SFB-Meeting, July 2013, Innsbruck

Poster Abstracts

Birgit Brandstätter (Exp.-Physik, Innsbruck)

Towards strong coupling in an ion-trap cavity apparatus

Quantum networks, in which atoms at quantum nodes are linked by photonic channels, offer a compelling solution to the challenge of scalability in quantum computing. In these networks, optical cavities provide an interface between photons and atoms; however, the technical requirements for such cavities are demanding. We utilize recent advances in mirrors fabricated on fiber facets in order to couple trapped calcium atoms to a high-finesse cavity with small mode volume. To that end, we develop and test curved, coated fiber mirrors and set up an integrated ion-trap cavity setup. Our ion trap is a miniaturized linear Paul trap which features a deep trapping potential, and our cavity parameters are designed to yield strong coupling between a single calcium ion and a cavity photon.

Kathrin Buczak (Atominstitut, Wien)

Creation of nitrogen-vacancy centres for cavity QED

We present the creation of NV centre ensembles for quantum applications, using a variety of irradiation and implantation techniques. We have irradiated nitrogen-rich artificial diamond samples for applications including magnetometry, electric field sensing and coupling of NV ensembles to microwave resonators. Here we compare the effects of neutron irradiation, electron irradiation and electron irradiation at high temperature, showing that the latter leads to high conversion efficiency and low damage in the crystal lattice. We furthermore present measurements which display the charge-state dynamics (population transfer between NV0 and NV-) in dependence of the density of nitrogen and NVs. Finally, we present our efforts towards the creation of arrays of NV centres by nitrogen implantation with a spatial resolution on the order of 25 nm. This will enable the precise positioning of NV centres in optical microcavity arrays, with the aim of enhancing their weak zero-phonon transition.

Marko Cetina (IQOQI, Innsbruck)

Strong Atom-Dimer Attraction in a Mass-Imbalanced Fermi-Fermi Mixture

Mass imbalance in strongly interacting Fermi mixtures is predicted to lead to new non-s-wave pairing mechanisms and quantum phases. We report on a striking phenomenon arising from mass imbalance, which has no counterpart in the mass-balanced case. Using radio-frequency spectroscopy, we investigate a mixture of ^{40}K atoms and ^{6}Li^{40}K halo dimers on the repulsive side of an interspecies Feshbach resonance. From the peak shifts in our spectra, we find that, for a sufficiently strong repulsive s-wave interaction, the ^{40}K atoms and the ^{6}Li^{40}K dimers interact attractively, in strong contrast to the mass-balanced case. Our observations are in good agreement with a theoretical prediction based on attractive atom-dimer interaction in odd angular momentum channels [1].

[1] J. Levinsen and D. Petrov , Eur. Phys. J. D 65, 67 (2011)

Benoît Descamps (CoQuS, Wien)

Asymptotically decreasing Lieb-Robinson Velocity for a class of dissipative quantum dynamics

We study the velocity of the propagation of information for a class of local dissipative quantum dynamics. This finite velocity is expressed by the so-called Lieb-Robinson bound. Besides the properties of the already studied dynamics, we consider an additional relation that expresses the propagation of certain subspaces. The previously derived bounds did not reflect the dissipative character of the dynamics and yielded the same result as for the reversible case. In this article, we show that for this class the velocity of propagation of information is time dependent and decays in time towards a smaller velocity. In some cases the velocity becomes zero. At the end of the article, the exponential clustering theorem of general frustration free local Markovian dynamics is revisited.

Claudiu Genes (Theor.-Physik, Innsbruck)

Protected state enhanced quantum metrology with dense two-level systems ensembles

We exploit the correlated coupling to the environment of an ensemble of tightly-packed two-level quantum systems in the context of quantum metrology (such as the two pulse Ramsey interferometry scheme) to devise an improved frequency detection scheme. We detail our mechanism for small number of systems in different configurations and present numerical evidence for systems of larger size.

Chiara Greganti, Rui Vasconcelos (Q. Opt., Q. Nanophys. & Q. Inf., Wien)

Experimental Measurement-Based Quantum Error Correction

We present the experimental implementation of a quantum error correction protocol using the framework of measurement-based quantum computing, where encoding, syndrome readout and decoding are achieved by measurement operations. The protocol is based on a 4-photon box cluster state, generated in a SPDC-type II process. One measurement on this state is used for encoding and two further measurements for syndrome read-out and decoding. Finally, we analyze the output state via quantum state tomography.

Jason Hoelscher-Obermaier[1], Sebastian G. Hofer[1], Witlef Wiezcorek[1], Karoline Siquans[1], Ralf Riedinger[1], Garrett D. Cole[1], Klemens Hammerer[2], Markus Aspelmeyer[1] ([1]VCQ, Uni Wien; [2]Theor. Phys., Leibniz University Hannover)

Optomechanical state reconstruction using Kalman filtering

Optomechanics uses light to control the state of a vibrational mode of a massive mechanical object. To verify the success of optomechanical protocols, the joint state of mechanical mode and light field needs to be measured. The mechanical mode can be measured only indirectly, however, by measuring the light which has interacted with it. Kalman filtering allows for the reconstruction of the joint state of the light field and the mechanical mode from measurements on the light field alone. The Kalman filter relies on a system model and a measurement model to provide an optimal estimate of the full state of the system. We illustrate this method for our cavity-optomechanical setup. To this end, we perform homodyne detection on the driving beam after interaction with the mechanical mode, and postprocess the results using the Kalman filter. Since the Kalman filter is based on the full system dynamics (quantum Langevin equations for the interacting optomechanical system together with a model of the detection setup), no further simplifying assumptions (such as weak optomechanical coupling or adiabaticity) enter.

Philip Holz (Exp.-Physik, Innsbruck)

Operating 2-dimensional arrays of addressable ion traps

In order for trapped-ion quantum computers to outperform classical computers in practice the problem of scalability must be solved. To do this we have proposed a 2D array of individual surface traps in which interactions between nearest-neighbour ions can be deterministically switched on and off. I will report on progress made in operating such 2D arrays of addressable ion traps.

Bo Huang (Exp.-Physik, Innsbruck)

Three-body recombination in a quasi-two-dimensional quantum gas

Collisional properties of interacting particles can dramatically change when the dimensionality of the system is reduced. One intriguing example is the disappearance of the weakly bound trimers known as Efimov states in two dimensions. Many open questions remain about the details of the crossover from three to two dimensions and how the Efimov-related three-body recombination losses are affected. We use ultracold cesium atoms trapped tightly in a harmonic potential along one spatial direction to realize a quasi-two-dimensional system with tunable confinement and tunable interactions. In our latest results, we succeed to trace a smooth transition of the three-body recombination rate from a three-dimensional to a nearly two-dimensional system, in good agreement with recent theoretical models.

Kosmas Kepesidis (Atominstitut, Wien)

Phonon Cooling and Lasing with Nitrogen-Vacancy Centers in Diamond

We study the strain-induced coupling between a nitrogen-vacancy impurity and a resonant vibrational mode of a diamond nanoresonator. We show that under near-resonant laser excitation of the electronic states of the impurity, this coupling can lead to substantial cooling and heating of the resonator, and either cool it close to the vibrational ground state or drive it into a large amplitude coherent state. We derive a semi-classical model to describe both effects and evaluate the stationary state of the resonator mode under various driving conditions. In particular, we find that by exploiting resonant single and multi-phonon transitions between near-degenerate electronic states, the coupling to high-frequency vibrational modes can be significantly enhanced and dominant over the intrinsic mechanical dissipation. Our results show that a single nitrogen-vacancy impurity can provide a versatile tool to manipulate and probe individual phonon modes in nanoscale diamond structures.

Amir Moqanaki (Q. Opt., Q. Nanophys. & Q. Inf., Wien)

A source of narrow-band photon-pairs

A source of narrow-band photon-pairs at 780nm, Rb D2 line has been presented. The expected brightness is ~ 100 pair/s/MHz/mW, and the line-width is ~ 8 MHz. This source can be used for investigating single photon interactions with atoms.

Wolfgang Niedenzu (Theor.-Physik, Innsbruck)

Subrecoil

We present a detailed numerical analysis of the temperature limit and timescale of cavity cooling of an ultracold dilute gas in the quantum regime for particles and light. For a cavity with a line width smaller than the recoil frequency, efficient cooling towards quantum degeneracy is facilitated by applying a tailored sequence of laser pulses transferring the particles towards lower momenta. Two particle wave function simulations reveal strongly improved cooling properties for a ring versus a standing wave geometry. Distinct quantum correlations and cooling limits for bosons and fermions demonstrate quantum statistical effects. In particular, in ring cavities, the photon mediated long range interaction favors momentum space pairing of bosons, while fermion pairs exhibit anti-correlated or uncorrelated momenta. The results are in good agreement with recent experiments and give encouraging prospects to replace evaporation by cavity cooling to achieve condensation of an enlarged class of species of polarisable particles. Tailoring detuning allows to induce and strongly enhance particle correlations and entanglement.

Lorenzo Procopio (Q. Opt., Q. Nanophys. & Q. Inf., Wien)

Superconducting nanowire single-photon detectors for femtosecond-pulsed multi-photon experiments

Scalable quantum information processing experiments have an increasing demand for new technologies that improve the detection efficiency of entangled multi-photon states. To date, the process of spontaneous parametric down-conversion (SPDC) is still the best available source for the generation of individually addressable multi-photon states. The downside of this photon source is the intrinsic probabilistic character that limits current experiments to generate up to 8 photons within reasonable detection time when using conventional single-photon detection technology. On the other hand superconducting nanowire single-photon detectors (SNSPDs) are very promising to open a new experimental parameter regime by superior detection efficiencies combined with picosecond timing resolution and low dark counts. Here, we will report on the investigation of operating SNSPDs in femtosecond-pulsed multi-photon experiments. We will also present perspectives of linear-optical quantum computation and quantum simulation experiments that are within reach when using efficient SNSPDs.

Sarah Stöckl, Max Tillmann (Q. Opt., Q. Nanophys. & Q. Inf., Wien)

Experimental Boson Sampling

Universal quantum computers promise a dramatic increase in speed over classical computers, but their full-size realization remains challenging2. However, intermediate quantum computational models have been proposed that are not universal but can solve problems that are believed to be classically hard. Aaronson and Arkhipov have shown that interference of single photons in random optical networks can solve the hard problem of sampling the bosonic output distribution. Remarkably, this computation does not require measurement-based interactions or adaptive feed-forward techniques. Here, we demonstrate this model of computation using laser-written integrated quantum networks that were designed to implement unitary matrix transformations. We characterize the integrated devices using an in situ reconstruction method and observe three-photon interference that leads to the boson-sampling output distribution. Our results set a benchmark for a type of quantum computer with the potential to outperform a conventional computer through the use of only a few photons and linear-optical elements.

Slava Tzanova (Exp.-Physik, Innsbruck)

Quantum degenerate mixtures of strontium and rubidium atoms

RbSr dimers are polar, open-shell molecules. Their electric dipole moment gives rise to anisotropic long-range interactions. In contrast to bi-alkali molecules, they possess an unpaired electron, which provides them with a rich spin structure and a magnetic dipole moment. This additional degree of freedom will enable a better design and control of the experimental parameter space and could also be used for suppressing inelastic collisions. With ultracold RbSr molecules, a new platform will be available to implement lattice-spin models or to imprint geometrical phases. After we extended our Sr apparatus to also manipulate Rb atoms, we have recently produced quantum degenerate mixtures of the two species. A central stage in our experimental scheme is the sympathetic narrow-line laser cooling of Rb by Sr, which allows us to reach a high phase-space density for both elements before evaporative cooling. We observe efficient thermalization for two isotope mixtures, ^{87}Rb-^{88}Sr and ^{87}Rb-^{84}Sr, and can deduce favorable interspecies scattering lengths. These advantageous interaction properties allow the creation of BECs with more than 10^5 atoms per element for the ^{87}Rb-^{84}Sr mixture. Currently we are performing 2-color photoassociative spectroscopy from which we can infer the shape of the RbSr molecular potentials and the interspecies collision properties. Our first results combined with theoretical calculations will deliver a suitable scheme for molecular formation, either by magneto-association via Feshbach resonances or optically by stimulated Raman adiabatic passage (STIRAP).