PROF. JEFF HANGST | Aarhus University

» Antihydrogen Spectroscopy: the ALPHA experiment at CERN «

Antimatter continues to intrigue scientists due to its apparent absence in the universe. In recent years, antimatter has come under unprecedented experimental scrutiny, as we can now test the fundamental symmetries of Nature to high precision using this unique tool. We have recently become able to study atoms of antihydrogen - the antimatter equivalent of hydrogen. The question to be addressed is fundamental and profound: "Do matter and antimatter obey the same laws of physics?" The so-called Standard Model of fundamental particles and interactions requires that hydrogen and antihydrogen have the same spectrum. I will discuss the latest exciting developments in antihydrogen physics: observation of the first laser-driven transition (1S-2S) in trapped antihydrogen observation of the antihydrogen hyperfine structure, and observation of the Lyman-alpha transition. Precise measurement of the frequency of the 1S-2S transition could well be described as the 'holy grail' of physics with anti-atoms. To study antihydrogen, it must first be produced, then trapped, and then held for long enough to observe a transition - using very few anti-atoms. I will discuss the techniques necessary to achieve the latest milestones, and then consider the future of optical and microwave spectroscopy, as well as gravitational studies, with antihydrogen.

WOLFGANG NIEDENZU | ESQ

» Cooperative many-body enhancement of quantum thermal machine power «

We study the impact of cooperative many-body effects on the operation of periodically-driven quantum thermal machines, particularly heat engines and refrigerators. In suitable geometries, N two-level atoms can exchange energy with the driving field and the (hot and cold) thermal baths at a faster rate than a single atom due to their SU(2) symmetry that causes the atoms to behave as a collective spin-N/2 particle. This cooperative effect boosts the power output of heat engines compared to the power output of N independent, incoherent, heat engines. In the refrigeration regime, similar cooling-power boost takes place.

STEFAN GERLICH | University of Vienna

» Long Baseline Molecular Interferometry «

We report on the development of the novel Long-Baseline Universal Matter-wave Interferometer (LUMI) in Vienna, which very recently has yielded its first experimental results. LUMI is a near-field, Kapitza-Dirac-Talbot-Lau type interferometer with a baseline of two meters. This constitutes an increase in length of one order of magnitude over previous designs and will render it possible to study the quantum interference of particles with masses well beyond 100,000 amu. The highly modular design of the experiment permits the in-vacuum exchange between optical and material diffraction gratings as well as the introduction of electric and magnetic fields, collision cells or spectroscopy lasers. This will allow us to explore the electronic, optical, magnetic and through these also the structural properties of a very large and diverse class of particles, ranging from atoms to complex molecules and metal clusters – all in free-flight and with much improved precision over previous devices. Most recent highlights include preliminary results documenting the sensitivity of the interferometer to the magnetic moment of even a single nuclear spin and first interference tests with macromolecules beyond 20.000 amu.

ÄMIN BAUMELER | ESQ

» Computational complexity theory and causality «

Traditionally, a causal structure is thought of as a directed acyclic graph where the nodes represent events and the edges point from causes to effects. Our current physical theories, however, question this view. We ask the question of how physical causality-breaking frameworks are when approached from a computer-science perspective. More concretely, the NP-hardness assumption asserts that in every physically realizable model of computation NP-complete problems cannot be solved efficiently. Does this still hold when we relax the assumptions on causality?

GIACOMO SORELLI | University of Freiburg

» Entanglement protection of high-dimensional states by adaptive optics «

High-dimensional, discrete quantum systems (qudits) present several advantages over simple two-level systems (qubits). In particular, qudits increase the information encoded in a single carrier. Besides, high-dimensional bases result in stronger violations of Bell inequalities, which can enhance the security of entanglement-based quantum key distribution. Spanning a discrete, infinite-dimensional Hilbert space, photonic orbital angular momentum (OAM) states are suitable candidates for the realisation of such high-dimensional states. %Moreover, photon pairs entangled in this degree of freedom are naturally produced in spontaneous parametric down-conversion. On the downside, the defining feature of OAM-carrying light beams, namely their helical wave front, is fragile with respect to turbulence induced phase distortions. In this talk, we consider the potential of adaptive optics (AO) to protect entanglement of high-dimensional OAM states against atmospheric effects. We show how AO is able to reduce crosstalk among the OAM modes, and consequently the entanglement decay as well as photon losses. Finally, a test of the AO-stabilised output state against high-dimensional Bell inequalities shows that the transmitted entanglement allows for secure communication, even under strong turbulence.

PETER KIRTON | ESQ

» The weak to strong light-matter coupling crossover with organic polaritons «

Polaritons are quasiparticles which form when light and matter are strongly coupled together by, for example, tightly confining a collection of emitters in a cavity. Recent experiments have shown that it is possible to realise polariton physics with organic molecules in an optical cavity, achieving coupling strengths at room temperature which are otherwise impossible. In this talk I will show how these systems can be effectively described by a relatively simple model, where both strong coupling to vibrational modes and strong matter-light coupling are essential ingredients. I will show how mean-field can provide the phase diagram of this model in the thermodynamic limit. I will discuss the mechanism of polariton lasing, uncovering a process of self-tuning, and identify the relation and distinction between regular dye lasers and organic polariton lasers.

DMITRY BYKOV | University of Innsbruck

» Ion traps for levitodynamical experiments with mesoscopic particles in high vacuum «

The field of optomechanics relies on the mutual interaction of light and mechanical motion. Recently, a new research direction called levitated optomechanics or levitodynamics has attracted interests in numerous research groups. To date, most of the experiments of the field deal with a single nanoparticle suspended in vacuum by means of optical forces. Our approach is different in that we exploit a Paul trap for levitation which will allow us to add a second object, a well-studied atomic ion, to our system. Once placed in an optical cavity, such a combination brings new opportunities for non-Gaussian state preparation and cooling motional degrees of freedom of a macroscopic object. In order to realize such a hybrid system, we need to be able to reach conditions that are necessary for trapping ions, one of the most crucial of which is ultra-high vacuum (UHV). This requirement puts constraints on the methods that can be used to load nanoparticles into the Paul trap. We demonstrate a clean, potentially UHV-compatible method of direct loading of nanoparticles into the trap. The method is based on a combination of laser-induced acoustic desorption of the particles and temporal control of the trap potential. We demonstrate high efficiency of the overall process and its lack of dependence on pressure. Once the particle has been loaded, its center of mass motion can be controlled and cooled by means of cold damping. We make use of an extra electrode mounted in a vacuum chamber in order to provide a friction force that is capable of damping the center of mass motion to an effective temperature of 2K, which is currently limited by performance of our detection system.

PROF. MARCO G. GIAMMARCHI | University of Milan

» First observation of antimatter wave interference «

In 1924 Louis de Broglie introduced the concept of wave-particle duality: the Planck constant h relates the momentum p of a massive particle to its de Broglie wavelength λ=h/p. The superposition principle is one of the main postulates of quantum mechanics; diffraction and interference phenomena are therefore predicted and have been observed on objects of increasing complexity, from electrons to neutrons and molecules. Beyond the early electron diffraction experiments, the demonstration of single-electron double-slit-like interference was a highly sought-after result. Initially proposed by Richard Feynman as a thought experiment it was finally carried out in 1976. A few years later, positron diffraction was first observed. However, an analog of the double-slit experiment has not been performed to date on any system containing antimatter. Here we present the first observation of matter wave interference of single positrons, by using a period-magnifying Talbot-Lau interferometer based on material diffraction gratings. Individual positrons in the 8-14 keV energy range from a monochromatic beam were detected by high-resolution nuclear emulsions. The observed energy dependence of fringe contrast proves the quantum-mechanical origin of the detected periodic pattern and excludes classical projective effects. Talbot-Lau interferometers are well-suited to the experimental challenges posed by low intensity antimatter beams and represent a promising option for measuring the gravitational acceleration of neutral antimatter.

LAURIN OSTERMANN | University of Innsbruck

» Super- and subradiance of clock atoms in multimode optical waveguides «

The transversely confined propagating modes of an optical fiber mediate virtually infinite range energy exchanges among atoms placed within their field, which adds to the inherent free space dipole-dipole coupling. Typically, the single atom free space decay rate largely surpasses the emission rate into the guided fiber modes. However, scaling up the atom number as well as the system size amounts to entering a collective emission regime, where fiber-induced superradiant spontaneous emission dominates over free space decay. We numerically study this super- and subradiant decay of highly excited atomic states for one or several transverse fiber modes as present in hollow core fibers. As particular excitation scenarios we compare the decay of a totally inverted state to the case of Pi/2 pulses applied transversely or along the fiber axis as in standard Ramsey or Rabi interferometry. While a mean field approach fails to correctly describe the initiation of superradiance, a second-order approximation accounting for pairwise atom-atom quantum correlations generally proves sufficient to reliably describe superradiance of ensembles from two to a few hundred particles. In contrast, a full account of subradiance requires the inclusion of all higher order quantum correlations. Considering multiple guided modes introduces a natural effective cut-off for the interaction range emerging from the dephasing of different fiber contributions.

SICONG JI | ESQ

» Simulating the Pokrovsky-Talapov Model with tunnelling coupled one-dimensional Bose gases «

Pokrovsky-Talapov (PT) model is related to a large variety of system displaying a commensurate-incommensurate (C-IC) transition. Here, we propose a quantum simulator of the PT model, which is based on the Raman assisted tunneling between a pair of one-dimensional (1D) Bose gases on an 'AtomChip'. It gives the possibility to directly watch the C-IC phase transition and the formation of a soliton lattice pattern in the continuous Bose gases system. In this talk, I will introduce the connection between the tunneling coupling Bose-Einstein condensate and PT model, the experimental setup and the simulation result from both mean field theory and microscopic model.

DAVID SAUERWEIN | University of Innsbruck

» Transformations among Pure Multipartite Entangled States via Local Operations are Almost Never Possible «

Entanglement is a resource under local operations assisted by classical communication (LOCC). To determine whether, or not, one entangled state can be transformed into another state via LOCC is therefore crucial to understand entanglement. We characterize almost all such LOCC transformations among multiqudit states, i.e., states with local dimension d>2. Combined with analogous results for qubit states shown by Gour et al. [J. Math. Phys. 58, 092204 (2017)] this gives a characterization of local transformations among almost all multipartite pure states. We find that LOCC transformations among generic multiqudit states are extremely restricted. More precisely, a generic state can neither be obtained from nor transformed to inequivalent fully entangled states via LOCC – it is LOCC isolated. However, we also identify a set of states that can always be transformed via LOCC. In order to derive these results, we prove a more general statement, namely, that a generic multiqudit state has only the trivial local symmetry. We discuss further consequences of this result for the characterization of optimal probabilistic single-copy and multicopy LOCC transformations and the characterization of LU-equivalence classes of multipartite pure states.

MARIO KRENN | University of Vienna

» On Computer-Inspired Quantum Experiments «

Designing experimental setups for complex entangled states is a notoriously difficult feat. For that reason, we have developed the computer algorithm MELVIN which is able to find new experimental implementations for the creation and manipulation of quantum states. The discovered experiments extensively use unfamiliar and asymmetric techniques which are challenging to understand intuitively. Nevertheless, several of these computer-designed experiments have already been successfully implemented in our laboratories. Interestingly, by analyzing MELVIN's proposals, we are able to discover novel techniques. One example is a novel concept of controlled entanglement generation (which we called Entanglement by Path Identity) that is based on ideas from 25 years ago; but has only now been discovered with the help of a computer algorithm. This example shows that computer designed quantum experiments can be inspirations for new techniques and ideas.

MARTIN HEBENSTREIT | University of Innsbruck

» Matchgate circuits and compressed quantum computation «

Although it is believed that quantum computation cannot be classically efficiently simulated in general, there exist certain restricted classes of quantum circuits for which classical simulation is indeed possible. The most prominent example are the Clifford circuits. Here, we consider another such class, the so-called matchgate circuits (MGCs) [1,2]. MGCs can be classically efficiently simulated and moreover, performed as a compressed quantum computation, i.e., the computation can be performed on an quantum computer using exponentially fewer qubits and only polynomial overhead in runtime [3]. We elaborate on and extend recent results [4] on classical simulability of MGCs. To this end, we discuss the notion of magic states in this context.