Thursday, December 14th

Talks

Thomas Konrad, University of KwaZulu Natal

Quantum Control through a Self-Fulfilling Prophecy

Sequential and continuous measurements allow to monitor the dynamics of quantum systems even in the presence of moderate noise [1, 2]. We demonstrate here that the same mechanism that leads to faithful monitoring can also be used to control quantum systems. At the example of qubits, we present consecutive measurements with unitary feedback that can drive quantum systems with unit probability into an arbitrary target state or even arbitrary target dynamics and protect them against noise.

References

[1] L. Diosi, T. Konrad, A. Scherer, and Audretsch J. Coupled Ito equations of continuous quantum state measurement and estimation. J. Phys A, 39, L575–L581(2006)

[2] T. Konrad and H.Uys. Maintaining quantum coherence in the presence of noise through state monitoring. Phys. Rev. A., 85, 012102 (2012).G. Barontini et al., Phys. Rev. Lett. **110**, 035302 (2013).

Stefan Ostermann, University of Innsbruck

Emergent Skyrmions in a two-component Bose-Einstein condensate in a ring cavity

Cavity QED is a versatile tool to simulate Quantum phase transitions on a fundamental level. In the present work we use a ring cavity setup with two counterpropagating modes coupled to a two-component BEC. The system shows a non-trivial phase diagram including a topological phase transition which can be realized by tuning the cavity pump intensities above a certain critical threshold.

Marc-Antoine Lemonde, TU Wien

Phonon networks with SiV centers in diamond waveguides

In this talk I will describe the implementation and operation of a solid-state quantum network, where separated silicon-vacancy centers are coupled via the phonon modes of a quasi-1D diamond waveguide. In this setup, quantum states encoded in long-lived spin degrees of freedom can be converted into propagating phonon wavepackets and be reabsorbed efficiently by a distant defect center. Our analysis shows that under experimentally achievable conditions, this approach enables the implementation of high-fidelity and scalable quantum communication protocols within chip-scale spin-qubit networks. Apart from quantum information processing applications, this setup provides a novel waveguide QED platform, where strong-coupling effects between solid-state defects and individual propagating phonons can be explored at the quantum level.

Phani Raja Mupalla, University of Innsbruck
Bi-stability in a mesoscopic Josephson Junction Array Resonator

We present an experimental analysis of the Kerr effect of extended plasma resonances in a 1000 Josephson junction (JJ) chain resonator inside a rectangular waveguide. The Kerr effect manifests itself as a frequency shift that depends linearly on the number of photons in a resonant mode. We study the bi-stable behaviour, using a pump probe scheme on two modes of the JJ array, exploiting the Cross-Kerr effect in our system. In order to understand the behaviour of the bi-stability we perform continuous time measurements to observe the switching between the two metastable states. We observe a strong dependence of the switching rates on the photon number and the drive frequency.

Vlatko Vedral, University of Oxford, CQT Singapore
An entanglement-based test of quantum gravity

Quantum mechanics is commonly said to be a theory of microscopic things: molecules, atoms, subatomic particles. Most physicists, though, think it applies to everything, no matter what the size. The reason its distinctive features tend to be hidden is not always a simple matter of scale. Over the past few years experimentalists have seen quantum effects in a growing number of macroscopic systems. The quintessential quantum effect, entanglement, can even occur in large systems as well as warm ones - including living organisms - even though molecular jiggling might be expected to disrupt entanglement.

Gravity, however, seems different and all existing quantum gravity proposals share the same problem. Their predictions are extremely hard to test in practice. Quantum effects in the gravitational field are exceptionally small, unlike those in the electromagnetic field. The fundamental reason, as I intend to elaborate on, is that the gravitational coupling constant is about 43 orders of magnitude smaller than the fine structure constant, which governs light-matter interactions. In that sense, the detection of gravitons – the hypothetical quanta of energy of the gravitational field predicted by certain quantum-gravity proposals – is deemed to be practically impossible.

In my talk I will present a different, quantum-information-theoretic approach, which circumvents the problem that quantum gravity is hard to test. I will discuss an experiment to witness quantum-like features in the gravitational field, by probing it with two masses each in a superposition of two locations. I will then argue that the degree of entanglement between the masses is an indirect witness of the quantisation of the field mediating the interaction. Remarkably, this experiment does not require any quantum control over gravity itself. It also seems possible to realise using the existing quantum technology.

Bernhard Rauer, TU Wien
Recurrences in an isolated quantum many-body system

The evolution of an isolated quantum system is unitary and therefore intrinsically periodic. For interacting many-body systems however, the complexity of the eigenstate spectrum prevents the observation of a dynamic return to the initial state for all but the smallest systems. In this talk I will show that by realizing a commensurate spectrum of collective excitations in one-dimensional superfluids, we can demonstrate recurrences of coherence and long range order in an interacting quantum many-body system containing thousands of particles. For this we take a coupled pair of superfluids out of equilibrium by quenching the tunnel-coupling to zero. During the subsequent evolution we monitor the relative phase field of the two condensates, which provides a local probe for the system. This allows us to directly observe how the phase coherence between the two many-body systems is initially lost and then recurs periodically. This observation opens a new window into the coherent dynamics of large quantum systems even after they reached a transient thermal-like state.

Simon Stellmer, TU Wien
Ultracold mercury for a measurement of the EDM

The fact that there is substantially more matter than antimatter in the universe hints at a powerful CP-violating mechanism that favors matter over antimatter. The details of this CP violation, which goes well beyond standard model predictions, are not yet understood and pose one of the most challenging questions in modern physics.

A prominent strategy to investigate CP violation is the measurement of an electric dipole moment (EDM) in fundamental particles (e.g. electrons, neutrons, and atoms). A large set of excellent experiments are already underway, and none of them has found a non-zero value for the EDM yet. The most sensitive measurements of an atomic EDM have been performed with room-temperature vapor cells of mercury, but such experiments seem to have reached their technical limitations.

I will present a new approach to measure atomic EDMs, using ultracold atoms. Taking the room-temperature mercury experiment into the quantum regime will allow us to increase the sensitivity to an EDM by at least one order of magnitude. We will set up the first experiment targeted at quantum degeneracy in mercury, which also connects to Hg optical clocks and quantum simulations on optical lattices. Experimental work will begin in April 2018, and I will discuss a number of ideas behind this project.

Christian Brand, University of Vienna
Test of multipath interference and conformer-selection with molecular matter-waves

The superposition principle is fundamental to quantum mechanics and has been directly tested with a number of experiments using coherent light, single photons, and nuclear spin states. Recently, we have extended these experiments to massive particles [1]. In our experiment we compare the interference patterns arising from a beam of dye molecules diffracting at single, double, and triple slit material masks to place limits on multipath interference. An upper bound of less than one particle in a hundred deviating from the expectations of quantum mechanics is observed over a broad range of transverse momenta and de Broglie wavelengths.

In the second part of the talk I will show that matter-wave interference at a near-resonant ultraviolet optical grating can be used to spatially separate individual conformers of complex molecules [2]. Such conformer-pure beams have a high potential to study structure-dependent uni- and bimolecular reactions. The proposed technique is generally applicable to conformers with isolated sharp electronic transitions and paves the way for conformer-isolation of larger and more complex system than shown yet.

References

[1] J. P. Cotter, C. Brand, C. Knobloch, Y. Lilach, O. Cheshnovski, and M. Arndt, Sci. Adv. 3 e1602478 (2017)

[2] C. Brand, B. A. Stickler, C. Knobloch, A. Shayeghi, K. Hornberger, and M. Arndt ArXiv 1710.01035 (2017)

Cornelis Ravensbergen, University of Innsbruck

Precise determination of the dynamical polarizability of dysprosium at 1064 nm

The dynamical polarizability is essential for the realization of optical dipole potentials, and its accurate knowledge is crucial for the identification of ¿magic wavelengths¿, which can, for example, be used to engineer identical optical traps for different species. For dysprosium with its complex atomic level structure there has been insufficient knowledge for precise theoretical calculations, and previous experiments showed large deviations from theoretical predictions. In our experiment, we use an alkali atom (potassium) as a reference species with a well-known polarizability and we measure center-of-mass oscillations of both species in an optical dipole trap formed by a single focused laser beam at 1064 nm. To study systematic effects we measure the trap anharmonicity by measuring the trap frequency dependence on the temperature, density and excitation scheme of the cloud. Our findings feature an order-of-magnitude improvement of the experimental uncertainty. Our result agrees well with theoretical calculations and thus resolves the discrepancy with previous experiments.

Friday, December 15th

Talks

Rudolf Gross, Walther-Meißner-Institut

Superconducting Quantum Circuits: Basic Science Pushes Technology

Superconducting quantum circuits can be flexibly engineered using modern thin film and micro/nano-fabrication techniques. These quantum electronic circuits are successfully used to study fundamental quantum effects and develop components for applications in quantum technology. Examples are the tailoring of light-matter interaction, the development of sources and detectors for quantum light, or the implementation of quantum information processing, quantum metrology and quantum simulation systems. Meanwhile, several companies such as Google, IBM or Intel have started the race towards a universal quantum computer based on a superconducting hardware platform.

I will address three topics of our recent research in superconducting quantum circuits at WMI. First, I will discuss how we can use a superconducting quantum bit to determine the photon statistics of propagating quantum microwaves [1]. In particular, I will show that we can quantify the $n2+n$ photon number variance of thermal microwave photons emitted from a black-body radiator for a mean photon number $0.05 \leq n \leq 1.5$. Second, I will show how we can engineer the parity of light-matter interaction in superconducting quantum circuits [2, 3]. To this end, I will present a novel technique for the in-situ transformation of the interaction parity in superconducting quantum cir-cuits. Third, I will show how we can construct a compact 3D quantum memory by simultaneously coupling a superconducting qubit to a long-lived memory cavity and low-quality readout cavity. The physical dimensions of such a device can be significantly reduced by integrating both functionalities into a single multimode cavity.

References

[1] J. Goetz et al., Phys. Rev. Lett. **118**, 103602 (2017)

[2] J. Goetz et al., *Parity-engineered light-matter interaction*, arXiv:1708.06405

[3] J. Goetz et al., Quantum Sci. Technol. **2**, 025002 (2017)

Marie-Christine Röhsner, University of Vienna

Quantum advantage for probabilistic one-time programs

One-time programs, computer programs which self-destruct after being run only once, are a powerful building block in cryptography and would allow for new forms of secure software distribution. However, ideal one-time programs have been proved to be unachievable using either classical or quantum resources. We relax the definition of one-time programs to allow some probability of error in the output and show that quantum mechanics offers security advantages over purely classical resources. We have introduced a scheme for encoding probabilistic one-time programs as quantum states with prescribed measurement settings, explored their security, and experimentally demonstrated various one-time programs using measurements on single-photon states. These include classical logic gates, computing the parity of a hidden set of bits, and a program to solve Yao's millionaires problem. By combining quantum and classical technology, we demonstrate the quantum techniques to enhance computing capabilities even before full-scale quantum computers are available.

Lee Rozema, University of Vienna
Experimental Entanglement of Causal Orders

Quantum entanglement is both one of the most debated topics in quantum physics and one of the most powerful tools in quantum information. The study of causal relations, a cornerstone of classical physics, has recently been applied to the quantum realm, leading to the discovery that not all quantum processes have a definite causal structure. Here, we present the first experimental demonstration of entangled causal orders, resulting in a process with a genuinely indefinite causal structure. While processes with indefinite causal orders have previously been observed, these observations required the assumption that the quantum formalism used to analyse the experiments was the correct model. To circumvent this assumption, we build a model which attempts to classically describe this process using hidden variables; we then experimentally invalidate this model by violating a Bell inequality. Thus we can conclude independent of any underlying theory, that the causal order in our experiment cannot be described classically.

Jason Hoelscher-Obermaier, University of Vienna
Quantum entanglement in cavity Optomechanics

The light field reflected from an optomechanical cavity can be entangled due to its optomechanical interaction with a mechanical mode. The entanglement of the reflected field can be measured in pulsed experiments [1,2], which indirectly proves the existence of entanglement between the mechanical mode of a macroscopic mechanical oscillator and the light field.

I discuss an alternative to the existing pulsed protocols which, surprisingly, can detect entanglement even for a continuously and resonantly driven optomechanical cavity. Simulations show that this continuous protocol works even in the presence of multiple, closely spaced mechanical modes (which can be problematic in pulsed experiments). In the proposed protocol, extraction and correlation of different temporal modes of the reflected field happen entirely in post-processing. The method is therefore highly flexible and can, in principle, be used to analyze correlations between arbitrary temporal modes of the reflected light field. This method will allow to detect entanglement in multi-mode, macroscopic mechanical oscillators.

References

[1] Hofer, S. G., Wieczorek, W., Aspelmeyer, M. & Hammerer, K. Quantum entanglement and teleportation in pulsed cavity optomechanics. Physical Review A 84, (2011)

[2] Palomaki, T. A., Teufel, J. D., Simmonds, R. W. & Lehnert, K. W. Entangling Mechanical Motion with Microwave Fields. Science 342, 710–713 (2013)

Mariona Moreno-Cardoner, (ICFO), guest University of Innsbruck
Non-Linear Two-Dimensional Atomic Mirrors

It is known that a single layer of atoms ordered in a two-dimensional array can reflect light as a perfect mirror, if the atoms are placed at close enough distances [1]. This represents a beautiful example of how the cooperative response of a collection of atoms, arising from strong interference and long-range re-scattering in light emission, can give rise to surprising behavior that is in contrast to our daily experience (where large amounts of material are needed to construct a mirror).

While the linear optical properties of dipole arrays have been relatively well studied, a feature unique to atoms is the ability to generate strong interactions between photons, such as by the excitation of an atom to a Rydberg state through photon absorption. Indeed, the influence on quantum light propagation due to Rydberg blockade in disordered atomic ensembles has generated intense interest. Here, we investigate the qualitatively different physics that can occur when Rydberg interactions are added to an ordered 2D array. We find that this system offers exciting possibilities, such as creating a non-linear optical mirror, which responds very differently depending on the number of photons of the incident light beam, and the generation of non-classical spatial correlations between scattered photons. In this work, we use a novel formalism [2] that enables us to properly describe atoms in the sub-wavelength regime and which captures the induced collective effects by radiation fields, to analyse and quantify the emergence of such non-linearities.

References

[1] F. J. Garcia de Abajo, Rev. Mod. Phys. 79, 1267 (2007)

[2] A. Asenjo-Garcia, J. D. Hood, D. E. Chang, H. J. Kimble, Phys. Rev. A 95, 033818 (2017)

Esteban Castro Ruiz, University of Vienna

Dynamics of quantum causal structures

It was recently suggested that causal structures are both dynamical, because of general relativity, and indefinite, due to quantum theory. The process matrix formalism furnishes a framework for quantum mechanics on indefinite causal structures, where the order between operations of local laboratories is not definite (e.g. one cannot say whether operation in laboratory A occurs before or after operation in laboratory B). Here we develop a framework for "dynamics of causal structures", i.e. for transformations of process matrices into process matrices. We show that, under continuous and reversible transformations, the causal order between operations is always preserved. However, the causal order between a subset of operations can be changed under continuous yet nonreversible transformations. An explicit example is that of the quantum switch, where a party in the past affects the causal order of operations of future parties, leading to a transition from a channel from A to B, via superposition of causal orders, to a channel from B to A. We generalise our framework to construct a hierarchy of quantum maps based on transformations of process matrices and transformations thereof.