International Conference on Quantum Optics

Obergurgl, Tirol, Austria
23–29 February 2020

Book of Abstracts

Chair:
Jörg Schmiedmayer (TU Vienna)

Co-Chairs:
Hanns-Christoph Nägerl (University of Innsbruck)
Helmut Ritsch (University of Innsbruck)

We gratefully acknowledge support from our industrial sponsors:

M
SQUARED

Radiant Dyes Laser

TOPTICA
PHOTONICS

Contents

Talks Monday, 24 February

Quantum measurement in the negative mass reference frame

Eugene Polzik
Niels Bohr Institute, Blegdamsvej 17, 2100 København Ø, Denmark
`polzik@nbi.ku.dk`

Precision of quantum measurement of motion and fields is not limited by the Heisenberg uncertainty if the motion is measured in a reference frame with an effective negative mass. Generation of entanglement between the object and the reference frame is necessary for such a measurement. The talk will present results on generation of Einstein-Podolsky-Rosen entanglement between a millimeter-size mechanical oscillator and an ensemble of atomic spins which plays the role of a negative mass reference. Generation of entanglement between increasingly macroscopic and distinct systems allows for probing the fundamental boundaries of quantum theory and is a resource for hybrid quantum networks with markedly new capabilities. Application of the negative mass reference principle to gravitational wave detectors will be described. Progress with experiments towards measurement based Fock state generation in macroscopic mechanical and atomic systems will be briefly presented.

Cooperative Scattering of light by cold atoms

Robin Kaiser
CNRS, INPHYNI, 6560 Valbonne, France
`robin.kaiser@inphyni.cnrs.fr`

Scattering of light by large clouds of cold atoms can shed new light on collective modes, including Dicke super and subradiant modes. In this talk, I will address resilience of such modes in respect to atomic motion and signatures of collective multi-mode vacuum Rabi splitting.

Simulating a Mott insulator using attractive interactions

Michael Köhl
Uni Bonn, Wegelerstrasse 8, 53115 Bonn, Germany
`michael.koehl@uni-bonn.de`

We study the particle-hole symmetry in the Hubbard model using ultracold fermionic atoms in an optical lattice. We demonstrate the mapping between charge and spin degrees of freedom and, in particular, show the occurrence of a state with "incompressible" magnetisation for attractive interactions. Our results present a novel approach to quantum simulation by giving access to strongly-correlated phases of matter through an experimental mapping to easier detectable observables.

Quantum optics and applications with cooperative 2D emitter arrays

Susanne Yelin
Harvard/University of Connecticut, 79 Larchwood Dr, 02138 Cambridge, MA, USA
`syelin@g.harvard.edu`

The physics of cooperative atoms/radiators in regular 2D arrays is dominated by two properties: first, a strongly frequency-selective reflectivity and second, the ability of confining polariton modes cleanly on the surface. This makes such a system highly sensitive to and controllable by light fields. Applications of these systems include quantum information, metrology, and nonlinear single-photon techniques.

On the vacua of cavity and waveguide QED

Peter Rabl
TU Wien, Wiedner Hauptstrasse 8-10, 1040 Wien, Austria
`peter.rabl@tuwien.ac.at`

Cavity QED is a minimal framework to study light-matter interactions in terms of two-level dipoles coupled to a single radiation mode and has therefore been a primary workhorse for the discussion of quantum optical phenomena for many decades. However, despite its omnipresence, most properties of this system are still pretty much unknown, once one enters the regime where the dipole-field coupling parameter is of order unity. Apart from a purely fundamental interest, understanding this regime becomes highly relevant in the field of circuit QED, where such conditions can now be achieved in experiments. Here I will report on some of our recent theoretical findings on this topic. Specifically, I will present a first detailed phase diagram of the possible vacua of a multi-dipole cavity QED systems as well as a general approximation method to evaluate the spectrum of extended waveguide QED systems for arbitrary coupling strength.

Macroscopic quantum superposition tests with rotating nanoparticles

Benjamin Stickler
Imperial College London, Exhibition Road, SW7 2AZ London, United Kingdom
`b.stickler@imperial.ac.uk`

Observing quantum features in the rotation dynamics of a levitated nanoparticle offers a viable route to test the quantum superposition principle and to realise ultra-precise torque sensors [1]. In this talk I will present the quantum and classical theory of how dielectric nanorotors interact with laser fields [2] and ambient environments [3]. I will argue that optically or electrically cooling the rotation into the quantum regime opens the door for the observation of macroscopic orientational quantum revivals [1], a complete recurrence of the initial orientation of a nanorotor after integer multiples of the revival time.

References

[1] Stickler, Papendell, Kuhn, Millen, Arndt, and Hornberger, New J. Phys. 20, 122001 (2018) [2] Stickler, Nimmrichter, Martinetz, Kuhn, Arndt and Hornberger, Phys. Rev. A 94 033818 (2016) [3] Stickler, Schrinski, and Hornberger, Phys. Rev. Lett. 121, 040401 (2018)

Optical Tweezer Arrays of Molecules

Loic Anderegg
Harvard University, Harvard Department of Physics, 2138 Cambridge, United States
`anderegg@g.harvard.edu`

Potential wide-ranging scientific applications have led to significant efforts in controlling molecules at the single quantum state level. Direct laser-cooling of molecules has seen great progress with the creation of the first molecular MOTs and have recently been trapped magnetically and optically. Molecules trapped in optical tweezer arrays are a powerful platform, offering the possibility of high-fidelity readout and control of individual molecules. This new platform is suited for many applications ranging from precision measurement to quantum simulation and quantum information processing. We report on the creation of such an array with ultracold CaF molecules. The high densities attained inside the tweezer traps have also enabled us to observe collisions of laser cooled molecules for the first time. We present our latest results of implementing internal state control of the molecules and tweezer merging to build a clean platform for collisional studies of ground state CaF.

Sticky collisions of ultracold RbCs molecules

Simon Cornish
Durham University, Department of Physics, DH1 4NE Durham, United Kingdom
`s.l.cornish@durham.ac.uk`

Ultracold polar molecules offer many exciting opportunities in the fields of quantum computation, quantum simulation and fundamental studies of quantum matter. Long-lived, trapped samples of molecules are crucial to many of these applications. Yet, remarkably, the nature of the collisions between molecules is poorly understood, with fast loss being observed even for chemically stable molecules such as RbCs. Here we report measurements of collisional loss in gases of ultracold RbCs molecules, comparing our findings with the “sticky collision” hypothesis that pairs of molecules form long-lived collision complexes. We demonstrate that the loss of molecules is best described by second-order rate equations, and that the rate differs from the limit of “universal loss” for s-wave collisions. Moreover, we present evidence that the loss of collision complexes is driven by laser excitation due to the dipole trapping light.

Talks Tuesday, 25 February

Dissipation-induced instability in a quantum gas

Tobias Donner
ETH Zurich, HPF D19, Otto-Stern-Weg 1, 8093 Zurich, Switzerland
`donner@phys.ethz.ch`

Dissipative and unitary processes define the evolution of a many-body system. Their interplay gives rise to dynamical phase transitions and can lead to instabilities. We observe a non-stationary, rotating state in a synthetic many-body system with independently controllable unitary and dissipative couplings. Our experiment is based on a spinor Bose gas interacting with an optical resonator. The orthogonal quadratures of the resonator field coherently couple the Bose-Einstein condensate to two different atomic spatial modes whereas the dispersive effect of the resonator losses mediates a dissipative coupling between these modes. In a regime of dominant dissipative coupling we observe a chiral evolution and map it to a positional instability.

Superfluid phases induced by the dipolar interactions

Giovanna Morigi
Universität des Saarlandes, Campus Gebäude E2.6, 66123 Saarbrücken, Germany
`giovanna.morigi@physik.uni-saarland.de`

Rebecca Kraus, Krzysztof Biedroń, Jakub Zakrzewski, Giovanna Morigi

We determine the quantum ground state of dipolar bosons in a quasi one-dimensional optical lattice and interacting via s-wave scattering. The Hamiltonian is an extended Bose-Hubbard model which includes hopping terms due to the interactions. We identify the parameter regime for which the coefficients of the interaction-induced hopping terms become negative. For these parameters we numerically determine the phase diagram for a canonical ensemble and by means of DMRG. We show that at sufficiently large values of the dipolar strength there is a quantum interference between the tunnelling due to single-particle effects and the one due to the interactions. Because of this phenomenon, incompressible phases appear at relatively large values of the single-particle tunnelling rates. This quantum interference cuts the phase diagram into two different, disconnected superfluid phases. In particular, at vanishing kinetic energy the phase is always superfluid with a staggered superfluid order parameter. These dynamics emerge from quantum interference phenomena between quantum fluctuations and interactions and shed light into their role in determining the thermodynamic properties of quantum matter.

Pulse delay statistics in a superradiant calcium laser

Andreas Hemmerich
Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
`hemmerich@physnet.uni-hamburg.de`

A superradiant laser using the 375 Hz clock line of calcium is reported. The delay time distribution of the emitted superradiant pulses is observed to directly reflect the arrival statistics of the initial spontaneous photons that trigger the classical pulses. A surprisingly elementary analytical description perfectly reproduces the observations. Laske et al., Phys. Rev. Lett. 123, 103601 (2019).

Memories, Memories, Memories, ...

Gerhard Rempe
Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1,
85748 Garching, Germany
`gerhard.rempe@mpq.mpg.de`

Photonic qubit memories are required for modern quantum information science and technology. They promote distributed computation and communication networks with hitherto classical sending and receiving nodes into quantum territory. Elementary quantum networks exist, but their memories are inefficient, and/or unfaithful, and/or fugacious. Better memories are required for long-distance quantum repeaters and possibly a quantum internet on a worldwide scale. Towards these goals, neutral-atom registers in optical cavities are ideal memories. They exhibit less dephasing than thermal ensembles, are largely insensitive to external perturbations, incorporate a directional communication interface, and enable quantum information processing. The talk presents recent advances like memory times compatible with global teleportation, the realization of a passive and heralded fiber-based memory, and a random-access memory featuring more than ten write-read cycles without re-initialization.

Supersolid properties of a Bose-Einstein condensate in a ring resonator

Claus Zimmermann
Univeristät Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany
claus.zimmermann@uni-tuebingen.de

We investigated the dynamics of a Bose-Einstein condensate interacting with two non-interfering and counter propagating modes of a ring resonator. Superfluid, supersolid and dynamic phases are identified. For sufficiently equal pump strengths we observe the emergence of a steady state with crystalline order, which spontaneously breaks the continuous translational symmetry of the system. Above a critical pump asymmetry the system evolves into a dynamic run-away instability commonly known as collective atomic recoil lasing.

Cavity induced self-organization of complex many body states

Corinna Kollath
Universität Bonn, Nussallee 14-16, 53115 Bonn, Germany
corinna.kollath@uni-bonn.de

The realization and control of non-trivial quantum phases by the coupling of quantum light and matter is currently of great interest. We investigate the coupling of atoms confined to optical lattices to a cavity field which leads to an effective long-range interaction between the atoms. We determine the coupled state of the cavity and the atoms beyond the typically employed mean field approach using two different approaches, a numerical approach based on the matrix product state and a analytical perturbative approach. We show that strong deviations from the predictions of the mean-field theory arise. In particular in the limit of strong cavity losses, a totally mixed state in the atomic sector is predicted.

Additionally, we discuss how designing a different coupling of the quantum gas to the optical cavity, can lead to a self-organization of a topologically non-trivial state. The cavity field emerges spontaneously and induces a dynamical gauge field. This feedback leads to the self-organization of the topological quantum state which carries an extended edge state as the attractor state of a dissipative dynamics in a finite system.

Cavity QED with strongly correlated Fermions

Kevin Roux
Institute of Physics, EPFL, Station 3 - Batiment PH, PH D3 304, 1015 Lausanne, Switzerland
`kevin.roux@epfl.ch`

Light-matter interaction has been investigated in cavity QED systems where the strong coupling of Bose-condensed or lattice gases to light has been realized. It has however never been achieved for Fermionic quantum matter nor for atoms with tunable interactions. We report on the first experimental realization of strong light-matter coupling for a quantum-degenerate unitary Fermi gas, in a new apparatus combining a high finesse cavity and ultracold Lithium 6 close to a Feshbach resonance. We map out the spectrum of the coupled system and observe well resolved dressed states, resulting from the strong coupling of cavity photons with each spin component of the gas. We study spin-balanced and spin-polarized gases and find quantitative agreement with ab-initio theory describing light-matter interaction. Our system offers complete and simultaneous control of atom-atom and atom-photon interactions in the quantum degenerate regime, opening a wide range of perspectives for quantum simulation.

Emergent Quasicrystalline Symmetry in Light-Induced Quantum Phase Transitions

Farokh Mivehvar
Universität Innsbruck, Technikerstraße 21/3, 6020 Innsbruck, Austria
`farokh.mivehvar@uibk.ac.at`

In many-body condensed-matter systems, the ground state of a system is usually less symmetric than the Hamiltonian of the system. That is, the ground state of the system breaks spontaneously the symmetry/symmetries of the Hamiltonian. In very rare, exotic situations, low-lying energy states of a system can be more symmetric than the Hamiltonian itself. In other words, the low-energy physics of a system possesses an "emergent" symmetry. In this talk, I show a quantum-gas-cavity system where across light-induced quantum phase transitions an eight-fold quasicrystalline symmetry emerges in low-lying energy states. More precisely, collective light scattering across superradiant phase transitions creates a quasicrystalline optical potential for the atoms. The quasicrystalline potential is "emergent" as its eight-fold rotational symmetry is not present in the Hamiltonian of the system, rather appears solely in the low-energy states.

Talks Wednesday, 26 February

Cavity-mediated spin-exchange interactions in strontium

James Thompson
JILA, 440 UCB, 80309 Boulder, USA
`jkt@jila.colorado.edu`

We will provide an overview of experimental work exploiting collective interactions between laser-cooled atoms and an optical cavity. The talk will provide a brief summary of work realizing 18 dB spin squeezed states [1], an intracavity matterwave interferometer, and a highly stable pulsed superradiant laser [2], but will largely focus on recent work observing spin-exchange interactions between strontium atoms mediated by the cavity [3] and the observation of a dynamical phase transition [4].

[1] Cox et al PRL 116, no. 9 (2016): 093602. [2] Norcia et al . "Frequency measurements of superradiance from the strontium clock transition." PRX 8, no. 2 (2018): 021036. [3] Norcia et al. "Cavity-mediated collective spin-exchange interactions in a strontium superradiant laser." Science 361, no. 6399 (2018): 259-262. [4] Muniz et al "Exploring Non-Equilibrium Phases of Matter with a Million Long-Lived Optical Dipoles in a Cavity." arXiv:1910.00439 (2019) (to appear in Nature)

Dual Bose Fermi Superfluids: probing the contact in a strongly interacting Fermi Gas

Christophe Salomon
Laboratoire Kastler Brossel, Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris, France
`salomon@lkb.ens.fr`

The contact introduced by S. Tan in 2008 is a fundamental quantity describing short range correlations in interacting quantum gases. In this talk we show that the lifetime of a Bose-Fermi mixture for weak interspecies coupling is governed by a very simple formula involving the fermionic two-body contact [1]. Using a 7Li/6Li mixture we probe the three-body recombination in both the thermal and dual superfluid regimes and find excellent agreement with our model in the BEC-BCS crossover. At unitarity where the fermion-fermion scattering length diverges, the loss rate is proportional to $\mathrm{nf}^{4/3}$ where nf is the Fermi gas density. This unusual exponent signals non-trivial two-body correlations in the system. 1. S. Laurent, M. Pierce, M. Delehaye, T. Yefsah, F. Chevy, C. Salomon, Connecting few-body inelastic decay to quantum correlations in a many-body system : a weakly coupled impurity in a resonant Fermi gas, Phys. Rev. Lett., 118, 103403 (2017)

Superradiant lasing on a forbidden transition in a thermal ensemble

Stefan Alaric Schäffer
University of Copenhagen, Blegdamsvej 17, 2100 Copenhagen, Denmark
`schaffer@nbi.dk`

The excellent advancement of atomic clocks and frequency references, has caused the community to look for quantum enhanced systems in order to further improve performance. In recent years superradiance in a bad-cavity laser has been investigated as an active rather than passive approach to optical atomic clocks and frequency references. A superradiant laser operated on a narrow optical transition in a broadband cavity will be inherently narrow in its spectrum, and further ensures suppression of mechanical cavity-noise. We present experimental and theoretical work on a superradiant laser based on the $\gamma = 2\pi 7.5\text{kHz}^1\text{S}_0 -^3\text{P}_1$ intercombination line of a thermal cloud of strontium-88. By cooling and exciting 7×10^7 atoms, we observe a superradiant pulse of light emitted into the cavity mode. We investigate dynamics and spectral dependencies to quantify the velocity-dependent effects and the systems ability to suppress Doppler-broadening in the emitted spectrum.

A dipolar supersolid of ultracold atoms

Francesca Ferlaino
Institut für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria and Institute for Quantum Optics and Quantum Information (IQOQI), Technikerstrasse 25, 6020 Innsbruck, Austria
`Francesca.Ferlaino@uibk.ac.at`

Ultracold quantum gases are both an ideal test-bed platform to address key questions in quantum physics and a powerful resource to realize novel paradigms and novel phases of quantum matter. Moreover, the potential of such systems is becoming ever more enabling as scientists acquire an increasingly fine control over optical manipulation and inter-particle interactions.

Recently, a novel class of atomic species, possessing an exceptionally strong magnetic character is entering the stage, offering a new conceptual twist for the field. In our laboratories in Innsbruck, we have realized the first dipolar Bose-Einstein condensate and Fermi gas of the highly magnetic Erbium species and the first dipolar quantum mixture of Erbium and Dysprosium.

I will report on our recent observations of the elusive and paradoxical supersolid state of quantum matter, using both Erbium and Dysprosium ultracold gases. Such paradoxical phase, in which crystal rigidity and superfluid flow coexist, has intrigued scientists across different disciplines for decades. It now became possible to create supersolidity in the ultracold thanks to the unique interplay between long-range dipolar interactions, contact interactions, and a powerful stabilization mechanism based on quantum fluctuations.

Inertial properties of blackbody radiation probed by matter wave interferometry

Philipp Haslinger
Technische Universitaet Wien- Atominstitut, Stadionallee 2, 1020 Wien, Österreich
`philipp.haslinger@tuwien.ac.at`

Blackbody (thermal) radiation is emitted by objects at finite temperature with an outward energy-momentum flow, which exerts an outward radiation pressure. At room temperature e. g. a cesium atom scatters on average less than one of these blackbody radiation photons every 10^8 years. Thus, it is generally assumed that any scattering force exerted on atoms by such radiation is negligible. However, particles also interact coherently with the thermal electromagnetic field [1] and this leads to a surprisingly strong force acting in the opposite direction of the radiation pressure [2].

[1] M. Sonnleitner, M. Ritsch-Marte, H. Ritsch, Attractive Optical Forces from Blackbody Radiation, Phys. Rev. Lett. 111 (2013) 023601. [2] P. Haslinger, M. Jaffe, V. Xu, O. Schwartz, M. Sonnleitner, M. Ritsch-Marte, H. Ritsch, H. Müller, Attractive force on atoms due to blackbody radiation, Nat. Phys. 14 (2018) 257–260.

Quantum computer in Russia: from dreams to reality

Ruslan Yunusov
Russian Quantum Center, Novaya street, 143025 Skolkovo, Russia
`ry@rqc.ru`

Russia entered the quantum race and announced the launch of the project of Rosatom corporation on building a quantum computer with a budget of $378 million. Being led by the team of the Russian Quantum Center, it aims to upgrade the level of development of quantum technologies in Russia according to the parameters described in the roadmap with guidelines by 2024 year. It includes not only the development of the quantum technologies but building new strong international collaborations, launching new competitive startups as American, Chinese and European and joining the world leaders in this field.

What's new in many body localization

Jakub Zakrzewski
Jagiellonian University, Lojasiewicza, 30-348 KRAKÓW, Poland
`jakub.zakrzewski@uj.edu.pl`

New results on MBL will be presented. In particular we shall show that MBL exists indeed despite recent claims coming from Prosen group (analysis of Thouless time). We shall report on estimates for MBL transition for experimental system sizes, discuss the existence of the mobility edge as well as consider different types of disorder amenable for cold atoms experiment (quasiperiodic, speckle). We shall also address the time-reversal symmetry breaking in MBL-related systems.

Ultra-smooth matter wave guides: Bose-Einstein Condensates at super-sonic speeds with(out) obstacles

Wolf von Klitzing
FORTH-IESL, Vassilika Vouton, 70013 Heraklion, Greece
`wvk@iesl.forth.gr`

Saurabh Pandey, Hector Mas, Giannis Drougakis, Premjith Thekkeppatt, Vasiliki Bolpasi, Georgios Vasilakis, Konstantinos Poulios, and Wolf von Klitzing

In this presentation, I will talk about our recent experiments of coherent transport of matterwaves in ultra-smooth waveguides over macroscopic distances of up to 40cm. We use optimal control theory to accelerate the atom clouds with minimal heating. The BECs move at speeds of many times the critical velocity of superfluidity. I will discuss the role of roughness of the guides and the limits for coherent transport.

[1] Gustavson, T. L., Bouyer, P. & Kasevich, M. A. Precision rotation measurements with an atom interferometer gyroscope. Phys. Rev. Lett. 78, 2046–2049 (1997).

[2] Rosi, G., Sorrentino, F., Cacciapuoti,L.,Prevedelli,M.&Tino,G.M. Precision measurement of the Newtonian gravitational constant using cold atoms. Nature 510, – (2014).

[3] Dutta, I. et al. Continuous cold-atom inertial sensor with 1 nrad/sec rotation stability. Phys. Rev. Lett. 116 (2016).

[4] Kovachy, T. et al. Quantum superposition at the half-metre scale. Nature 528, 530–533 (2015).

[5] van Zoest, T. et al. Bose-Einstein condensation in microgravity. Science 328, 1540–1543 (2010).

[6] Barrett, B. et al. Dual matter-wave inertial sensors in weightlessness. Nat. Commun. 7, 13786 (2016).

[7] Soriano, M. et al. Cold atom laboratory mission system design. 2014 IEEE Aerosp. Conf. (2014).

[8] Amico, L., Birkl, G., Boshier, M. & Kwek, L.-C. Focus on atomtronics-enabled quantum technologies. New J. Phys. 19, 20201 (2017).

[9] Lesanovsky, I. & von Klitzing, W. Time-Averaged Adiabatic Potentials: Versatile Matter-Wave Guides and Atom Traps. Phys. Rev. Lett. 99, 83001 (2007)

Correlating photons using the collective nonlinear response of atoms weakly coupled to a light field

Jürgen Volz

Insitut für Physik, HU Berlin, Newtonstr. 15, 12489 Berlin, Germany

`juergen.volz@hu-berlin.de`

The generation of correlated states of light typically requires a highly nonlinear medium that is strongly coupled to an optical mode. Here, I will report on the opposite approach. Using a strongly dissipative, weakly coupled medium, we generate and study strongly correlated states of light. Specifically, we study the transmission of resonant light through an ensemble of non-interacting atoms that weakly couple to a guided optical mode. Dissipation removes uncorrelated photons while preferentially transmitting highly correlated photons created through collectively enhanced nonlinear interactions. As a result, the transmitted light constitutes a strongly correlated state of light. This is revealed by the second-order correlation function which exhibits strong antibunching or bunching, depending on the number of atoms. This mechanism opens new ways for generating nonclassical states of light such as a novel approach towards realizing a single photon source.

Talks Thursday, 27 February

Analog Quantum Simulation: From physics to chemistry

Ignacio Cirac
Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1,
85748 Garching, Germany
`ignacio.cirac@mpq.mpg.de`

Many-body systems are very hard to simulate due to the explosion of parameters with the system size. Quantum computers can help in this task, although one may need scalable systems, something that is out of reach in the short run. An attractive alternative is provided by analog quantum simulators which, even though they are not universal, they can still be tuned to study interesting problems. Atoms in optical lattices seem to be idealy suited for that task. Most of the proposals of such simulators have focused so far on condensed matter or high energy physics problems. In this talk I will show how one can extend the range of problems to quantum chemistry.

Atom-by-atom engineering of electronic states of matter

Cristiane Morais Smith
Institute for Theoretical Physics, Utrecht University, Princetonplein 5,
3584CC Utrecht, The Netherlands
`C.deMoraisSmith@uu.nl`

Feynman's original idea of using one quantum system that can be manipulated at will to simulate the behavior of another more complex one has flourished during the last decades in the field of cold atoms. More recently, this concept started to be developed in nanophotonics and in condensed matter. In this talk, I will discuss a few recent experiments, in which 2D electron lattices were engineered on the nanoscale. The first is the Lieb lattice [1,2], and the second is a Sierpinski gasket [3], which has dimension D = 1.58. The realization of fractal lattices opens up the path to electronics in fractional dimensions. Finally, I will show how to realize topological states of matter using the same procedure. We investigate the robustness of the zero modes in a breathing Kagome lattice, which is the first experimental realization of a designed electronic higher-order topological insulator [4]. Then, we investigate the importance of the sample termination in determining the existence of topological edge modes in crystalline topological insulators. We focus on the breathing Kekule lattice, with two different types of termination [5]. In all cases, we observe an excellent agreement between the theoretical predictions and the experimental results.

[1] M.R. Slot, T.S. Gardenier, P.H. Jacobse, G.C.P. van Miert, S.N. Kempkes, S.J.M. Zevenhuizen, C. Morais Smith, D. Vanmaekelbergh, and I. Swart, "Experimental realisation and characterisation of an electronic Lieb lattice", Nature Physics 13, 672 (2017).

[2] M. R. Slot et al., "p-band engineering in artificial electronic lattices", Phys. Rev. X 9, 011009 (2019).

[3] S.N. Kempkes, M.R. Slot, S.E. Freeney, S.J.M. Zevenhuizen, D. Vanmaekelbergh, I. Swart, and C. Morais Smith, "Design and characterization of electronic fractals", Nature Physics 15, 127(2019).

[4] S.N. Kempkes, M. R. Slot, J. J. van den Broeke, P. Capiod, W. A. Benalcazar, D. Vanmaekelbergh, D. Bercioux, I. Swart, and C. Morais Smith, "Robust zero-energy modes in an electronic higher-order topological insulator: the dimerized Kagome lattice", Nature Materials 18, 1292 (2019).

[5] S. E. Freeney, J. J. van den Broeke, A. J. J. Harsveld van der Veen, I. Swart, and C. Morais Smith, "Edge dependent Z2 topology in Kekulé lattices", ArXiv: 1906.09051, under review (2019).

Universal aspects in non-equilibrium dynamics

Sebastian Erne
Atominstitut TU Wien, Stadionallee 2, 1020 Wien, Austria
`erne@atomchip.org`

Understanding the behavior of isolated quantum systems far from equilibrium and their equilibration concerns one of the most pressing open problems in quantum many-body physics. We discuss universal aspects during the non-equilibrium evolution of quantum many-body systems. Particular interest is given to self-similar scaling evolutions associated with the approach to non-thermal fixed points, offering a conceptually new access to time evolution based on a comprehensive classification of systems according to their universal properties far from equilibrium. This may be the basis for a new type of non-equilibrium quantum simulation relevant for a large variety of systems, including the early Universe after inflation, quark-gluon matter generated in heavy-ion collisions, and cold quantum gases. For the latter we present recent achievements, opportunities, and discuss open questions towards a systematic classification of universal aspects far from equilibrium.

Quantum information systems based on atom arrays and atom-like systems

Mikhail Lukin
Harvard University, 17 Oxford Street, 02138 Cambridge, MA, USA
`lukin@physics.harvard.edu`

We will describe our recent advances towards developing quantum information systems. Specifically, approaches based on reconfigurable arrays of trapped neutral atoms for realizing programmable quantum simulators and quantum information processors, as well as atom-like color center in diamond nanophotonic devices for long-distance quantum communication will be discussed.

Creation and interference of multiphoton states

Gregor Weihs
Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25,
6020 Innsbruck, Austria
`Gregor.Weihs@uibk.ac.at`

Quantum states of multiple photons are conjectured to enable all-optical quantum repeaters and quantum computers. While photon loss is ubiquitous and source and detection efficiencies are from perfect, there are models that can deal with these errors with reasonable overhead and the advantage that stochastic noise is very small in typical circuit implementations.

In our work on efficient semiconductor sources of multiphoton states we employ several types of quantum dots to create entangled photon pairs and photon triplets. Sophisticated growth and control techniques boost the efficiency and quality of the emitted quantum states. For example, with two-photon coherent excitation, we achieve high-quality time-bin entanglement [1] and nanowires act as antennas to guide multiple photons from a quantum dot molecule [2] to a collection lens. Applying multiphoton states in any linear optical network involves multiparticle interference. Our theoretical results on the complete generalization of the Hong-Ou-Mandel interference covers all possible scenarios of an arbitrary number of bosons or fermions in an arbitrary multiport beamsplitter with a surprisingly simple criterion [3]. In a slightly different setting, we experimentally investigated the interference of a time-correlated three-photon state through Franson interferometry [4]. I will show how we achieved genuine three-photon interference with high visibility, which enables tests of the foundations of quantum mechanics.

References

[1] H. Jayakumar, A. Predojević, T. Kauten, T. Huber, G. S. Solomon, and G. Weihs, Time-bin entangled photons from a quantum dot, Nature Commun. 5, 4251 (2014).

[2] M. Khoshnegar, T. Huber, A. Predojević, D. Dalacu, M. Prilmüller, et al., A solid state source of photon triplets based on quantum dot molecules, Nature Commun. 8, 15716 (2017).

[3] C. Dittel, G. Dufour, M. Walschaers, G. Weihs, A. Buchleitner, and R. Keil, Totally Destructive Many-Particle Interference, Phys. Rev. Lett. 120, 240404 (2018).

[4] S. Agne, T. Kauten, J. Jin, E. Meyer-Scott, J. Z. Salvail, et al., Observation of Genuine Three-Photon Interference, Phys. Rev. Lett. 118, 153602 (2017).

Quantum Non-Demolition Measurement of a Many-Body Hamiltonian in Analog Quantum Simulation

Peter Zoller

Center for Quantum Physics, University of Innsbruck, and IQOQI, Austrian Academy of Sciences, Innsbruck, Austria, Technikerstrasse 21a, 6020 Innsbruck, Austria

`Peter.Zoller@uibk.ac.at`

Seminal quantum optics experiments have achieved quantum non-demolition (QND) measurements in systems where the QND variable of interest is essentially a single degree of freedom. Instead, we are interested in developing scenarios of realizing, and applying QND-measurement of a complex many-body Hamiltonian. In other words, we wish to perform ‘single-shot measurements’ of ‘the energy’ of an an engineered many-body system. This involves first of all the design of a QND-Hamiltonian of a many-body ‘system’ coupled to a ‘meter’, which we illustrate for trapped ion and Rydberg tweezer arrays. QND measurement can be performed in both in an analog continuous measurement mode of the meter, e.g. as a homodyne current in a single run measuring ‘energy’; or in a digital, stroboscopic version based on a QND coupling of the system to an atomic clock qubit, allowing us to run e.g. quantum phase estimation algorithm. We illustrate various applications of the QND toolbox applicable to existing experimental settings: this includes preparation of highly excited energy eigenstates, as is of interest in ETH and quantum thermodynamics, to measurement protocols of the spectral form factor.

*) work performed in collaboration with D. Yang, A. Grankin, D. V. Vasilyev, L.M. Sieberer, M. Baranov

Heat-pumped masers as autonomous quantum heat engines

Wolfgang Niedenzu
Universität Innsbruck, Technikerstraße 21a, 6020 Innsbruck, Austria
`Wolfgang.Niedenzu@uibk.ac.at`

One of the fundamental questions in quantum thermodynamics concerns the decomposition of energetic changes into heat and work. Contrary to classical engines, the entropy change of the piston cannot be neglected in the quantum domain. As a consequence, different concepts of work arise, depending on the desired task and the implied capabilities of the agent using the work generated by the engine. Each work quantifier—from ergotropy to non-equilibrium free energy—has well defined operational interpretations. We analyse these work quantifiers for a heat-pumped three-level maser and derive the respective engine efficiencies. In the classical limit of strong maser intensities the engine efficiency converges towards the Scovil–Schulz-DuBois maser efficiency, irrespective of the work quantifier.

Cavity quantum optomechanics with an atom-array membrane

Efi Shahmoon
Weizmann Institute of Science, 234 Herzl Street, 7610001 Rehovot, Israel
`ephraim.shahmoon@weizmann.ac.il`

We consider a quantum optomechanical scheme wherein the role of a movable membrane is taken by an ordered two-dimensional array of laser-trapped atoms. The extremely light mass of the atoms yield very strong optomechanical coupling, while their spatial order and directional emission largely eliminate scattering losses. We show that this combination opens the way for the exploration of unprecedent, few-photon regimes of optomechanics. As an example, we analyze the possibility to observe optomechanically-induced quantum effects such as photon blockade or time-delayed non-classical correlations. We discuss novel opportunities opened by the optomechanical backaction on the internal states of the array atoms.

Talks Friday, 28 February

Quantum sensing of spin order

Jörg Wrachtrup
3rd Institute of Physics/ University of Stuttgart, Pfaffenwaldring 57,
70569 Stuttgart, Germany
`j.wrachtrup@pi3.uni-stuttgart.de`

Solid state spin quantum sensors have evolved into a versatile tool for measuring various parameters with quantum limited precision and nanoscale resolution. The use of single electron spins as sensors and ancilla nuclear spins as memory and processing qubits enables the application of quantum algorithms achieving improved signal processing. This allows measuring signals with multiple frequency components in an optimal way. In the talk, I will discuss the use of such spin clusters for quantum sensing. Further on, I will show application of the sensor to measure phases and structure of correlated electron materials. Prominent examples are measurements on two-dimensional spin systems showing ferro- or antiferromagnetic spin order. Phase transitions as well as novel phases by combining two-dimensional layers with different spin order can be detected.

A Large, Ion-based Quantum Computer

Marko Cetina
University of Maryland / Joint Quantum Institute, 2249 Atlantic Bldg., 4254
Stadium Dr., 20740 College Park, USA
`mcetina@umd.edu`

Marko Cetina, Laird Egan, Andrew Risinger, Daiwei Zhu, Debopriyo Biswas, Crystal Noel and Christopher Monroe

In collaboration between universities and industrial partners, we have constructed an ion-based quantum computer with the goal of realizing an error-corrected quantum bit.

I will report on the performance of our integrated system, including fidelities of single-qubit and two-qubit gates, operation with many qubits, crosstalk, and error detection.

This work is supported by the ARO with funding from the IARPA LogiQ program, the NSF Practical Fully-Connected Quantum Computer program, the DOE program on Quantum Computing in Chemical and Material Sciences, the AFOSR MURI on Quantum Measurement and Verification, and the AFOSR MURI on Interactive Quantum Computation and Communication Protocols.

Verification and characterization of large-scale quantum systems

Borivoje Dakic
University of Vienna, Faculty of Physics, 1090 Vienna, Austria
`borivoje.dakic@univie.ac.at`

An important prerequisite for real applications of quantum technologies is reliable verification, i.e. the ability to accurately benchmark the functionality of quantum devices. While practical solutions for small-sized quantum systems exist, there are two major difficulties to be addressed when dealing with quantum systems of realistic sizes: a) the issue of finite (low) measurement statistics, b) high memory and computational costs needed for classical post-processing. In this talk, I will present recent developments in probabilistic verification and characterization of large-scale quantum systems in the context of entanglement verification [1,2] and quantum state tomography [3]. These findings bring novel insights into quantum information processing, ranging from foundational to practical.

[1] A. Dimić and B. Dakić, Single-copy entanglement detection, njp Quantum Information 4, 11 (2018), [2] Saggio et al, Experimental few-copy multipartite entanglement detection, Nature Physics 15, 935–940(2019).

[3] J. Morris and B. Dakić, Selective Quantum State Tomography, arXiv:1909.05880, 2019.

Quench dynamics in integrable atomic systems

Jean-Sébastien Caux
University of Amsterdam, Institute of Physics, U. of Amsterdam, 1090 GL Amsterdam, Netherlands
`prof@jscaux.org`

This talk will present recent results on the post-quench time evolution of one-dimensional systems of relevance to atomic physics. A quick review will be given of various methods based on integrability, including the Quench Action, Generalized Hydrodynamics and Numerical Renormalization. Applications to interaction quenches and to spatially inhomogeneous quenches will be discussed.

Cavity-based non-destructive measurements

Karol Gietka
Okinawa Institute of Science and Technology Gradua, 1919-1, Tancha, 904-0495 Onna, Japan
`karol.gietka@gmail.com`

The interaction between atoms and light inside an optical cavity can lead to the creation of exotic quantum states with interesting topological properties. These properties can be harnessed to perform some specific tasks, for example, a very precise measurement of gravitational acceleration; or they can be studied by measuring the properties of the light leaking out from the cavity.

Topological excitations in quantum spin systems

Frank Verstraete
Ghent University, Krijgslaan 281, 9000 Gent, Belgium
`frank.verstraete@ugent.be`

I will discuss the nature of topological excitations in quantum spin systems, and relate their essential features to the structure of entanglement. The case of spin chains will be contrasted to the one of higher dimensional case.

Experimental manipulation of encoded qubits

Thomas Monz
Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria
`Thomas.Monz@uibk.ac.at`

Quantum information processing has seen tremendous progress in the field of control of individual qubits. As systems are scaled up, encoded qubits consisting of several physical qubits paired with quantum error correction promise to overcome remaining limitations large-depth calculations due to error rates. In this presentation the experimental correction of loss of a physical qubit within a topologically encoded qubit will be presented and complemented by work towards lattice surgery in an ion-trap based quantum computer.

Recent developments of atom optics experiments in space

Naceur Gaaloul
Leibniz Universität Hannover / Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany
`gaaloul@iqo.uni-hannover.de`

Space-borne quantum technologies and more particularly atom-based devices are announcing a new era of strategic intense space exploitation. Indeed, space offers a unique environment characterised by low-noise and low-gravity necessary for various applications ranging from time and frequency transfer to Earth observation and the exploration of fundamental laws of physics. Efforts to operate atom physics experiments in these ideal conditions are however challenged by a number of technical limitations. In this contribution, we report about the results of two pioneering successful space implementations of atom optics experiment. The first is the launch of an atom-chip-based BEC machine aboard a sounding rocket. The second is a BEC facility on board of the ISS establishing an in-orbit presence of quantum optics in space. The outcome of several campaigns of experiments is presented. Their significance for follow-up fundamental physics missions is also highlighted.

Posters

Quantum Computing with Graphene Plasmons

Irati Alonso Calafell
University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria
`irati.alonso.calafell@univie.ac.at`

Among the various approaches to quantum computing, all-optical architectures are especially promising due to the robustness and mobility of single photons. However, the creation of the two-photon quantum logic gates required for universal quantum computing remains a challenge. Here we propose a universal two-qubit quantum logic gate, where qubits are encoded in surface plasmons in graphene nanostructures, that exploits graphene's strong third-order nonlinearity and long plasmon lifetimes to enable single-photon-level interactions. In particular, we utilize strong two-plasmon absorption in graphene nanoribbons to prevent the gate from evolving into undesired failure modes via the quantum Zeno effect. Our gate does not require any cryogenic or vacuum technology, has a footprint of a few hundred nanometers, and reaches fidelities and success rates well above the fault-tolerance threshold, suggesting that graphene plasmonics offers a route towards scalable quantum technologies.

Observation of the relativistic reversal of the ponderomotive potential

Jeremy Axelrod
University of California, Berkeley, 366 LeConte Hall #7300, 94720-7300 Berkeley, USA
`jaxelrod@berkeley.edu`

The interaction between a non-relativistic charged particle and a free-space electromagnetic wave can be described by the ponderomotive potential. Although ponderomotive electron-laser interactions at relativistic velocities are important for emerging technologies from laser-based particle accelerators to laser-enhanced electron microscopy, the effects of special relativity on the interaction have only been studied theoretically. We use a transmission electron microscope to measure the position-dependent phase shift imparted to a relativistic electron wave function when it traverses a standing laser wave. In contrast to the non-relativistic case, we demonstrate that the phase shift depends on both the electron velocity and the wave polarization. Remarkably, if the electron's speed is greater than $1/\sqrt{2}$ of the speed of light, the phase shift at the electric field nodes of the wave can exceed that at the antinodes. In this case there exists a polarization such that the phase shifts at the nodes and antinodes are equal, and the electron does not experience Kapitza-Dirac diffraction.

Multipartite entanglement criteria for two body reduced states

Flavio Baccari
MPQ, Hans-Kopfermann-Straße 1, 85748 Garching bei München, Germany
`flavio.baccari@mpq.mpg.de`

Entanglement is one of the most peculiar aspects of quantum theory and is a key feature for several quantum information protocols. However, detecting its presence in multipartite states remains challenging both experimentally and theoretically. The main reason being that most of the know criteria either apply to very specific sets of states or require an effort that scales exponentially with the system size. Here I will present a separability criterion that applies to the two-body reduced density matrices of any multipartite state. Such a criterion allows for a numerical test of entanglement, based on semidefinite programming, whose computational effort scales polynomially with the systems size. Additionally, since the knowledge of only the two-body reduced states is required, the proposed test can be efficiently implemented in state-of-the-art experiments. I will show examples of applications of the proposed entanglement test and comparison to previous separability criteria.

Polarization-preserving quantum frequency conversion as tool for long-distance quantum networks

Matthias Bock
Saarland University, Campus E26, Room 2.05, 66123 Saarbrücken, Germany
`m.bock@physik.uni-saarland.de`

An essential part of quantum networks is entanglement of remote stationary quantum nodes mediated by photons transmitted through optical fiber links. Most quantum nodes, however, have transition wavelengths in the blue, red or near-infrared spectral regions, whereas long-range fiber-communication requires wavelengths in the low-loss telecom regime. A proven tool to interconnect flying qubits at visible/NIR wavelengths to the telecom bands is quantum frequency conversion (QFC). Focusing on trapped single atoms or ions as quantum nodes, photon polarization is commonly used to encode quantum information. In this context, we will present highly efficient (57%) and low-noise polarization-preserving QFC devices connecting 854nm – a transition wavelength in a Ca-ion – and the D2-line of neutral Rb-atoms at 780nm to the telecom bands. This enabled the demonstration of photon-photon entanglement, atom/ion-photon entanglement and atom-to-photon state transfer over 20km of fiber.

Optimised Raman pulses for atom interferometry

Max Carey
University of Southampton, School of Physics & Astronomy, SO17 1BJ University of Southampton, Highfield, UK
`max.carey@soton.ac.uk`

Max Carey, Jack Saywell, Mohammad Belal, Ilya Kuprov, Tim Freegarde

Fractional Rabi oscillations between ground hyperfine states are commonly used as the mirror and beamsplitter operations of atom interferometers. However, contrast and sensitivity are reduced when there are variations in laser intensity, atom velocity, Zeeman state or magnetic field across the atomic sample. Happily, NMR composite pulses, and their development using optimal control techniques, offer robust alternatives provided the laser phase can be modulated during the pulse operation. This is in many atom interferometers straightforward.

We report the theoretical design and experimental demonstration of robust mirror and beamsplitter operations and sequences for atom interferometry. For a 35μK sample of ^{85}Rb we have shown that the inversion efficiency of a mirror pulse is increased from 75(3)% to 99.8(3)%, and that 90% transfer efficiency is maintained at detunings for which the pi-pulse fidelity is below 20%. By applying symmetries to cancel errors between pulses, we have begun to explore optimisation of the interferometer sequence as a whole, achieving a threefold improvement in fringe visibility for a 100μK sample. We have also designed augmentation pulses that track the velocities of the two arms of a large momentum transfer interferometer and promise significant improvements over previous pulses including adiabatic rapid passage.

Classical verification of quantum computations on small quantum computers

Jose Carrasco
University of Innsbruck, Technikerstraße 21, 6020 Innsbruck, Austria
`jose.carrasco@uibk.ac.at`

We review the protocol allowing classical verification of efficient quantum computations and explicitly show how it admits a simple analytical treatment for systems made up of a small number of qubits, where security requirements can be relaxed. From a general point of view, since this construction has been possible by properly combining several techniques and previous research, one of the main aims of these notes is to provide a self-contained review of the different ideas that leaded to this result. We try to give a clear and unifying global picture and to provide specific examples, specially for a small number of qubits, at every step of this process.

Using deep learning to model and control a reconfigurable quantum photonic device

Robert Chapman
University of Innsbruck, Photonics Group, Technikerstrasse 25D, 6020 Innsbruck, Austria
`robert.chapman@uibk.ac.at`

As reconfigurable quantum photonic circuits grow in complexity, they become increasingly challenging to model and control. Not only can the structure of the internal Hamiltonian be unknown, but the electrical control signals can suffer from drift and coupling losses can distort the optical measurement. Here, we present a deep neural network to model and control a programmable photonic continuous-time quantum walk. We develop a novel "grey-box" approach where we treat unknown parameters, such as the form of the Hamiltonian and the electrical control response as a "black-box", while treating the known components, including Hamiltonian evolution and measurements analytically as a "white-box". We demonstrate high-performance on a simulator of the chip for modelling and subsequently preparing desired unitaries, with typical fidelities $> 99\%$. Our method is efficient in the number of required parameters and fully generic to the quantum circuit design and physical hardware.

Cooling and Coherence of ions in a Penning trap.

Oliver Corfield
Imperial College London, Imperial College London, SW72AZ London, UK
`oliver.corfield16@imperial.ac.uk`

In trapped ions, the coherent manipulation of quantum states has historically been the domain of RF traps. This is primarily due to the increased complexity of laser cooling, and reduced optical access available in Penning traps. However Penning traps operate using static fields, enabling the formation of crystals with no micromotion, and low anomalous heating rates. We present results of sideband cooling the motion of a single ion, achieving mode occupation of $n_z = 0.02(1)$ in the axial, and $n_+ = 0.35(5)$, $n_- = 1.7(2)$ in the coupled radial modes. These studies are extended to ground state cooling of the motion in small ion crystals. We can coherently manipulate both atomic and motional states, and present preliminary results showing coherence between 3 motional states. A coherent superposition of 3 path alternatives will exhibit interference in a manner analogous to a 'triple slit' version of Young's famous double slit experiment.

Tailoring light states using cavity QED

Severin Daiss
Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany
`severin.daiss@mpq.mpg.de`

The generation of non-classical light states with custom temporal shapes is an important ingredient in many Quantum Communication protocols. Here we use a single 87Rb atom strongly coupled to an optical resonator to manipulate an incident weak laser pulse. We reflect the light from our atom-cavity system and thus entangle it with the atomic state. Suitable measurements on the atom allow for the production of optical cat-states with full control over phase and amplitude of the final light state (Hacker, Welte, Daiss, Shaukat, Ritter, Li and Rempe, Nat. Photon. 13, 110 (2019)). Furthermore, we can use our experiment to distill single photons with tailored temporal mode profiles out of incoming weak coherent pulses (Daiss, Welte, Hacker, Li and Rempe , Phys. Rev. Lett. 122, 133603 (2019)). Our protocol only requires an emitter strongly coupled to a resonator and can thus be a valuable tool in different experimental platforms.

Self-similar scaling dynamics in a far-from-equilibrium homogeneous Bose gas

Lena Dogra
University of Cambridge, Cavendish Laboratory, J J Thomson Avenue, CB3 0HE Cambridge, United Kingdom
`lhb31@cam.ac.uk`

Out-of-equilibrium processes can exhibit remarkable scaling properties independent of a system's microscopic details. Here we demonstrate such scaling using a weakly interacting Bose gas of K-39 in a homogeneous trapping potential. To create a well-defined far-from-equilibrium state we first prepare a non-interacting cloud just above the critical temperature for Bose-Einstein condensation. We then dramatically truncate the momentum distribution by temporarily lowering the trap depth, removing over 2/3 of the atoms and over 90% of the energy. In order to start the experimental clock we rapidly turn on the inter-particle interactions, before observing the ensuing relaxation dynamics through the BEC phase transition in a closed environment. We find that the evolution of the momentum distribution displays self-similar scaling behaviour in time and we map out the effect of inter-particle interactions on these dynamics.

Entanglement and symmetries of stabilizer states

Matthias Englbrecht
University of Innsbruck, Innrain 83, 6020 Innsbruck, Austria
`Matthias.Englbrecht@uibk.ac.at`

Stabilizer states constitute a set of pure states which play a dominate role in quantum error correction, measurement-based quantum computation, and quantum communication. Central in these applications are the local symmetries of the states. We characterize all local symmetries of arbitrary stabilizer states and provide an algorithm which determines them. We demonstrate the usefulness of these results by showing that the additional local symmetries find applications in quantum error correction and entanglement theory.

Characterizing large-scale quantum computers via cycle benchmarking

Alexander Erhard
University of Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria
`alexander.erhard@uibk.ac.at`

Quantum computers promise to solve certain problems more efficiently than their digital counterparts. A major challenge towards practically useful quantum computing is characterizing and reducing the various errors that accumulate during an algorithm running on large-scale processors. Current characterization techniques are unable to adequately account for the exponentially large set of potential errors, including cross-talk and other correlated noise sources. Here we develop cycle benchmarking, a rigorous and practically scalable protocol for characterizing local and global errors across multi-qubit quantum processors. We experimentally demonstrate its practicality by quantifying such errors in non-entangling and entangling operations on an ion-trap quantum computer with up to 10 qubits, with total process fidelities for multi-qubit entangling gates ranging from 99.6(1)% for 2 qubits to 86(2)% for 10 qubits. Furthermore, cycle benchmarking data validates that the error rate per single-qubit gate and per two-qubit coupling does not increase with increasing system size.

A new mass record of matter-wave interference

Yaakov Fein
University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria
`Yaakov.fein@univie.ac.at`

Interferometry of massive particles can be used to rule out modifications to quantum mechanics, test the equivalence principle, and measure molecular properties. I present results from the new Long Baseline Universal Matter-wave Interferometer (LUMI) in Vienna, a three-grating Talbot-Lau interferometer with a two-meter baseline. The long baseline makes the experiment compatible with de Broglie wavelengths as small as 35 fm. We have recently demonstrated interference with the most massive particles to date [1], a molecular library with masses exceeding 25.000 u, allowing us to set new bounds on the parameter space of continuous spontaneous localization models.

[1] Fein et al., Nat. Phys. (2019) doi:10.1038/s41567-019-0663-9.

Slow light pulse propagation through spherical quantum dot with hydrogen impurity in magnetic field

Nikola Filipovic
Faculty of Sciences and Mathematics Nis, Visegradska 33, 18000 Nis, Serbia
`nikola.filipovic@pmf.edu.rs`

The weak probe pulse propagation through the medium consisted of semiconductor spherical quantum dots with on-center hydrogen impurity is theoretically studied. The strong control laser couples to the medium as well, forming the three-level ladder scheme and creating the effect of the electromagnetically induced transparency. The density matrix formalism is used to describe the dynamics of the medium, and Maxwell-Bloch equations are solved numerically to obtain the spatio-temporal dependence of the probe pulse envelope. It is found that by manipulating the control field one can generate effects such as slow and stored light. The external static magnetic field is shown to affect the energy structure and dipole transition elements of the confined hydrogen atom, making a significant impact on the pulse propagation. These phenomena can be of huge importance in the area of quantum information processing, leading to the construction of optical buffers, optical switches and memory elements.

Photonic architecture for reinforcement learning

Fulvio Flamini
University of Innsbruck, Technikerstrasse 21a, 6020 Innsbruck, Austria
`fulvio.flamini@uibk.ac.at`

The last decade has seen an unprecedented growth in artificial intelligence and photonic technologies, both of which drive the limits of modern-day computing devices. This work brings together the state of the art of both fields within the framework of reinforcement learning. We present the blueprint for a photonic implementation of an active learning machine incorporating contemporary algorithms such as SARSA, Q-learning, and projective simulation. We numerically investigate its performance within typical reinforcement learning environments, showing that realistic levels of noise can be tolerated or even be beneficial for the learning process. Remarkably, the architecture itself enables mechanisms of abstraction and generalization, key features for artificial intelligence. The proposed architecture, based on single-photon evolution on a mesh of tunable beamsplitters, is simple, scalable, and a first integration in quantum optics appears to be within the reach of near-term technology.

Quantum Rangefinding

Stefan Frick
University of Innsbruck, Technikerstraße 25d, 6020 Innsbruck, Austria
`stefan.frick@uibk.ac.at`

If the illumination source of a rangefinder is replaced with a spontaneous parametric down-conversion source, producing broadband photon-pairs, the light emitted from such a device becomes thermal. This is achieved by engineering the poling structure of a periodically poled potassium titanyl phosphate crystal to enable broad phase-matching. One half of the resulting two-mode squeezed state is sent towards a rangefinding target which can only detect this mode in a maximally mixed state due to the lack of the information stored in its partner mode. On the other hand, full information of the targets position can be reconstructed on the rangefinders side when the time delay between both modes is correlated. Moreover, a signal-to-noise ratio comparable to single spectral mode illumination can be recovered by exploiting the frequency correlations in the broad-band state. Here we present an implementation of such a rangefinder developed at the University of Bristol.

Scrambling in Bose Einstein condensate

Martin Gärttner

Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

`martin.gaerttner@kip.uni-heidelberg.de`

Out-of-time-order correlators are indicators of quantum chaos and scrambling of quantum information. We propose a scheme for measuring out-of-time order correlators in a spinor Bose Einstein condensate subject to mode-changing collisions. This system features a well-defined classical limit for large mode occupations. The classical mean-field dynamics can be tuned from regular to chaotic by changing the strength of a driving field. We study traditional indicators of classical and quantum chaos like Poincaré sections, Lyapunov exponents, and level statistics and then focus on the dynamics of the squared commutator at finite particle numbers. Full quantum calculations reveal the onset of a regime of exponential growth of the OTOC which we confirm using semi-classical truncated Wigner simulations.

Observation of First and Second Sound in a Homogeneous Bose Gas

Timon Hilker

University of Cambridge, JJ Thomas Avenue, CB3 0HE Cambridge, United Kingdom

`tah48@cam.ac.uk`

The existence of two distinct sound velocities is one of the hallmarks of superfluids. In a compressible quantum gas both modes couple to density, which allows us to observe, for the first time, both sound velocities in a moderately interacting ultracold Bose gas. Using a magnetic field gradient, we excite centre-of-mass oscillations of a homogeneous K-39 Bose gas in a three-dimensional box trap, revealing two distinct resonant oscillations. In a microscopic analysis of the mode structure, we find quantitative agreement with the hydrodynamic description of Landau's two-fluid model in terms of in-phase (out-of-phase) oscillations dominated by the thermal (BEC) atoms for the first (second) sound. We study the speed and the damping of both modes for various interaction strengths and temperatures and investigate in particular the highly non-linear damping of the BEC close to zero temperature.

Scalable quantum information processing with trapped ions

Pavel Hrmo
University of Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria
`pavel.hrmo@uibk.ac.at`

Trapped atomic ions offer an advanced platform to perform universal gate operations for performing arbitrary quantum computation. One remaining major challenge is scaling up the number of qubits, such that quantum error correction on logical qubits may be performed. We use a cryogenically cooled planar surface trap with multiple trapping zones as an approach to overcome this challenge. This setup supports the confinement of two ion species, Ca+ and Sr+. By using the Ca+-ion as an optical qubit, we are able to reach coherence times up to 11.5ms and create maximally entangled Ca-Ca states with fidelities of 98(3)%.

Non-equilibrium magnetic phases in spin lattices with gain and loss

Julian Huber
TU Wien, Wiedner-Hauptstr. 8-10, 1040 Wien, Austria
`huberjulian@gmail.com`

We study the magnetic phases of a prototype non-equilibrium spin chain, where coherent interactions between neighboring lattice sites compete with alternating gain and loss processes. We show that this competition between coherent and incoherent dynamics induces transitions between magnetically aligned and highly mixed phases, across which the system changes from a low- to an efective infinite-temperature state. Although in many ways consistent with regular first- and second-order phase transitions, a striking difference in this model is that the corresponding stationary states do not exhibit the expected signatures of phase co-existence or the breaking of the underlying U(1) symmetry. Instead, we find that the origin of these transitions can be traced back to the purely dynamical effect of parity-time-reversal symmetry breaking, which has no counterpart in the conventional theory of phase transitions.

Geometric phases for periodically driven systems

Gediminas Juzeliunas
Vilnius University, Department of Physics, Saulėtekio 3, LT-10257 Vilnius, Lithuania
`gediminas.juzeliunas@tfai.vu.lt`

We show that adiabatic evolution of a system within a degenerate Floquet band can provide geometric phases. This is the case if the Hamiltonian is a product of a slowly changing Hermitian operator V and a fast oscillating periodic with a zero temporal average [1]. The former operator V depends on a set of slowly changing parameter u=u(t). By fixing the parameters u, the system has fully degenerate Floquet bands. When the slowly varying parameters u=u(t) complete a closed loop, non-Abelian (non-commuting) geometric phases are formed with no dynamical phases masking the geometric phases. This can be used for precisely controlling the evolution of quantum systems, such as for performing qubit operations. The general formalism is illustrated by analyzing a spin in an oscillating magnetic field with a slowly changing direction. [1] V. Novičenko, G. Juzeliūnas, G. Phys. Rev. A 100, 012127 (2019).

Interfacing and entangling single 40Ca+ ions with single photons for quantum network applications

Stephan Kucera
Saarland University, Campus E2 6, 66123 Saarbrücken, Germany
`stephan.kucera@mx.uni-saarland.de`

We are implementing a comprehensive set of single-atom-single-photon quantum interfaces that enable controlled generation, storage, transmission, conversion, and entanglement of photonic and atomic qubits in quantum networks. Specifically, we demonstrated a programmable ion-photon interface, employing controlled quantum interaction between a single trapped 40Ca+ ion and single photons. Depending on the choice of input and output qubits, the interface protocol serves as an atom-to-photon or photon-to-atom qubit converter, as a source of entangled atom-photon pair states, or for atom-photon Bell-state projection. To increase the efficiency of the interfaces, we investigate a new segmented ion trap design with an integrated fiber cavity. The fiber cavity is incorporated into the center electrodes of the trap, which shields the fibers from lasers and protects the ion from charge accumulation on the fiber mirrors.

Nondestructive photon counting in waveguide QED

Daniel Malz
Max Planck Institute of Quantum Optics, Hans-Kopfermann-Strasse,
85748 Garching, Germany
`daniel.malz@mpq.mpg.de`

Number-resolving single-photon detectors represent a key technology for a host of quantum optics protocols, but despite significant efforts, state-of-the-art devices are limited to few photons. In contrast, state-dependent atom counting in arrays can be done with extremely high fidelity. Here we show that in waveguide QED, the problem of photon counting can be reduced to atom counting by means of engineered dissipation. Our scheme is robust to disorder and finite Purcell factors, and its fidelity increases with atom number. We further show that if the initial atom state is a symmetric Dicke state, dissipation engineering can be used to implement a nondestructive photon number measurement, where the incident state is re-emitted into the waveguide unchanged.

Atom interferometry with a large spacing beat-note optical lattice

Leonardo Masi
CNR (INO) - LENS, Via nello Carrara, 1, 50019 Sesto Fiorentino, Italy
`masi@lens.unifi.it`

The size of the sensors and the finite interrogation time still pose limitations to the spatial resolution and the sensitivity of interferometers based on free falling atomic samples. Interferometric schemes based on trapped Bose-Einstein condensates can overcome these limitations. We report the realization of a large spacing optical lattice making use of an innovative technique that exploits the beating note between two retro-reflected lattices at 1064 nm and 1013 nm. The resulting potential exhibits a slow modulation that provides an effective optical lattice with a periodicity of 10 micron, much larger than the wavelengths implemented. We study spatial Bloch oscillations in presence of an external force cancelling the interactions via a magnetic Feshbach resonance and observing a coherent dynamics up to 1 s. The novel lattice offers interesting perspectives for the realization of high-sensitivity and highly compact double-well interferometers.

Emission of correlated jets from a driven matter-wave soliton

Tadej Mežnaršič
Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia
`tadej.meznarsic@ijs.si`

Modulation of the interaction between the atoms in a Bose-Einstein condensate excites a density wave. If the modulation is strong, matter-wave jets are emitted from the condensate. We demonstrate the emission of correlated atom jets from a matter-wave soliton in a quasi-one-dimensional optical trap. We characterize the dependence of jet properties on the frequency, amplitude and length of the modulation, and qualitatively reproduce the trends in the mean-field picture with a one-dimensional time-dependent Gross-Pitaevskii equation simulation. High-order jets are observed for sufficiently long pulses. A double-pulse modulation sequence produces consecutive jets, and a multi-pulse sequence may lead to irregular 3D jets at a finite angle to the direction of the channel. In the limit of vanishing high-order jets beyond-mean-field number correlations of jet pairs and number squeezing are demonstrated.

Portable BECs and Degenerate Cavity QED

Devang Naik
LP2N Institut d'Optique d'Aquitaine, LP2N Institut d'Optique d'Aquitaine, 33400 Talence, Francia
`paolofaviano@gmail.com`

We will present our work on exploring emergent phenomena – such as crystallization, glassiness, supersolidity – with multiple BECs inside a butterfly cavity. The degenerate and translationally-invariant nature of a traveling-wave ring cavity allows one to explore so far inaccessible phenomena such as the dynamics of defects, melting, phonon-like excitations, crystal frustration, super-solidity, and massively entangled systems. Exploiting the peculiar geometry of the cavity, we seek to implement cavity-mediated long-range interactions between independent BEC's trapped in the high order cavity modes. We will present our work on both portable BECs for test of the Weak Equivalence Principle.

Towards characterization of LOCC transformations in a multi-state setting

Antoine Neven
Universität Innsbruck, Technikerstraße 21, 6020 Innsbruck, Austria
`antoine.neven@uibk.ac.at`

The LOCC paradigm provides a physically meaningful (partial) ordering of entangled states. For bipartite states this ordering can be simply established using a majorization condition. For multipartite states, however, this ordering becomes trivial as almost all states are isolated under LOCC. To overcome this limitation, one can for instance increase the resource of LOCC by considering a multi-state setting. A transformation between two states that is impossible in the single-copy regime may then become possible with the addition of auxiliary states. In this poster, we show that already in the two-state setting and with operations restricted to local unitaries, transformations that were not possible even probabilistically become now possible in a deterministic way. For bipartite states, we provide a characterization of the new possible transformations.

Tweezer arrays and dipolar interacting gases with multi-electron atoms

Matthew Norcia
IQOQI, , ,
`mattanorcia@gmail.com`

Extending techniques of experimental control to more complex atomic species can yield exciting new opportunities for metrology and explorations of systems of interacting quantum objects. This poster will discuss recent results from two such experimental systems: arrays of alkaline earth atoms confined within optical tweezers, and quantum gases formed from atoms with dipolar interactions. The former has enabled highly coherent atom-light interactions, making it a promising new platform for optical frequency metrology, while the latter has enabled studies of the elusive and counterintuitive supersolid quantum phase.

Extraordinary subradiance and excitation transfer in dipole-coupled rings of quantum emitters

Laurin Ostermann
Institute for Theoretical Physics, Technikerstraße 21a, 6020 Innsbruck, Austria
`laurin.ostermann@uibk.ac.at`

A ring of sub-wavelength spaced dipole-coupled quantum emitters possesses only few radiant but many extraordinarily subradiant collective modes. These exhibit a 3D-confined spatial radiation field pattern forming a nano-scale high-Q optical resonator. We show that tailoring the geometry, orientation and distance between two such rings allows for increasing the ratio of coherent ring-to-ring coupling versus free-space emission by several orders of magnitude. In particular we find that subradiant excitations, when delocalized over several ring sites, are effectively transported between the rings with a high fidelity.

Unraveling the quantum nature of atomic self-ordering in a ring cavity

Stefan Ostermann
University of Innsbruck, Technikerstraße 21a, 6020 Innsbruck, Austria
`stefan.ostermann@uibk.ac.at`

Atomic self-ordering to a crystalline phase in optical resonators is a consequence of the intriguing non-linear dynamics of strongly coupled atom motion and photons. Generally the resulting phase diagrams and atomic states can be largely understood on a mean-field level. However, close to the phase transition point, quantum fluctuations and atom-field entanglement play a key role and initiate the symmetry breaking. Here we propose a modified ring cavity geometry, in which the asymmetry imposed by a tilted pump beam reveals clear signatures of quantum dynamics even in a larger regime around the phase transition point. Quantum fluctuations become visible both in the dynamic and steady-state properties. Most strikingly we can identify a regime where a mean-field approximation predicts a runaway instability, while in the full quantum model the quantum fluctuations of the light field modes stabilize uniform atomic motion.

Chimera states in small optomechanical arrays

Karl Pelka
University of Malta, 26, Triq Nazju Falzon, Flat Nr. 6, MSD 1721 Msida, Malta
`karl.a.pelka@um.edu.mt`

The study of optomechanical systems is evolving beyond the exploration of a single optomechanical "cell," composed of a moving mirror interacting with the electromagnetic field, towards the study of optomechanical networks consisting of several cells. In this work we explore the emergence of chimera states in such systems. These states, which straddle the boundary between synchronised and non-synchronised dynamics, are a genuinely many-body effect. Our work lies firmly in reach of present-day experiments, showcases a new method (Ott–Antonsen ansatz) to study the dynamics of optomechanical networks analytically, and has implications for optomechanical technologies.

Relaxation to a Phase-locked Equilibrium State in a One-dimensional Bosonic Josephson Junction

Marine Pigneur
TU Wien - Atominstitut, Stadionallee 2, 1020 Wien, Austria
`marine.pigneur@tuwien.ac.at`

We present the experimental study of a relaxation phenomenon occurring in a one-dimensional bosonic Josephson junction. The system consists of two 1D quasi Bose-Einstein condensates of 87Rb, magnetically trapped on an atom chip. Using radio-frequency dressing, we deform a single harmonic trap, in which the atoms are initially condensed, into a double-well potential and realize a splitting of the wave function. A large spatial separation and a tilt of the double-well enable us to prepare a broad variety of initial states by precisely adjusting the initial population and relative phase of the two wave packets, while preserving the phase coherence. By re-coupling the two wave packets, we investigate tunneling regimes such as Josephson (plasma) oscillations and macroscopic quantum self-trapping.

In both regimes, we observe that the tunneling dynamics exhibits a relaxation to a phase-locked equilibrium state contradicting theoretical predictions. We support the experimental results with an empirical model that allows quantitative discussions according to various experimental parameters.

Tackling numerical problems in quantum optics with Julia

David Plankensteiner
Theoretical Physics / University of Innsbruck, Technikerstrasse 21a,
6020 Innsbruck, Austria
`david.plankensteiner@uibk.ac.at`

We present the open-source computational framework QuantumOptics.jl geared towards the efficient numerical investigation of open quantum systems written in the Julia programming language. Built exclusively in Julia and based on standard quantum optics notation, the toolbox offers speed comparable to low-level statically typed languages, without compromising on the accessibility and code readability found in dynamic languages. We showcase the framework's capabilities in examples implementing generic quantum models. Furthermore, we explore ways to circumvent the fundamental limitation introduced by the size of the Hilbert space by truncating large systems to low orders of quantum correlations.

Operationally meaningful representations of physical systems in neural networks

Hendrik Poulsen Nautrup
Innsbruck University, Technikerstraße 21a, 6020 Innsbruck, Austria
`hendrik.poulsen-nautrup@uibk.ac.at`

Recent years have seen a surge of interest in applying machine learning techniques to questions in science. To make fundamental progress in science, we often build representations of nature endowed with a meaningful and abstract structure to describe physical systems. The representations learnt by current machine learning techniques reflect statistical structure present in the training data; however, they do not allow us to specify explicit and physically meaningful requirements on the representation. Here, we present a neural network architecture that learns representations of physical systems from experimental data such that different parameters in the representation are operationally meaningful within various experimental settings. We provide an interpretation of this model in terms of communicating agents collectively learning a physical theory and present toy examples involving classical and quantum physics as well as the design of experimental settings.

Ultracold atom-ion systems in spatially separated traps

Fabio Revuelta
Universidad Politecnica de Madrid, ETSIAAB, Univ.Politecnica de Madrid, 28040 Madrid, Spain
`fabio.revuelta@upm.es`

We present a numerical method for describing a hybrid system of an ultracold neutral atom and a single ion confined in spatially separated three-dimensional trapping potentials. The interaction between the neutral atom and the ion is modeled using realistic Born-Oppenheimer potential curves obtained from ab initio quantum chemistry calculations. An application of the approach to the hybrid atom-ion system of Li_2^+ isotope reveals the trap-induced resonances that manifest as avoided crossings between the molecular bound states and the unbound trap states as a function of the separation between the two traps.

Quantum-assisted molecule measurements

Philipp Rieser
University of Vienna, zur Fischa 3, 2440 Gramatneusiedl, Austria
`philipp.rieser@univie.ac.at`

Philipp Rieser, Armin Shayeghi and Markus Arndt Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna

Molecular quantum optics deals with phenomena related the wave nature of molecules, particularly their interaction with light. Molecule interferometers create nanoscale fringe patterns in molecular beams and are sensitive to shifts caused by external perturbations at nanometre scale [1]. This sensitivity to beam shifts and dephasing can be used to extract molecular properties [2,3], which are particularly interesting for complex biomolecular systems [4]. Molecular matter-wave experiments with biomolecules may open a wide field of research at the interface between quantum optics and bioanalytical chemistry.

References [1] M. Arndt, Phys. Today 67, 30-36 (2014). [2] S. Eibenberger et al, Phys. Rev. Lett. 112, 250402 (2014). [3] L. Mairhofer et al, Angew. Chem. Int. Ed. 56, 10947 (2017). [4] M. F. Jarrold, Annu Rev. Phys. Chem. 51, 179 (2000).

Higher-Order Interference within Quantum Mechanics induced by Nonlinearities

Lee Rozema
University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria
`lee.rozema@univie.ac.at`

The double-slit experiment is a direct demonstration of interference between quantum objects. Similar experiments with more slits also produce interference. Quantum theory is often interpreted as stating that higher-order interference come from a combination of double-slit interference; this is a direct consequence of Born's rule depending on the square of the wavefunction. Hence, it is concluded that quantum theory is a second-order theory. Higher-order extensions of quantum theory have been proposed, and recent experiments have attempted to place limits such theories.

We show that standard quantum mechanics actually allows for high-order interference, if one considers multiple quantum objects and nonlinearity. We provide experimental confirmation using a photonic system and strong optical nonlinearities. Our work highlights hidden assumptions in the framework of higher-order quantum theories, and will help guide future experiments bounding quantum theory.

Towards ultrafast infrarfred spectroscopy with trapped ions

Philipp Schindler
University of Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria
`philipp.schindler@uibk.ac.at`

We propose a method to investigate the vibrational dynamics of single polyatomic molecular ions confined in a Paul trap. Quantum logic techniques are employed to detect the recoil of single photon absorption events on the molecule via a co-trapped atomic ion. In particular, the recoil is mapped onto the electronic state of the atom which can be read out with high fidelity. This recoil detection serves as the basis for a pump-probe scheme to investigate ultrafast molecular dynamics, such as intra-molecular vibrational redistribution. The total recoil from the interaction with a sequence of ultrafast laser pulses with the molecular vibration is measured. This work discusses the experimental requirements and expected performance for multiple molecular ions with masses ranging from 17 to 165 Dalton.

Macroscopicity of matter wave interference

Björn Schrinski
Universität Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany
`bjoern.schrinski@uni-due.de`

One driving force to motivate interference experiments involving high masses, long interference times, and large path separations is to verify the validity of the Schrödinger equation on ever larger scales. The degree of macroscopicity can be assessed by the amount of falsified modifications of quantum mechanics (collapse models [1]) which may be quantified with help of the underlying parameter space [2]. We focus on the fundamental measurement outcomes by applying Bayesian parameter estimation [3] and discuss state of the art experiments [4,5,6].

[1] Bassi et al., Rev. Mod. Phys. 85 (2013) [2] Nimmrichter et al., Phys. Rev. Lett. 110 (2013) [3] Schrinski et al., Phys. Rev. A 100 (2019) [4] Kovachy et al., Nature 528 (2015) [5] Fein et al., Nat. Phys. (2019) [6] Xu et al., Science 366 (2019)

Towards Feshbach spectroscopy of K+Cs mixture

Mariusz Semczuk
University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland
`msemczuk@fuw.edu.pl`

One of the defining characteristics of each ultracold atomic mixture is the spectrum of Feshbach resonances. Thanks to the knowledge of molecular potentials, such spectra can be calculated but it is always desirable to test the predictions against experimental data. Here, we present preliminary results of the measurements of the Feshbach resonances in the ultracold 41K+Cs mixture including the characterization of the scattering length in the vicinity of each resonance. Our results might be useful for the studies of Efimov effect in this new heteronuclear system and are a starting point for the production of heteronuclear Feshbach molecules, photoassociation spectroscopy of molecular potentials and subsequent production of ground state 41KCs molecules. The results will thus supplement existing ultracold-regime measurements of the 39K+Cs mixture. Some details of our unique single chamber experimental setup will be also presented.

Towards a new generation of quantum computers with hundreds of neutral atom qubits

Giulia Semeghini
Harvard University, 17 Oxford Street, 2138 Cambridge, United States
`SEMEGHINI@FAS.HARVARD.EDU`

I will report on the most recent progresses on our arrays of Rydberg atoms, from the latest experiments performed in 1D to demonstrate the generation and control of interesting entangled states, to the most recent development of large 2D arrays suitable for the implementation of complex quantum algorithms.

Free-space QED with Rydberg superatoms

Nina Stiesdal
University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark
`stiesdal@sdu.dk`

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 inital 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.

Improving a photon-photon quantum gate using Rydberg interactions

Thomas Stolz
Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1,
85748 Garching b. München, Germany
`thomas.stolz@mpq.mpg.de`

We recently realized a photon-photon π-phase gate based on free-space Rydberg EIT in an ultracold atomic ensemble [1]. The performance in terms of efficiency and postselected fidelity is limited by dephasing resulting from the interaction between the Rydberg electron and surrounding ground-state atoms. The dephasing rate can be much reduced by working at lower atomic density [2]. To keep the gate operational in this regime, we plan to place the ensemble inside a moderate-finesse optical resonator [3,4]. We report on experimental progress toward this goal.

[1] D. Tiarks et al. Nat. Phys. **15**, 124 (2019). [2] S. Schmidt-Eberle et al. arXiv:1909.00680. [3] Y. M. Hao et al. Sci. Rep. **5**, 10005 (2015). [4] S. Das et al. PRA **93**, 040303 (2016).

Deterministic correction of qubit loss

Roman Stricker
University of Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria
`roman.stricker@uibk.ac.at`

The loss of qubits - the elementary carriers of quantum information - poses one of the fundamental obstacles towards large-scale and fault-tolerant quantum information processors. We demonstrate an experimental toolbox for ion-qubit control and implement a full cycle of qubit-loss detection and correction on a minimal instance of the topological surface code. This includes a quantum non-demolition measurement of a qubit-loss event, triggering an in-circuit conditional code-switching operation. This enables the restoration of encoded logical information by mapping it onto a new quantum correcting code on a reduced number of qubits. Together with techniques to correct computational errors, this constitutes essential building blocks for complete and scalable quantum error correction.

Convergence proof of projective simulation-based-reinforcement learning approach in Markov decision

Lea Trenkwalder
University of Innsbruck, Technikerstraße 21A, 6020 Innsbruck, Austria
`lea.trenkwalder@uibk.ac.at`

The interest in leveraging quantum effects for enhancing machine learning tasks has significantly increased in recent years. In this poster, we focus on projective simulation a framework that allows to exploit quantum resources specifically for the broader context of reinforcement learning. Although classical variants of projective simulation have already been benchmarked against common reinforcement learning algorithms, few formal theoretical analyses have been provided for its performance in standard learning scenarios. Here, we present a proof that one version of the projective simulation model understood as a reinforcement learning approach, converges to optimal behavior in a large class of Markov decision processes. Thereby, we show that a physically-inspired approach to reinforcement learning can guarantee to converge.

Giant nonlinear optical enhancement in graphene-metal heterostructures and quantum applications

Alessandro Trenti
University of Vienna, Boltzmanngasse, 5, 1090 Vienna, Austria
`alessandro.trenti@univie.ac.at`

The ability to concentrate light into nanometric volumes enables access to an ultrastrong light-matter coupling regime. Graphene-based platforms are extremely appealing for achieving this goal. Indeed, this unique 2D material possesses a strong third-order nonlinear response, which, thanks to the intense near-fields associated with the excitation of surface plasmons, can be made substantial even at the single-photon level. Here we report unprecedentedly gate-tunable strong optical nonlinearities in graphene-insulator-metal heterostructures, demonstrating an enhancement of three orders of magnitude in the third-harmonic signal. This strong third-order nonlinearity can be further exploited for generating quantum states of light by spontaneous four wave mixing. Interestingly, due to the ultra-small nonlinear interactive length, the phase mismatch term is relaxed. This leads to interesting features in the generated biphoton state.

Quantum Heuristics for near-term devices

Jordi Tura
Max Planck Institute of Quantum Optics, Max Planck Institute of Quantum Optics, 85748 Garching bei München, Germany
`jordi.tura@mpq.mpg.de`

In this work we present a method to build a quantum circuit to heuristically minimize the energy of a quantum Hamiltonian under a set of restrictions, such as having a limited number of gates of a given type. The algorithm is based on an adaptive algorithmic cooling procedure, aided by some classical optimization. In our work we focus on the following directions: first, we benchmark the performance of the algorithm in for a number of qubits $\mathrm{N} > 50$, thus going beyond the limits of classical simulation; second, we take into consideration and study the effect of different noise models; and third, we take into account the statistical noise arising from estimating expectation values of operators, thus giving realistic estimates for the number of measurements and actual run-time of the algorithm.

Spin-orbit coupling in the presence of strong atomic correlations

Ayaka Usui
OIST Graduate University, 1919-1, Tancha, 904-0495 Onna, Japan
`ayaka.usui@oist.jp`

We explore the influence of contact interactions on a synthetically spin-orbit coupled system of two trapped bosons. The two bosons are described by two identical atoms with different hyperfine states, and therefore can be regarded as a two-level system with a pseudo-spin. The system is tractable since it is solvable exactly for some sets of parameters. Even though the system we consider is bosonic, we show that a regime exists in which the competition between the contact and spin-orbit interactions results in the emergence of a ground state that contains a significant contribution from the anti-symmetric spin state. This ground state is unique to few-particle systems and does not exist in the mean-field regime. The transition to this state is signalled by an inversion in the average momentum from being dominated by centre-of-mass momentum to relative momentum and also affects the global entanglement shared between the real- and pseudo-spin spaces.

Anomalous Floquet phases in periodically-driven hexagonal lattices

Karen Wintersperger
LMU Munich, Schellingstrasse 4, 80799 Munich, Germany
`k.wintersperger@physik.uni-muenchen.de`

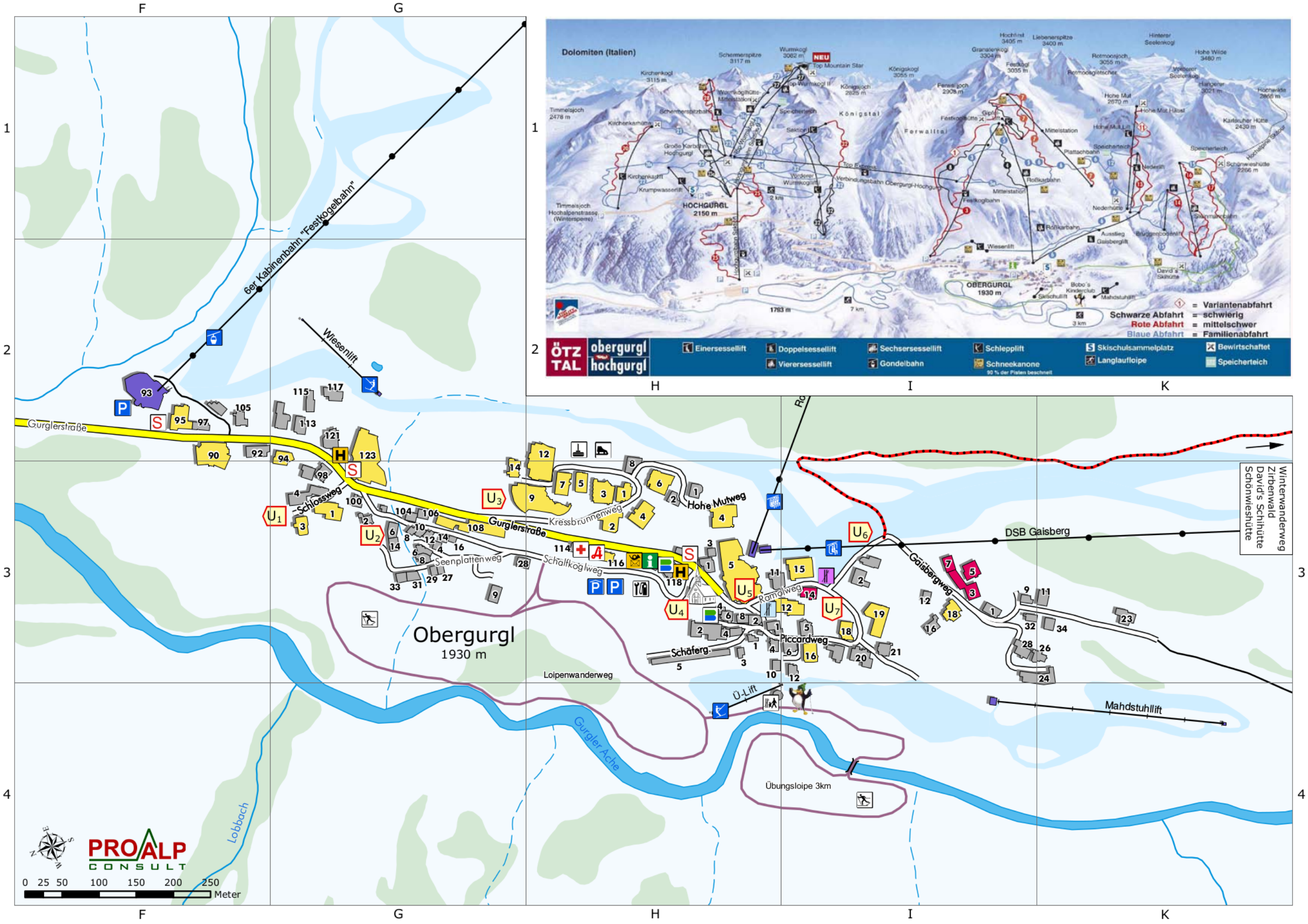
Ultracold atoms in periodically-driven optical lattices can be used to simulate systems with nontrivial topological properties. Due to the periodic driving, energy conservation is relaxed which makes it possible to realize systems with properties that go beyond those of conventional static systems [1]. We study such anomalous Floquet phases experimentally using a BEC of K39 in an optical honeycomb lattice with periodically modulated tunnel couplings. By monitoring the closing and reopening of energy gaps in the band structure we are able to track the transitions between different Floquet phases. Moreover, we probe the local changes in the Berry curvature by measuring the Hall deflection. Combining these measurements enables us to extract the topological invariants of the bulk bands and the energy gaps [2,3]. [1] T. Kitagawa et al., Phys. Rev. B 82, (2010) [2] M. Rudner et al., PRX 3, (2013) [3] N. Ünal et al., PRL 122, (2019)

Towards a Suburban Quantum Network Link

Tim van Leent
LMU München, Schellingstr. 4/III, 80799 München, Germany
`t.van.leent@physik.uni-muenchen.de`

Quantum repeaters will allow for scalable quantum networks, which is essential for large scale quantum communication and distributed quantum computing. Yet, still missing on the road towards a quantum repeater, is to achieve entanglement between quantum memories over long distances. Here we present results on observing entanglement between a Rubidium 87 atom and a telecom photon at 1522 nm over 20 km optical fiber with a fidelity of 79% [1]. For this purpose, we use polarization-preserving quantum frequency conversion, where the photon at 780 nm is mixed with a strong pump field at 1600 nm inside a nonlinear waveguide crystal in a Sagnac-type configuration [2]. Furthermore, we report on progress towards implementing frequency conversion for the second atom and employing the entanglement swapping protocol to generate atom-atom entanglement on a suburban scale. [1] T. van Leent et al., arXiv:1909.01006 (2019) [2] M. Bock et al., Nat. Comm. 9, 1998 (2018)

Index


F
G
H
I
K
1
2
3
4
Dolomiten (Italien)
Einersessellift
Doppelsessellift
Vierersessellift
Sechsersessellift
Gondelbahn
Schlepplift
Schneekanone
90 % der Pisten beschneit
Skischulsammelplatz
Langlaufloipe
Bewirtschaftet
Speicherteich
= Variantenabfahrt
Schwarze Abfahrt = schwierig
Rote Abfahrt = mittelschwer
Blaue Abfahrt = Familienabfahrt
ÖTZ TAL
obergurgl hochgurgl
OBERGURGL 1930 m
HOCHGURGL 2150 m
6er Kabinenbahn "Festkogelbahn"
Wiesenlift
Gurglerstraße
Schlossweg
Kressbrunnenweg
Hohe Mutweg
Seenplattenweg
Schalfkoglweg
Ramolweg
Piccardweg
Schäferg.
Gaisbergweg
DSB Gaisberg
Winterwanderweg
Zirbenwald
David's Schihütte
Schönwieshütte
Obergurgl
1930 m
Loipenwanderweg
Ü-Lift
Mahdstuhllift
Übungsloipe 3km
Gurgler Ache
Lobbach
U1
U2
U3
U4
U5
U6
U7
PROALP CONSULT
0 25 50 100 150 200 250 Meter

		Sunday 23.2.	Monday 24.2	Tuesday 25.2.	Wednesday 26.2.	Thursday27.2.	Friday 28.2.	Saturday 29.2.
			Ensembles	Quantum Gases & Cavities	Ultracold	BeyondC	BeyondC	
8.20			*Opening*					
8.30-9.00	Invited		Polzik	Donner	Thompson	Cirac	Wrachtrup	return bus
9.00-9.30	Invited		Kaiser	Morigi	Salomon	DeMorais-Smith	Cetina	return bus
9.30-10:00	Hot topic		Köhl	Hemmerich	Schäffer	Erne	Dakic	
10.00-10.30	Coffee							return bus
10.30-11.00	Invited		Yelin	Rempe	Ferlaino	Lukin	Caux	return bus
11.00-11.30	Hot topic		Rabl	Zimmermann	Haslinger	Weihs	Gietka	
11.30-15.30	**lunch break**							
15.30-16.15	**Coffee + Cake**	BUS			Yunusov			
16.15-16.45	Invited	BUS	Stickler	Kollath	Zakrzewski	Zoller	Verstraete	
16.45-17.15	Hot topic	BUS	Anderegg	Roux	von Klitzing	Niedenzu	Monz	
17.15-17.45	Hot topic	registration	Cornish	Mivehvar	Volz	Shahmoon	Gaaloul	
17.45-18.00	**Discussions**	registration						
18.00-18.30		registration	Dinner	Dinner		Dinner	Dinner	
18.30-19.00		Dinner	Dinner	Dinner	Conference	Dinner	Dinner	
19.00-20.00		Dinner		Posters1	Dinner	Posters2		
20.00-22.00				Posters1	Hohe Mut	Posters2		