests multi-photon excitation in thermal vapor with suitable laser configuration to probe Rydberg blockade interaction based optical non-linearity and many-body effects.

Observation of three-body correlations for photons coupled to a Rydberg superatom

Mr. Kevin Kleinbeck, Institute for theoretical Physics III, Stuttgart University

We report on the experimental observation of non-trivial three-photon correlations imprinted onto initially uncorrelated photons through interaction with a single Rydberg superatom. Exploiting the Rydberg blockade mechanism, we turn a cold atomic cloud into a single effective emitter with collectively enhanced coupling to a focused photonic mode which gives rise to clear signatures in the connected part of the three-body correlation function of the out-going photons. We show that our results are in good agreement with a quantitative model for a single, strongly coupled Rydberg superatom. Furthermore, we present an idealized but exactly solvable model of a single two-level system coupled to a photonic mode, which allows for an interpretation of our experimental observations in terms of bound states and scattering states.

Long-range optical interactions

Prof. Gershon Kurizki, Weizmann Institute of Science

Nonlinear optical phenomena are typically local. We have predicted the possibility of highly nonlocal optical nonlinearities mediated by long-range interactions of photons propagating in atomic media [1]. Part of our predictions has concerned the possibility of entangling photons in waveguides that has recently been experimentally confirmed by M.Lukin’s group. It has grown out of our work on the enhancement of long-range interactions by virtual quanta exchanged via the bath in confined geometries [2]. It is at present the only mechanism capable of deterministically entangling distant photons. This mechanism is one of our predictions of bath-induced entanglement [3]. Its essence is that the mediation of

virtual quanta by the modes of a waveguide can cause their enhancement by many orders of magnitude and drastically extend their range [1].

For atoms trapped near a nano-waveguide, where long-range interactions between the atoms can be tailored in an electromagnetically-induced transparency configuration, the atomic interactions may be translated to long-range interactions between photons and thus to highly nonlocal optical nonlinearities. We find a roton-like excitation spectrum for light [4] and the emergence of order in its output intensity.

For atoms coupled to a waveguide with a bandgap spectrum illuminated by an off-resonant laser, the resulting dynamics of the atoms is predominantly affected by an extremely long-range conservative force that can enhance their interaction. Even more dramatic, giant, enhancement of the interaction is achievable via the control of the geometry, for dipolar forces induced by the electromagnetic vacuum, namely, the Casimir and van der Waals (vdW) forces. The idea is to consider atoms coupled to an electric transmission line (TL), such as a coaxial cable or coplanar waveguide, which support the propagation of quasi-1d transverse electromagnetic (TEM) modes. Virtual excitations (photons) of these extended modes can mediate much stronger and longer-range Casimir and vdW forces than in free-space [1].

These predictions open the door to studies of unexplored wave dynamics and many-body physics with highly-nonlocal interactions of optical fields in one dimension.

[1] E. Shahmoon et al, Optica 3, 725 (2016); PRA 89, 043419 (2014); PRA 87, 03383 (2013); PNAS 111, 10485 (2014); PRA 83, 033806 (2011).
[2] I. Friedler et al., PRA 72, 043802 (2005).
[3] DDB Rao et al., PRL 106, 010404 (2011).
[4] D.J. O'Dell et al. PRL 90, 110402 (2003); 84, 5687 (2000).

Variational cooling

Mr. Viacheslav Kuzmin, IQOQI, University of Innsbruck

We investigate variational preparation of a circuit which unconditionally cools a system of qubits to the ground state of a given Hamiltonian. In comparison with the standard variational method exploiting only unitary operations, our method uses auxiliary qubits, which are entangled with the "system" qubits by unitary gates and afterward are coupled to the physical environment. Optimizing the parameters of the unitary operations, we achieve cooling of the "system" qubits to the desired pure state. The developed algorithm is suitable for various platform, including a system of Rydberg atoms.

Quantum Spin Systems far from equilibrium: Theory and applications

Prof. Igor Lesanovsky, University of Nottingham

Cold atomic gases are a versatile platform for the study of non-equilibrium phenomena in quantum many-body systems. Especially atoms excited to highly-lying electronic states -- so-called Rydberg atoms. They form the building blocks of the most recent generation of quantum simulators and offer rather intriguing opportunities for exploring strongly correlated dynamics in interacting spin systems. I will present an overview of the research that our group has conducted on this topic in the past years. I will show that the out-of-equilibrium behaviour of Rydberg gases is governed by emergent kinetic constraints. Such constraints are often used to mimic dynamical arrest or excluded volume effects in idealized models of glass forming substances and lead to a remarkably rich physics including non-equilibrium phase transitions and localisation phenomena. Moreover, Rydberg gases offer intriguing opportunities for the systematic exploration of the role of competing quantum and classical dynamical effects on non-equilibrium phase transitions. I will conclude by discussing how the above findings can be employed to gain a new perspective on the physics of Dynamic Nuclear Polarisation in interacting electronic and nuclear ensembles, which is an out-of-equilibrium method to drastically enhance the performance of Magnetic Resonance Imaging applications.

Experimental realization of an optical Feshbach resonance using ultra-long range Rydberg molecules

Mr. Carsten Lippe, University of Kaiserslautern

Over the last decades Feshbach resonances in ultra cold atomic gases have led to some of the most important advances in atomic physics. Not only did they enable ground breaking work in the BEC-BCS crossover regime, but they are also a widely used tool for the association of ultra cold molecules, leading to the emergence of ultra cold dipolar molecular systems. The commonly used magnetic Feshbach resonances are specific for each species and are restricted with respect to their temporal and spatial modulation. These limitations can be overcome with optical Feshbach resonances.
We show that ultra-long range Rydberg molecules can be used to realize an optical Feshbach resonance. Demonstrating their practical use by tuning the on-site interaction of a quantum many-body system quenched into a deep optical lattice, we achieve a similar performance compared to recent realizations of optical Feshbach resonances using intercombination transitions. Our results open up a complete new class of optical Feshbach resonances as ultra-long range Rydberg molecules have a plenitude of available resonances for many atomic species.

Rydberg Dressed Quantum Many-Body Systems

Mr. Nikolaus Lorenz, Max Planck Institute for Quantum Optics

We are setting up a novel experiment for the study of quantum many-body systems with engineered long-range interactions. These interactions are induced by off-resonant laser coupling to Rydberg states, so called Rydberg dressing. The combination of state selective laser coupling with the complex interactions between Rydberg atoms enables to design these interactions with unprecedented flexibility. A great potential of this dressing technique lies in the combination of Rydberg induced interactions and atomic motion in the quantum regime. This requires the long-range interaction between Rydberg atoms to be coherent on the timescale set by the atomic motion. Rydberg dressing has been proposed as a technique

exactly for this purpose. By the choice of the laser parameters the extremely strong dipolar interactions can be balanced with the rate of dissipative light scattering.
A first intermediate goal of our experiment is to study tailored quantum magnets in microtrap arrays, where Potassium provides interesting prospects for deterministic array loading. The microtrap approach has been chosen in order to have a flexible and fast system for experiments that require high statistics.

Numerical study of Bose-Hubbard Models with finite-range interactions

Mr. Guido Masella, University of Strasbourg

The search for phases of matter where exotic states may be stabilized by the simultaneous breaking of different symmetries is a subject of central interest in condensed matter physics. A prominent example is supersolidity (i.e. coexistence of superfluidity and crystalline order). In this context, a large class of Extended-range Repulsive (pair-wise) Interactions (ERI) has recently elicited considerable scientific attention. ERI are of immediate interest for experiments employing Rydberg-dressed atoms. At high enough densities ERI are characterized by clusterization, a feature that has been shown to be linked to supersolidity in two- dimensional continuous space and supersolidity and (super)glassiness (the latter in the absence of external frustration) on a triangular lattice. Here we are interested in studying the ground state phases of monodisperse bosonic particles on a square lattice interacting via ERI of soft-shoulder type. We demonstrate the presence of a novel type of stripe crystal, an isotropic supersolid, and self-assembled array of one-dimensional superfluids (superstripes).

Rydberg excitation of cold, trapped ions

Dr. Arezoo Mokhberi, Johannes Gutenberg University Mainz

Cold ions in a radiofrequency ion trap are among the most promising candidates for quantum information processing and quantum simulation. We aim for combining the superb control over external and internal degrees of freedom in trapped ions with high flexibility for tuning Rydberg interactions between them. Moreover, Rydberg ions offer a unique opportunity for observing novel effects arising from the interplay between the Coulomb interaction and their giant dipole moments, and hence, are excellent platforms for investigating strongly correlated many-body quantum systems as well as for exploring non-equilibrium dynamics in structural phase transitions and symmetry breaking mechanisms. The talk will discuss the current Rydberg ions experiment in Mainz using coherent vacuum ultra-violet radiation, as well as our future experiment for coherent manipulation of Rydberg states of calcium ions.

A Rydberg amplifier for cavity QED

Prof. Klaus Mølmer, Aarhus University

The efficient coupling of travelling photon qubits to single stationary atomic ones has been pursued in cavity QED experiments, but reaching the strong coupling regime for high fidelity gates remains an experimental challenge. I shall present novel schemes [1,2] where an ensemble of atoms serves as an "amplifier" for the interaction between a single atom and a single photon. The nature of the interaction lends itself to efficient schemes where the state of the photon factors out while its propagation and reflection mediates multi-qubit gate between atoms in the same and in different cavities [3].

[1] A. C. J. Wade, M. Mattioli and K. Mølmer, Phys. Rev. A 94, 053830 (2016).
[2] F Motzoi and K Mølmer, New J. Phys. 20 053029 (2018)
[3] I. Cohen and K. Mølmer, Deterministic Quantum Network for Distributed Entanglement and Quantum Computation; http://xxx.lanl.gov/abs/1802.08124, to appear in Phys. Rev. A.

Photon-assisted quantum state transfer and entanglement generation in spin chains

Dr. George Nikolopoulos, Foundation for Research and Technology – Hellas

We propose a protocol for state transfer and entanglement generation between two distant spin qubits (sender and receiver) that have different energies. The two qubits are permanently coupled to a far-off-resonant spin chain, and the qubit of the sender is driven by an external field, which provides the energy required to bridge the energy gap between the sender and the receiver. State transfer and entanglement generation are achieved via virtual single-photon and multiphoton transitions to the eigenmodes of the channel.

Rydberg Physics Meets Ultracold Quantum Gases

Prof. Dr. Herwig Ott, Technische Universität Kaiserslautern

During the last two decades, ultracold quantum gases have become a valuable experimental platform for many-body physics, and a series of groundbreaking studies with bosonic and fermionic quantum gases has been carried out. At the same time, cooling and trapping of ultracold atoms has revolutionized the field of Rydberg physics. Today, both research directions are closely linked to each other and I will discuss how the two formerly disjunct areas of physics can benefit from each other. In particular, I will show that an atomic Mott insulator can serve as a platform to study driven-dissipative Rydberg gases in the antiblockade regime and that Rydberg molecules can be employed to tune the interaction in an ultracold quantum gas via an optical Feshbach resonance.

Quantum simulators for open quantum systems using quantum Zeno dynamics

Ms. Sabrina Patsch, University of Kassel

A watched quantum arrow does not move. This effect, referred to as the quantum Zeno effect, arises from a frequent measurement of a quantum system's state. In more general terms, the evolution of the quantum system can be confined to a subspace of the system's Hilbert space leading to quantum Zeno dynamics. Resulting from the measurement process, a source of dissipation is introduced into the systems dynamics. However, different than for a common open quantum system, we can choose the strength of the dissipation by changing the parameters of the Zeno measurement. We capitalise on the property of tunable dissipation to create a quantum simulator for open quantum systems and derive a Lindblad master equation to describe the evolution of the open system. Moreover, we extend the picture to enable also non-Markovian evolution. The considered quantum system are photons inside a cavity being subject to a indirect measurement using circular Rydberg atoms.

Simulating spin-lattice models with cold Rydberg atoms

Dr. David Petrosyan, Foundation for Research and Technology – Hellas

Spin lattice models play central role in the studies of quantum magnetism and nonequilibrium dynamics of spin excitations -- magnons. But realizing tunable spin lattices in the quantum regime is challenging. We show that a spin lattice with strong nearest-neighbor interactions and tunable long-range hopping of excitations can be realized by a regular array of laser driven atoms, with an excited Rydberg state representing the spin-up state and a Rydberg-dressed ground state corresponding to the spin-down state. We find exotic interaction-bound states of magnons that propagate in the lattice via the combination of resonant two-site hopping and non-resonant second-order hopping processes.

Novel quantum devices based on atomic vapor cells

Prof. Tilman Pfau, Stuttgart University

Photonic quantum devices based on atomic vapors at room temperature combine the advantages of atomic vapors being intrinsically reproducible and highly nonlinear with scalability and integrability. We show the integration of photonic and electronic components into vapour cells. In the future integrated optical and electronic circuits in atomic vapor cells will enable applications in quantum sensing and quantum networks. As an example we report a first demonstration of an on-demand single-photon source based on four-wave mixing (FWM) and the Rydberg blockade effect. We also investigate an integrated optical chip immersed in atomic vapour providing several waveguide geometries for spectroscopy applications. This work demonstrates a next step towards miniaturization and integration of alkali atom spectroscopy and provides a platform for further fundamental studies of strong atom light coupling.

From many-body physics to quantum optimization with Rydberg atoms

Dr. Hannes Pichler, Harvard University

Individually trapped neutral atoms are a promising platform for studying quantum many-body physics and implementing quantum information protocols. The high degree of programmability of the atomic positions, strong and highly coherent Rydberg interactions, and single atom state readout allow to engineer and analyze a wide range of spin models. Already for a 1D arrangement, the phase diagram of such arrays of trapped atoms shows a rich structure, with several phases breaking various spatial symmetries. We numerically analyze the universality classes of the accessible phase transitions and experimentally probe the associated critical dynamics via the quantum Kibble-Zurek mechanism. We then describe how the experimentally available tools to control such systems can be employed for quantum optimization to solve maximum independent set (MIS) problems. Optimizing independent sets is one of the paradigmatic, NP-hard problems in computer science. Specifically, we show that solutions of MIS problems can be efficiently encoded in the ground state of interacting atoms in 2D arrays by utilizing the Rydberg blockade mechanism. By studying the performance of leading classical algorithms, we identify parameter regimes, where computationally hard instances can be tested using near-term experimental systems.

Rydberg physics with excitons

Prof. Thomas Pohl, Aarhus University

Highly-excited states of excitons in semiconductors exhibit many of the intriguing properties of Rydberg excitations in an atomic gas. This talk will explore such systems with special emphasis on the strong interactions between Rydberg excitons and corresponding perspectives for nonlinear optics. As compared to cold-gas settings, such solid-state systems hold additional challenges but also new opportunities which will be considered in this talk. Recent experiments will also be discussed.

A hybrid atom-superconductor quantum interface

Dr. Jonathan Pritchard, University of Strathclyde

Quantum mechanics offers a revolutionary approach to how information is processed, with unprecedented levels of security through quantum encryption and exponential speed up with quantum computing. A key challenge to exploiting these benefits is the development of the next-generation hardware required for creating networks exploiting light at the single photon level, including quantum repeaters and routers. Hybrid quantum devices seek to overcome these challenges by combining the unique strengths of disparate quantum technologies, enabling realization of a scalable quantum devices.

Rydberg atoms coupled to superconducting microwave circuits are an ideal candidate for such a device, enabling generation, storage and entanglement of photons in both microwave an optical domains using a scalable on-chip design. In this talk we present application of this platoform to quantum enhanced radar and present experimental progress towards this goal, including generation of an entangled atom with long lived coherence.

Algebraic localization of long-range quantum models

Prof. Guido Pupillo, University of Strasbourg

Several atomic, molecular, and optical systems, as well as certain condensed matter models, exhibit long-range interactions that decay with distance r as a power law $1/r^{\alpha}$. In this talk, we will present recent results for the localization properties of correlation functions of long-range quantum models in the presence of disorder. The latter is usually associated with exponential localization of wave functions and correlations. We demonstrate that in most situations power-law interactions imply algebraic decay of correlations. We will discuss the generality of these results and their application to experiments in atomic and molecular physics.

Mirrorless optical parametric oscillator inside an all-optical waveguide

Ms. Sushree Subhadarshinee Sahoo, NISER Bhubaneswar

We report the demonstration of mirrorless optical parametric oscillator under the effect of an all-optical waveguide. The efficient four wave mixing process due to counter-propagating pump and control fields interacting with a multilevel atomic system facilitates the generation of mirrorless Stokes and anti-Stokes fields counter propagating to each other. The maximum generated laser power could rise upto mW with pump conversion efficiency more than 30%. Furthermore the cross-phase modulation due to the pump field creates an all-optical waveguide for the generated fields and hence induces different spatial modes in stokes as well as anti-stokes fields. With suitable experimental parameters, we could generate correlated Gaussian mode or Laguerre-Gaussian mode for both the generated fields.

Faithful state transfer between two-level systems via an actively cooled finite-temperature cavity

Dr. Lorinc Sarkany, University of Tubingen

We consider state transfer between two qubits - effective two-level systems represented by Rydberg atoms - via a common mode of a microwave cavity at finite temperature. We find that when both qubits have the same coupling strength to the cavity field, at large enough detuning from the cavity mode frequency, quantum interference between the transition paths makes the SWAP of the excitation between the qubits largely insensitive to the number of thermal photons in the cavity. When, however, the coupling strengths are different, the photon-number-dependent differential Stark shift of the transition frequencies precludes efficient transfer. Nevertheless, using an auxiliary cooling system to continuously extract the cavity photons, we can still achieve a high-fidelity state transfer between the qubits.

A master equation for strongly interacting dipoles

Dr. Adam Stokes, University of Manchester

We consider a pair of dipoles for which direct electrostatic dipole-dipole interactions may be significantly larger than the coupling to transverse radiation. We show using a generalised arbitrary-gauge light-matter Hamiltonian that the standard two-dipole master equation usually obtained using the multipolar gauge is obtained in other gauges only if the inter-dipole Coulomb interaction is kept within the interaction Hamiltonian rather than the unperturbed part. Instead, we derive a master equation using the Coulomb gauge, which naturally enables us to include the inter-dipole Coulomb energy within the system Hamiltonian rather than the interaction. Thus, our master equation, while still gauge-invariant, depends on different S-matrix elements, which give separation-dependent corrections to the standard matrix elements describing resonant energy transfer and collective decay. The two master equations coincide in the large separation limit where static couplings are negligible. We provide an application of our master equation by finding separation-dependent corrections to the natural emission spectrum of the two-dipole system.

Excitation of Strongly Interacting Moving Rydberg Atoms by Photon Recoil Momentum

Dr. Razmik Unanyan, University of Kaiserslautern

Based on the fact that an ensemble of moving Rydberg atoms in two counterpropagating laser beams in the limit of complete dipole blocking, is isomorphic to a Jaynes-Cummings model a scheme for robust and effcient excitation of atomic Rydberg states is proposed. It is shown that the Doppler frequency shifts play an important role in atomic population transfer processes. The suggested method can be employed to detect the symmetric entangled states and paves the way to preparing entangled states with a single excited atom in a Rydberg state. It is shown that this process is robust with respect to parameter fluctuations, such as the laser pulse area, the relative spatial offset (the delay) of the laser beams and the number of atoms.

Universal Non-Equilibrium Dynamics in a Disordered Rydberg Spin System

Prof. Matthias Weidemüller, Heidelberg University

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Out of equilibrium spin systems with disorder can show extremely slow dynamics as known, e.g., in spin glasses, where the magnetization relaxes slowly over several orders of magnitude in time. To investigate such dynamics in the presence of quantum fluctuations we implement an isolated disordered spin system composed of long-range interacting Rydberg atoms which can be described by a Heisenberg XXZ spin model [1]. We present an experiment which disentangles the role of fluctuations stemming from disorder and quantum fluctuations. We initially prepare all spins in an eigenstate of the XXZ mean field Hamiltonian. We find strong deviation from the mean field prediction of the magnetization. Instead, it evolves with a universal non-exponential decay much slower than the timescale associated to the exchange coupling strength. This dynamics, which bears similarities to spin glasses, is in good agreement with a discrete truncated Wigner approximation revealing that the evolution is determined by the build-up of entanglement driven by quantum fluctuations.
[1] A. Piñeiro Orioli et al., Phys. Rev. Lett. 120, 63601 (2018).

Self-organisation and universal non-equilibrium dynamics in driven Rydberg gases

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We explore the dynamics of driven-dissipative Rydberg gases under the conditions of facilitated excitation and slow loss of excited atoms out of the system. In contrast to previous studies which treated loss as something to be avoided, we show that the non-conservation of population is a crucial ingredient of the nonlinear dynamics that drives the system to a stationary state that is independent of the initial conditions. Our measurements show that this state exhibits scale invariance and a strong response to external perturbations characteristic of self-organised criticality. These experiments establish Rydberg atoms as a well controlled platform for exploring self-organisation phenomena and non-equilibrium universality with unprecedented access to the underlying microscopic properties of the system.

Long-range interactions and symmetry-breaking in quantum gases through optical feedback

Dr. Yongchang Zhang, Aarhus University

A lot of recent attention has been focused on long-range interaction in dipolar atoms and in cavity-assisted systems. Yet, it is an open challenge to engineer long-range interaction

between atoms without large dipole moment in free space. Here, we propose to generate an exotic type of long-range interaction between ultracold atoms using a simple single-mirror optical feedback setup. We show that this effective interaction gives rise to a rich spectrum of ground states. In particular, we find that it can cause the spontaneous contraction of the quasi-2D condensate to form a self-bound one-dimensional chain of mesoscopic quantum droplets. We have also studied the real dynamics of the system using relevant parameters within the reach of current experimental capabilities, which shows that all of our predictions are experimentally feasible.
