Atomic Physics and Quantum Optics

Tuesday, 05.09.2023, Room 116

Time	ID	**Atomic Physics and Quantum Optics I** *Chair: Jean-Philippe Brantut, EPFL*
14:00	**401**	**Ultra-low quantum decoherence nano-optomechanical systems** *Mohammad Bereyhi, EPFL* Thermal motion of a room-temperature mechanical resonator typically dominates the quantum backaction of its position measurement. Optomechanics provides a path towards quantum control of the mechanical motion by dominating the thermal effects with optical backaction. In this work we design, fabricate, and characterize three different classes of nanomechanical resonators with Q factors exceeding 3 billion at room temperature and demonstrate their optical readout using an integrated nearfield nano-optomechanical transducer using high stress silicon nitride. Our approach allows individual optimization of optical and mechanical resonators, while maintaining a high optomechanical coupling rate.
14:30	**402**	**Optical coherent feedback control of a mechanical oscillator** *Maryse Ernzer, Manel Bosch Aguilera, Matteo Brunelli, Gian-Luca Schmid, Thomas Karg, Christoph Bruder, Patrick P. Potts, Philipp Treutlein* *Department of Physics and Swiss Nanoscience Institute, University of Basel, Klingelbergstr. 82, 4056 Basel* We employ coherent feedback as strategy to improve quantum control of an optomechanical system, by implementing a feedback platform that avoids measurements and their associated decoherence. This is implemented via an optical light beam that sequentially interacts twice with a nanomechanical membrane placed inside an optical cavity. Theoretically this scheme allows for ground-state cooling even in the unresolved cavity sideband regime. Experimentally, tuning the optical phase and delay of the feedback improves our motional state control and allows to cool the membrane to a state with $n_m = 4.89 \pm 0.14$ phonons which lies below the theoretical limit of cavity dynamical backaction cooling in the unresolved sideband regime.
14:45	**403**	**Photophysics of single NV centers in diamond and its application to electric field detection at cryogenic temperatures** *Jodok Happacher, Juanita Bocquel, Patrick Maletinsky, University of Basel* We present the strain and magnetic field dependent photophysics of individual Nitrogen-Vacancy (NV) color centers in diamond from cryogenic to ambient conditions. Our experimental results and matching model predictions offer new insights into the structure of the NVs' excited states and its significant effect on the optical spin contrast, which directly relates to the performance of NV centers as quantum sensors. Based on the high sensitivity of the NV's orbital excited states to electric fields, we present a study of charge dynamics in the diamond host as well as a low-temperature, all optical electromagnetic field sensing scheme.

15:00	404	**Integrated polariton condensate in silicon-on-insulator high contrast grating microcavities** *Pietro Tassan [1], Darius Urbonas [1], Bartos Chmielak [2], Thorsten Wahlbrink [2], Ullrich Scherf [3], Rainer Mahrt [1], Thilo Stöferle [1]* *[1] IBM Research Europe, [2] AMO GmbH, [3] Bergische Universität Wuppertal* Integrated all-optical logic could define a new paradigm for computing architectures. Strong light-matter coupling based all-optical transistors exhibiting ultra-fast switching and room-temperature operation have recently been demonstrated using free-space optical setups. Here, we leverage silicon-on-insulator (SOI) technology to realize high-index contrast grating (HCG) as mirrors to form microcavities filled with an organic polymer (MeLPPP) as photoactive material to demonstrate room temperature strong light-matter interaction and polariton condensation on chip. This opens the door to integrated all-optical transistors with the scalability to enable more complex optical logic circuits to operate at room temperature with sub-picosecond switching times.
15:15	405	**Chiral sensing with void modes** *Diana Shakirova, Adrià Canós Valero, Thomas Weiss, University of Graz* Chirality is a property of living organisms molecules, chemicals and drugs, which makes their detection and analysis an extremely important task in biology, chemistry, and pharmacology. One of the most well known methods for detecting chiral matter handedness is the measurement of circular dichroism (CD) that can be defined as the difference in the transmission of right- and left-handed circularly polarized light. In this work we present a system supporting bound state in the continuum and radiative void modes for CD enhancement. Different types of modes interaction, including weak coupling, strong coupling and exceptional point regimes are demonstrated, and the efficiency of each for chiral sensing is analyzed.
15:30	406	**Polarimetric measurements of the bright triplet emission of single cesium lead halide perovskite quantum dots at cryogenic temperature** *Virginia Oddi [1], Michael Becker [1], Dmitry Dirin [2,3], Maksym Kovalenko [2,3], Rainer Mahrt [1], Gabriele Rainò [2,3], Yesim Sahin [2,3], Thilo Stöferle [1], Chenglian Zhu [2,3]* *[1] IBM Research Europe – Zurich, Säumerstrasse 4, CH-8803 Rüschlikon* *[2] Department of Chemistry and Applied Biosciences, ETH Zürich – Vladimir Prelog Weg 1, CH-8093 Zürich* *[3] Laboratory for Thin Films and Photovoltaics, Empa, CH-8600 Dübendorf* Cesium lead halide perovskite quantum dots (QDs) have recently emerged as promising platform for quantum light sources. They exhibit exceptional photoluminescence properties due to the emission from a bright triplet exciton state with dominantly but not fully linear emission polarization. Here, we are investigating the polarization properties of individual cesium lead halide perovskite QDs by advanced polarimetric techniques that allow to measure the complete Stokes polarization vector at cryogenic temperature for each fine structure line. The presentation will discuss the characteristics of the small fraction of circularly polarized emission and its potential origin.
15:45	407	**A Keldysh Path Integral Approach to Input-Output Theory** *Aaron Daniel, Matteo Brunelli, Patrick Potts, Universität Basel* Input–output theory is a well–known tool in cavity electrodynamics and ubiquitous in the description of quantum systems interacting with the environment. We present a new approach to input–output theory using the Keldysh path integral formalism. This approach allows us to get perturbative results for non–linear systems. We apply this novel approach to a single mode in a cavity solvable through standard input–output theory and then treat a Kerr oscillator to showcase the specific strength of our approach to yield perturbative results.

16:00	**408**	**Exploring molecular properties using far-field matter-wave diffraction** *Ksenija Simonović [1], Markus Arndt [1], Christian Brand [2], Alfredo Di Silvestro [3], Richard Ferstl [1], Klaus Hornberger [4], Lukas Martinetz [4], Marcel Mayor [3], Armin Shayeghi [5], Benjamin Stickler [4]* *[1] University of Vienna, Faculty of Physics, [2] Deutsches Zentrum für Luft- und Raumfahrt (DLR)* *[3] Department of Chemistry, University of Basel, [4] University of Duisburg-Essen* *[5] Institute for Quantum Optics and Quantum Information - IQOQI Vienna, Austrian Academy of Sciences* We report on first single-grating diffraction of molecular matter-waves at a continuous 266 nm optical grating. While pulsed UV gratings are already used in molecular interferometry, continuous ones have so far been hindered by lack of high-power lasers and fast degradation of UV optics in vacuum. Our focus is on applications for quantum-assisted measurements of molecular electronic properties, such as polarizabilities and absorption cross-sections at 266 nm. The deep UV diffraction grating paves the way for studying photophysical and photochemical processes of biologically and technologically relevant molecules in matter-wave diffraction. Furthermore, it explores new grating mechanisms for interferometry of complex biomolecules, such as depletion gratings based on single photon-induced photocleavage.
16:15	**409**	**Cavity-mediated coupling of terahertz antiferromagnetic resonances in distant crystals** *Marcin Bialek, Jean-Philippe Ansermet, EPFL* In the regime of strong light-matter coupling, polaritons are formed that are hybrids of a cavity mode and a matter excitation. Recently, magnon-polaritons were researched using ferromagnets in the microwave range. Exploring antiferromagnets rises magnon-polariton frequencies into the terahertz range. We report on coupling of antiferromagnetic resonance (AFMR) in two parallel-plane crystals of hematite (alpha-Fe_2O_3) placed at a well controlled gap, forming a tunable Fabry-Perot cavity. Frequency of AFMR in each crystal was independenty controlled by changing their temperatures. Reflection spectra in the range 0.2 - 0.3 THz, collected as a function of temperature difference between the two crystals, show avoided crossings of AFMR from both slabs mediated by Fabry-Perot cavity modes.
16:30		***Coffee Break***
		Atomic Physics and Quantum Optics II *Chair: Tilman Zibold, Universität Basel*
17:00	**411**	**Minimalistic efficient quantum devices build of dipole coupled nano arrays of quantum emitters** *Helmut Ritsch, Universität Innsbruck* An array of closely spaced, dipole coupled quantum emitters exhibits collective energy shifts as well as super- and sub-radiance with characteristic tailorable spatial radiation patterns. As striking example we identify a sub-wavelength sized ring of exactly 9 identical dipoles with an extra identical emitter with a extra loss channel at the center as the most efficient configuration to deposit incoming photon energy to center without reemission. For very tiny structures below a tenth of a wavelength a full quantum description exhibits an even larger enhancement than predicted from a classical dipole approximation. Adding gain to such systems allows to design minimalistic classical as well as non-classical light sources.

17:30	**412**	**Cavity-QED Quantum Simulator of Random Spin Models** *Francesca Orsi, Rohit Bhatt, Gaia Bolognini, Jean-Philippe Brantut, Jonas Faltinath, Nick Sauerwein, EPFL* Cavity QED systems have proved valuable for quantum simulations, specifically for the long-range interactions that the cavity field mediates between the atoms. We have realized a random spin model with atoms in a cavity where we introduce controlled disorder in the the atomic transition frequencies with a light-shift of the excited state. We study the competition between the collective many-body physics and the disorder. In the dispersive regime, we observe the ferromagnetic gap of our system closing as a function of the disorder strength. I will also discuss how we plan to use a modulation of our light-shifting beam to locally control the atom-cavity coupling and tailor the long-range interactions.
17:45	**413**	**Entanglement-induced collective multiparticle interference** *Tommaso Faleo [1], Eric Brunner [2], Jonathan W. Webb [3], Christoph Dittel [2], Gregor Weihs [1], Gabriel Dufour [2], Alessandro Fedrizzi [3], Robert Keil [1]* *[1] University of Innsbruck, [2] University of Freiburg, [3] Heriot-Watt University* Multiparticle interference phenomena have been crucial to the understanding of quantum physics. In two-particle systems, Hong, Ou, and Mandel showed how particles' indistinguishability forbids retrieving information about the pairwise exchange process, playing a key role in witnessing interference. Contrarily, in systems of $N \geq 3$ partially distinguishable particles, multiple interference terms originate from the different exchange processes, enabling the observation of genuine N-particle interference that is no longer fully determined by pairwise indistinguishability. Here, we introduce yet another fundamental feature of quantum physics, i.e., quantum entanglement, to demonstrate the genuine four-particle interference of photons which, however, only interfere in pairs at two separate and independent beamsplitters, thus suggesting a nonlocal collective interference.
18:00	**414**	**Einstein-Podolsky-Rosen experiment with two Bose-Einstein condensates** *Paolo Colciaghi, Yifan Li, Philipp Treutlein, Tilman Zibold* *Department of Physics, University of Basel, CH-4056 Basel* We observe for the first time the famous Einstein-Podolsky-Rosen (EPR) paradox with two spatially separated, massive many-particle systems. We split a spin-squeezed Bose-Einstein condensate into two spatially separated parts, on which we perform independent spin measurements to demonstrate the paradox. Our results show that the conflict between quantum mechanics and the classical understanding of locality and realism does not disappear as the system size is increased to over 1000 massive particles. Furthermore, we demonstrate the individual control of both systems on the quantum level, which is a necessary condition to exploit EPR entanglement as a resource for quantum technology.
18:15	**415**	**The Wave-Particle Duality in Quantum Heat Engine** *Marcelo Janovitch Broinizi Pereira, Matteo Brunelli, Patrick Potts, Universität Basel* According to the wave-particle duality (WPD), quantum systems show both particle- and wave-like behavior, and cannot be described using only one of these classical concepts. The WPD implies that comparison to one classical model is generally insufficient; one wave and one particle model should be considered. We exploit this insight, contrasting a bosonic quantum heat engine with particle and wave counterparts. While both classical models reproduce the average output power of the quantum engine, neither reproduces its fluctuations. We find regimes where wave and particle descriptions agree with the quantum, and a regime where neither classical model is adequate, revealing the role of the WPD in non-equilibrium bosonic transport.

18:30	**416**	**Verification of the area law of mutual information in a quantum field simulator** *Mohammadamin Tajik [1], Ivan Kukuljan, Spyros Sotiriadis [2], Bernhard Rauer [1], Thomas Schweigler [1], Federica Cataldini [1], João Sabino [1], Frederik Møller [1], Philipp Schüttelkopf [1], Si-Cong Ji [1], Dries Sels [3], Eugene Demler [4], Jörg Schmiedmayer [1]* *[1] TU Wien, [2] FU Berlin, [3] New York University, [4] ETH Zürich* Understanding scaling laws of entropies and mutual information has benefited studying correlated states of matter, quantum field theory, and gravity. Measuring von Neumann entropy experimentally in quantum many-body systems is challenging. In my talk, I will present our measurements of von Neumann entropy of subsystems in an ultracold atom simulator of Klein-Gordon field theory, verifying a foundational property of equilibrium states of gapped quantum many-body systems - the area law of quantum mutual information (Tajik, M. et al. Nat. Phys. 2023). I will also discuss the effect of temperature and subsystem separation on mutual information. Finally, I will address the challenges of measuring entanglement in many-body systems.
18:45	**417**	**Positron manipulation and control at ASACUSA** *Daniel James Murtagh, Austrian Academy of Sciences* The ASACUSA-Cusp experiment aims to perform spectroscopy of the hyperfine structure of anti-hydrogen by producing a beam of cold, spin polarised, ground state antihydrogen. Recently, a major technological milestone was achieved by the collaboration. Previously, it has not been possible to cool plasma below 130 K, however, a new electrode stack and coldbore with a focus on blocking microwaves from the room temperature region has allowed particles to cool to 25 K maintaining the large open solid angle for the beam to escape. In this presentation I will discuss the methods used by the ASACUSA Cusp experiment to manipulate and control positrons and give details on the most recent work
19:00		***END; Postersession with Apéro***

ID	Atomic Physics and Quantum Optics Poster
431	**Laser cooling and shuttling of trapped ions in strongly inhomogeneous magnetic fields** *Christian Mangeng, Richard Karl, Stefan Willitsch, Yanning Yin, University of Basel* We demonstrate laser-cooling of Ca^+ ions confined in a segmented linear Paul trap and in presence of a strongly inhomogeneous magnetic field. We show that by employing two cooling lasers with properly adjusted wavelengths and polarizations, the trapped ions can efficiently be cooled to millikelvin temperatures despite strong position-dependent Zeeman shifts. The experimental results are complemented by a theoretical analysis. We further demonstrate successful shuttling of the ions through these magnetic field gradients. These experiments pave the way for studying cold collisions and reactions between ions and neutral molecules in hybrid traps composed of a Paul trap and a magnetic trap.
432	**Coupling a mechanical Oscillator to single trapped Ions** *Moritz Weegen, Panagiotis Fountas, Martino Poggio, Stefan Willitsch, University of Basel* Ultracold ions in linear radiofrequency traps are well-established and highly controllable quantum systems with a variety of applications in the quantum sciences. The combination with a charged nanomechanical oscillator may offer novel ways for state preparation and readout by coupling both systems within a single quantum device. Here we demonstrate the transfer of energy from a mechanically driven oscillator to the motion of trapped ions in a classical regime. This is obtained by coupling one of the oscillator mechanical modes to the ion motion of matching frequency. We further characterise the interaction by varying different defining parameters such as the mechanical drive amplitude and the effective charge on the oscillator.

433 Precision spectroscopy and coherent manipulation of single trapped nitrogen molecules

Mikolaj Franciszek Roguski, Aleksandr Shlykov, Richard Karl, Prerna Paliwal, Mudit Sinhal, Stefan Willitsch, University of Basel

Complex energy-level structure of molecules with rotational and vibrational degrees of freedom provides transitions with various properties but also presents challenges toward molecular state initialization, manipulation, and readout. We followed a quantum-logic protocol that uses a single co-trapped atomic ion as a probe for the molecular state, and demonstrated a quantum non-demolition state detection with fidelities > 99 %. Currently, we are implementing precision-spectroscopic measurements on a narrow infrared quadrupole transition referenced to the Swiss primary frequency standard at METAS in Berne. The present method paves the way for the implementation of molecular qubits, for establishing new frequency standards in the mid-IR regime, and for investigating state-to-state dynamics of chemical reactions.

434 Towards quantum control of polyatomic molecular ions

Mikhail Popov, Prerna Paliwal, Stefan Willitsch, University of Basel

Complete control over the quantum state of single molecules possesses significant challenges due to the complexity of their energy level structure and was demonstrated only recently for diatomic molecular ions. We report on the progress of a generalization of a quantum control scheme that employs quantum logic spectroscopy with a co-trapped atomic ion of calcium to polyatomic molecules. This will open the possibility of studying chemical reactions and ultracold collisions on a state-to-state level and conducting precision spectroscopy with polyatomic species.

435 Towards OH-ion reaction studies at astrochemically relevant conditions

Pietro Vahramian, Dominik Haas, Claudio von Planta, Yanning Yin, Dongdong Zhang, Thomas Kierspel, Stefan Willitsch, University of Basel

In interstellar space, reactions involving neutral dipolar molecules and ions are the main mechanism with which new molecules are formed, yet there is sparse data about reactivities in this range. Here we present an experiment aimed at studying radical-ion reactivities at conditions relevant for astrochemistry – high vacuum and temperatures down to few Kelvins.
A Stark decelerator slows down to temperatures of a few K a beam of radicals, which are then shot onto trapped, laser cooled Ca^+ ions.
I will report on advancements on the deceleration and detection of the OH molecules and on prospects to couple them to the trapped ion.

436 Investigation of the dipole moment of 6,11-dihydroxy-5,12-naphthacenedione using molecular diffraction

Richard Ferstl [1], Markus Arndt [1], Anders Barlow [2], Christian Brand [3], Armin Shayeghi [4], Ksenija Simonovic [1]
[1] University of Vienna, Faculty of Physics
[2] University of Melbourne, Faculty of Engineering and Information Technology
[3] Deutsches Zentrum für Luft- und Raumfahrt (DLR)
[4] Institute for Quantum Optics and Quantum Information - IQOQI Vienna, Austrian Academy of Sciences

Permanent electric dipole moments have been found to significantly reduce the interference contrast in molecular diffraction experiments at nanomechanical gratings. Dephasing caused by the interactions with implanted charges in the nanogratings has been presented as a possible explanation for this behavior. Here we investigate the polarity of 6,11-dihydroxy-5,12-naphthacenedione, which could be assumed to be polar by its lack of inversion symmetry, yet shows a surprisingly high interference contrast. This may suggest a reduction of the electric dipole moment, attributed to coherent or fast incoherent proton transfer between adjacent functional groups. We will report on the comparison of these results with diffraction of molecules that are known to be polar.

437	**Charge and pair density waves induced by light in a strongly interacting Fermi gas** *Tabea Nelly Clara Bühler [1], Timo Zwettler [1], Giulia Del Pace [2], Jean-Philippe Brantut [1]* *[1] Ecole Polytechnique Fédérale de Lausanne, Institute of Physics, CH-1015 Lausanne* *[2] Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO) and European Laboratory for Nonlinear Spectroscopy (LENS), University of Florence, IT-50019 Sesto Fiorentino* Quantum gas experiments provide the unique opportunity to study complex quantum many-body systems. Starting from a dilute gas non-local, all-to-all interactions can be implemented by means of a high-finesse optical cavity. In our experiment we prepare a degenerate, strongly interacting Fermi gas of ^{6}Li atoms trapped inside a high-finesse optical cavity. We induce long-range atom-atom, atom-pair and pair-to-pair interactions mediated by cavity photons. We observe a density-wave ordering phase transition in the presence of these interactions, suggesting a pair-density-wave state of the gas. We characterize the transition threshold and the lifetime of this state as we vary the strength and sign of the long-range interactions.
438	**Levitated optomechanics in ultra-high vacuum** *Florian Goschin, University of Innsbruck* We envision preparing mesoscopic motional quantum states by coupling the motion of a levitated particle to a trapped ion qubit. First, we levitate a charged silica nanoparticle in a Paul trap in ultra-high vacuum resulting in an ultra-high quality factor ($Q = 1.6(4) \times 10^{10}$) of mechanical oscillations. Second, we control the particle's center-of-mass motion by applying measurement-based active feedback cooling. To increase the particle detection efficiency we implement a detection method based on self-interference of the particle with its image. Finally, we introduce the trapped ion qubit into the system. For the first time, we experimentally realize the simultaneous trapping of a single ion and a nanoparticle in the same Paul trap.
439	**The Scalar Magnetometer on board ESA's JUICE Mission and its Potential as a Vector Magnetometer** *Christoph Amtmann [1], Martín Agú [2], Alexander Betzler [2], Irmgard Jernej [2], Sunny Laddha [1], Roland Lammegger [1], Werner Magnes [2], Andreas Pollinger [1]* *[1] Institute of Experimental Physics, Graz University of Technology* *[2] Space Research Institute, Austrian Academy of Sciences* The scalar magnetometer on board ESA's JUICE mission is an optically pumped magnetometer, based on the coherent population trapping (CPT) effect in the atomic vapour of the rubidium isotope 87. The CPT effect is a quantum mechanical interference effect which allows the precise detection of the external magnetic field strength by measuring the so-called Zeeman shifts. The instrument excites and couples several CPT resonances to enable a measurement principle which is inherently drift and dead-zone free. The presentation will give an overview of the scalar magnetometer for the JUICE mission as well as the first results of its potential for vector measurements.