Thursday, December 17th

Talks

Herwig Ott, Department of Physics, University of Kaiserslautern
Driven-dissipative Bose-Einstein condensates

Ultracold quantum gases are usually well isolated from the environment. This allows for the study of ground state properties and unitary dynamics of many-body quantum systems under almost ideal conditions. Introducing a controlled coupling to the environment "opens" the quantum system and non-unitary dynamics can be investigated. Such an approach provides new opportunities to study fundamental quantum effects in open systems and to engineer robust many-body quantum states. I will present an experimental platform [1,2] that allows for the controlled engineering of dissipation in ultracold quantum gases by means of localized particle losses. This technique is exploited to study quantum Zeno dynamics [3] and non-equilibrium dynamics in an ultracold quantum gas [4]. Recently, we were also able to realize non-equilibrium steady-states in a driven-dissipative Bose-Einstein condensate [5].

References

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Siddarth Koduru Joshi, IQOQI, University of Vienna
Approaching Tsirelson's Bound in a Photon Pair Experiment

We present an experimental test of the Clauser-Horne-Shimony-Holt Bell inequality on photon pairs in a maximally entangled state of polarization in which a value S=2.82759 ± 0.00051 is observed. This value comes close to the Tsirelson bound of $|S| \leq 2\sqrt{2}$, with $S-2\sqrt{2}=0.00084 \pm 0.00051$. It also violates the bound $|S| \leq 2.82537$ introduced by Grinbaum by 4.3 standard deviations. This violation allows us to exclude that quantum mechanics is only an effective description of a more fundamental theory.

Christoph Dittel, Institute for Experimental Physics, Innsbruck
Symmetric Suppression in Many-Body Quantum Interferences

We investigate how symmetry considerations in many-boson scattering experiments allow the formulation of symmetry suppression laws which predict events occurring with zero probability due to constructive interference. In particular, we theoretically formulate and experimentally test a suppression law, based uniquely on the symmetries of the setup, leaving the exact form of the scattering matrix open. Since this suppression relies on genuine N-body interference, it represents a stringent certification criterion that can be used to ensure the functionality of boson-samplers. Moreover, calculating which events are suppressed and testing the suppression for a few such events is efficient and scalable to very large particle numbers in practice.

Miguel Navascués, IQOQI, University of Vienna
The structure of Matrix Product States

For the past twenty years, Matrix Product States (MPS) have been widely used in solid state physics to approximate the ground state of one-dimensional spin chains. In this talk, exploiting an unnoticed connection with the theory of matrix algebras, I will derive two structural properties of MPS, namely: a) there exist local operators which annihilate all MPS of a given bond dimension; and b) there exist local operators which, when applied over any MPS of a given bond dimension, decouple the particles where they act from the spin chain while at the same time glue the two loose ends back again into a MPS. Exploiting property a), I will show how to construct instances of local Hamiltonians for which standard MPS-based variational methods will return arbitrarily bad estimations of the ground state energy. Combining properties a) and b), I derive a family of local operators whose average values are non-negative for all MPS. I use this family to devise convex relaxations for linear optimizations over MPS. Finally, I generalize some of these results to the ansatz of Projected Entangled Pairs States (PEPS).

Pavel Sekatski, Institute for Theoretical Physics, Innsbruck
Error-correction assisted quantum metrology: the ultimate limits

We consider ultimate limits on how precise a parameter, such as frequency or magnetic field strength, can be estimated in the presence of general noise. We show that the usage of full quantum control, in particular of auxiliary systems and fast continuous quantum error correction, allows one to improve the achievable accuracy. When an overall Hamiltonian description is appropriate, we find that a quadratic improvement (Heisenberg scaling) is achievable for all kinds of noise except noise generated by the Hamiltonian to be estimated. For generic incoherent noise processes we show that despite full quantum control the possible improvement is limited to an overall constant factor over the standard quantum limit. However, a significant improvement is still possible for limited resources. We introduce a simple experimentally accessible sequential scheme, making use of a single sensing system plus one auxiliary system that outperforms entanglement-based schemes without error correction operating with a finite number of parallel systems.

Flaminia Giacomini, Faculty of Physics, University of Vienna
Infinite-dimensional quantum systems on indefinite causal structures

Standard quantum mechanics assumes that events are embedded in a global causal structure such that, for every pair of events, the causal order between them is always fixed. The process matrix framework keeps the local validity of standard quantum mechanics while relaxing the assumption on the global causal structure. This allows to describe situations in which the order of events is not fixed, i.e. there are processes where it is not possible to specify whether A causes B or B causes A. Such processes are called causally nonseparable. So far, the formalism has been developed only for finite-dimensional systems and a straightforward generalization to infinite dimensions leads to singularities. Here we develop such generalization, and derive the correlations arising from a causally nonseparable process — the quantum switch — in infinite dimensions. The correlations exhibit interference which is due to superposition of processes in which A is before B and B is before A.

Friday, December 18th

Talks

Alban Kellerbauer, Max Planck Institute for Nuclear Physics, Heidelberg
Driven-dissipative Bose-Einstein condensates

Currently available cooling techniques for negatively charged particles allow cooling only to the temperature of the surrounding cryogenic environment, typically at 4 K if the apparatus itself is cooled with liquid helium. At these temperatures, the precision of spectroscopic or interferometric investigations is limited by inhomogeneous broadening due to thermal motion. A fast electronic transition in an atomic anion could be used to laser-cool an ensemble to microkelvin temperatures. The technique would allow the cooling of any species of negatively charged particles -- from antiprotons to molecular anions -- to ultracold temperatures by sympathetic cooling.

Atomic anions are generally not amenable to optical spectroscopy or laser cooling because they are loosely bound systems and rarely have bound excited states. Until now, there are only three known negative ions with strong electronic transitions. We have been investigating the bound--bound electric-dipole transitions in Os^{-} and La^{-} by high-resolution laser spectroscopy to investigate their suitability for laser cooling. The study of these transitions also provides unique insights into the structure of atomic anions. The principle of the method, its potential applications, as well as recent experimental results will be presented.

Stefan Putz, Institute of Atomic and Subatomic Physics, Vienna
Engineering of long lived Collective Dark States in Spin Ensembles

Inhomogeneously broadened solid-state spin ensembles are a prime candidate for a multimode quantum memory. However, spin dephasing together with the dissipation from a cavity interface causes short memory storage times. To overcome this we create long-lived dark states in an ensemble of electron spins hosted by nitrogen-vacancy centers in diamond strongly coupled to a superconducting microwave cavity by burning narrow spectral holes into the strongly broadened spin ensemble. We observe Rabi oscillations with high visibility and coherence times characterised by drastically reduced values for the decay rate that goes significantly below the fundamental limit attainable by the cavity protection effect. To demonstrate the potential of our approach we create multiple long-lived dark states, which paves the way for long-lived quantum memories and solid-state microwave frequency combs.

Óscar-Andrey Herrera, IQOQI, University of Innsbruck
Quantum logic spectroscopy with a $^{40}Ca+$ / $^{27}Al+$ ion crystal

Over the years, the physical quantity frequency has always had a special status in physics primarily because accurate knowledge of emission lines shaped by quantum state transitions in atoms is crucial in the realization of fundamental physics tests with the development of better clocks and measurement standards [1, 2]. Recently with the inclusion of essential ingredients from quantum information science it was possible to perform high precision spectroscopy in the otherwise difficult-to-reach transitions of $^{27}Al^{+}$ ions by means of Quantum Logic Spectroscopy (QLS) [3]. Briefly, QLS uses an auxiliary “logic” ion, which is stored in a miniature linear radio-frequency trap together with a “spectroscopic” ion. The “logic” ion is then used to cool down the initially hot “spectroscopic” ion via the Coulomb interaction and additionally allows the preparation and detection of the internal state of the "spectroscopic" ion.

In our experimental demonstration of QLS, a single $^{40}Ca^+$ ion ("logic" ion) and a single $^{27}Al^+$ ion ("spectroscopic" ion) are laser-ablation loaded and simultaneously trapped in a linear Paul trap in order to perform optical spectroscopy on the Al^+ ion. We observe long sympathetic cooling times before crystallization occurs. Therefore, we develop a new technique for detecting the loading of an initially hot ion ("spectroscopic" ion) with energy in the electron-volt range by monitoring the motional state of a Doppler-cooled ion ("logic" ion) already present in the trap [4]. When the two-ion crystal of Ca^+ and Al^+ is cooled near its motional ground state by laser-cooling the Ca^+ ion, we interrogate the "spectroscopic" ion and map its internal state onto the Ca^+ ion via the common vibrational state. By using QLS, we have measured the $^{27}Al^+$ ($^1S_0$, $F = 5/2$, $m_F = 5/2$) $\rightarrow$ ($^3P_1$, $F = 7/2$, $m_F = 7/2$) transition frequency with a preliminary value of 1 122 842 857 335 kHz.

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Cornelia Spee, Institute for Theoretical Physics, Innsbruck
The maximally entangled set of multipartite quantum states

Entanglement is the resource to overcome the restriction of operations to Local Operations assisted by Classical Communication. In particular, entanglement is non-increasing under LOCC. Hence, a bipartite maximally entangled state has the property that it allows to obtain any other state via deterministic LOCC transformations but there exists no Local Unitary (LU)-inequivalent state from which this state can be reached via LOCC. In the multipartite setting there exists no single state with this property but a whole set of states, the Maximally Entangled Set (MES, [1]), is required. That is the MES is the minimal set of n-partite states such that any truly n-partite entangled pure state can be obtained via deterministic LOCC transformations from a state in this set.

We characterized the MES for three qubits and four qubits (up to one SLOCC class) [1, 2], as well as the MES for generic three qutrit states [3]. Whereas for three qubits the MES is of measure zero, it is of full measure for four qubits and three qutrits. For four qubits we observe that most SLOCC classes show a similar behaviour. In particular, almost all states are isolated, i.e. they can neither be reached nor converted to any non-LU equivalent state. We also identify classes with very different behaviour. Whereas in the W- and GHZ-class no state is isolated, we find classes in which no deterministic LOCC conversions are possible. Moreover, we identify a class whose transformation properties differ from all the other SLOCC classes for four qubits.

In the generic three qutrit case we identify a family of pure states which can be reached via separable maps (SEP) but not via LOCC. To our knowledge these are the first examples of transformations among pure states that can be accomplished via SEP but not via LOCC.

References

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Thomas Lang, Institute for Theoretical Physics, Innsbruck
Deconfined quantum criticality beyond designer Hamiltonians

The SU(6) symmetric generalization of the Hubbard model on the square lattice provides the simplest microscopic realization of the quantum phase transition from a Néel to a valence bond solid (VBS) ordered phase. By constructing dimensionless quantities such as ratios of the magnetic structure factor and valence bond correlations we are able to determine the existence of weak, but robust antiferromagnetic order in the weak coupling regime and a plaquette VBS in the strong coupling limit. Furthermore these ratios provide a tool to accurately determine the (critical) point from both sides of the phase transition separating the two limits. Preliminary results suggest a direct continuous transition beyond the Landau paradigm, for which we extract estimates for the critical exponents and compare the scaling function with the SU(6) designer spin-models to investigate whether this quantum phase transition is compatible with the scenario of deconfined quantum criticality.