Topical Sessions

1 Atomic- and Molecular Physics & Quantum Optics

Wednesday, 2. Sept. 2009, Room A

Time	ID	**Atomic- and Molecular Physics & Quantum Optics** *Chair: A. Weis, Uni Fribourg*
09:00		***PLENARY SESSION***
12:40		***Postersession, Lunchbuffet***
14:00	**101**	**A quantum gas of rovibronic ground state molecules in an optical lattice** *Johann Georg Danzl [1], Manfred Mark [1], Elmar Haller [1], Russell Hart [1], Lukas Reichsöllner [1], Mattias Gustavsson [1], Nadia Bouloufa [2], Olivier Dulieu [2], Houssam Salami [3], Tom Bergeman [3], Helmut Ritsch [4], Hanns-Christoph Nägerl [1]* *[1] Institute for Experimental Physics, University of Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria* *[2] Laboratoire Aimé Cotton, CNRS, Université Paris-Sud, 91405 Orsay, France* *[3] Department of Physics and Astronomy, SUNY, 3800 Stony Brook, United States* *[4] Institue for Theoretical Physics, University of Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria* Ultracold samples of molecules are ideally suited for fundamental studies in physics and chemistry. For many of the proposed experiments full molecular state control and high phase-space densities are needed. We create a dense quantum gas of Cs_2 molecules in the rovibronic ground state, i.e. in the $\|\nu=0, J=0\rangle$ level of the $X\,^1\Sigma_g^+$ electronic ground state, where each molecule is trapped at an individual site of an optical lattice. Starting from an atomic Mott insulator state, we associate pairs of atoms to Feshbach molecules and then efficiently transfer the molecular population by means of the STIRAP technique to one particular quantum level in the rovibronic ground state with a total of four laser transitions. Our results show that full control over all molecular degrees of freedom is possible and that the creation of a BEC of molecules in their rovibronic ground state is within reach.
14:30	**102**	**Laser and Microwave-Laser Double Resonance Spectroscopy of Alkali Atoms in Wall-coated cells** *Thejesh Bandi, Gaetano Mileti* *Laboratoire Temps-Fréquence, University of Neuchâtel, Bellevaux 51, 2009 Neuchâtel, Switzerland* We present the spectroscopy of ^{87}Rb atoms in paraffin-coated cells using a DFB laser, in view of potential applications in atomic clocks and magnetometers. To characterize the quality of coating, we measured the hyperfine relaxation time (T1) by "relaxation in the dark" technique. The measured T1 for a buffer gas cell

		was 4.6ms, which was five times smaller to that obtained with a wall-coated cell, 25.8ms. The latter value corresponds to the atoms undergoing ≥ 500 wall collisions before losing their polarization state. We also used the optical-microwave double resonant (DR) field for interrogation of ^{87}Rb atoms in the wall-coated cell. The line-width and the centre frequency of the DR signal measured were ~1kHz and 6.834682430GHz, respectively. The ongoing experiment aims to study the T1 relaxation time of ^{87}Rb clock transition levels (F_g=1, m_F=0→F_g=2, m_F=0), and the T2 relaxation time, which gives a measure of the relaxation of coherences.
14:45	**103**	**Magic L-serine clusters in cold helium nanodroplets** *Stephan Denifl [1], Filipe Ferreira da Silva [1], Peter Bartl [1], Andrew Ellis [2], Tilmann D. Märk [1], Paul Scheier [1]* *[1] Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria* *[2] Department of Chemistry, University of Leicester, University Road, Leicester LE1 7RH, United Kingdom* The emergence of homochirality in living systems is not fully explained. Why is it that L-amino acids and D-sugars predominate in living organisms? Cooks *et al.* and Hodyss *et al.* have reported a strong chirality preference in clusters of serine. In their studies, they propose that serine could be the original chiral progenitor. Recently our group has performed the first measurements with L-serine in cold He nanodroplets. The nanodroplets are produced by supersonic expansion and then doped with L-serine monomers generated by heating solid L-serine. The serine-doped helium droplets are then probed by electron impact ionization mass spectrometry. We have studied clustering of serine in the nanodroplets and observe with decreasing droplet size a profound change in the shape of the serine cluster distribution. For this case we observe a distinct magic peak for Ser_8H^+ and also a magic peak for the protonated dimer Ser_2H^+ . Possible explanations for such a pronounced cluster distribution will be discussed. Acknowledgements: This work has been supported by the FWF, Wien, Austria and the European Commission, Brussels. A.E. is grateful for the support of his visit to Innsbruck by ECCL COST Action CM0601. S. D. gratefully acknowledges an APART-fellowship from the Austrian Academy of Sciences.
15:00	**104**	**Observation of elastic doublon decay in the Fermi-Hubbard model** *Thomas Uehlinger, Niels Strohmaier, Daniel Greif, Robert Jördens, Leticia Tarruell, Henning Moritz, Tilman Esslinger* *Institute for Quantum Electronics, ETH Zürich, Schafmattstrasse 16, 8093 Zürich, Switzerland* The investigation of interacting quantum ensembles in non-equilibrium is receiving a lot of attention, yet the theoretical understanding of experimental results often remains challenging due to the complexity of the systems and their coupling to the environment. In contrast, ultracold atoms in optical lattices offer a unique cleanliness and tunability of parameters. They are therefore well suited for the study of both equilibrium and non-equilibrium states in strongly correlated systems. We implement the Fermi-Hubbard model by trapping a repulsively interacting two-component Fermi gas in a three dimensional optical lattice. This model encompasses intriguing quantum phases near the Mott insulator and may even hold the key to understanding high-temperature superconductivity. The relaxation of highly excited states of our system, which are doubly occupied lattice sites (doublons), is investigated. After creating additional doublons by

		lattice modulation, we monitor the subsequent relaxation of the system over time. In units of the tunneling time, the measured doublon lifetime is found to depend exponentially on the ratio of on-site interaction energy to kinetic energy. We argue that the dominant mechanism for the relaxation is a high order scattering process.
15:15	**105**	**Ion-cavity system for quantum networks** *Helena Goncalves de Barros, Andreas Stute, Tracy Northup, Birgit Brandstätter, Piet O. Schmidt, Rainer Blatt* *Universität Innsbruck, Institut für Experimentalphysik, Technikerstrasse 25/4, 6020 Innsbruck, Austria* A single atom interacting with a single mode of a cavity allows us to probe the quantum interaction between light and matter. In the context of quantum networks, such a system can provide an interface between stationary and flying qubits, making it possible for single photons to transport quantum information between the network nodes. We study a single $^{40}Ca^{+}$ ion trapped inside a high-finesse optical resonator. First, we demonstrate and characterize a single-photon source, in which a vacuum-stimulated Raman process transfers atomic population between two Zeeman states of the ion, creating a single photon in the cavity. We evaluate the photon statistics by measuring the second-order correlation function. Moreover, we obtain the photon temporal profile and investigate the dynamics of the process. Secondly, we perform Raman spectroscopy using the cavity. Residual motion of the ion introduces motional sidebands in the Raman spectrum and thus offers prospects for cavity-assisted cooling.
15:30	**106**	**Cavity Optomechanics with a Bose-Einstein Condensate** *Kristian Bauman [1], Ferdinand Brennecke [1], Silvan Leinss [1], Stephan Ritter [2], Tobias Donner [3], Christine Guerlin [1], Tilman Esslinger [1]* *[1] ETH Zürich, Institute for Quantumelectronics, Schafmattstrasse 16, HPF D22, 8093 Zürich, Switzerland* *[2] Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany* *[3] JILA, University of Colorado and National Institute of Standards and Technology, 440 UCB, 80309 Boulder / CO, United States* In our experiment we couple a Bose-Einstein condensate with an ultrahigh-finesse optical cavity. The tremendous degree of control over atomic gases achieved in Bose-Einstein Condensates combined with the rich field of cavity quantum electrodynamics opens access to a wealth of new physics. In the dispersive regime, our system realizes a model of cavity optomechanics. This research field typically studies the coupling of the mechanical motion of one of the cavity mirrors to the light field. In our case, the mechanical oscillator is given by a coherent density modulation of the atomic cloud. We have observed this density modulation and strong optical nonlinearities, present at the single photon level. Furthermore our mechanical oscillator naturally starts in its ground state, from which a single motional excitation can cause a shift of the cavity resonance on the order of the cavity linewidth. Our system is promising to study the quantum regime of cavity optomechanics.

15:45	**107**	**Evidence of a pair of universal four-body states tied to an Efimov Trimer** *Martin Berninger [1], Francesca Ferlaino [1], Steven Knoop [2], Walter Harm [1], Jose P. D'Incao [3], Alessandro Zenesini [1], Hanns-Christoph Nägerl [1], Rudolf Grimm [1,4]* *[1] Inst. für Experimentalphysik, Univ. of Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria* *[2] Kirchhoff-Institut für Physik, University of Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany* *[3] Department of Physics and JILA, Univ. of Colorado , CU JILA Tower, 80309 Colorado, United States* *[4] IQOQI, Technikerstr. 25, 6020 Innsbruck, Austria* Ultracold cesium atoms and Feshbach molecules provide unique model systems to explore universal few-body phenomena. In previous experiments, we have obtained clear evidence for Efimov three-body states by studying atomic three-body recombination and atom-dimer relaxation in ultracold atomic and molecular samples. Here, we report on a fundamental step beyond the Efimov scenario by investigating universal four-body processes. We measure the four-body recombination rate coefficients in an atomic gas at large negative scattering lengths and we observe two resonant enhancements of losses. This provides strong evidence for the existence of a pair of four-body states, which is strictly connected to Efimov trimers via universal relations. Our findings confirm recent theoretical predictions and demonstrate the enrichment of the Efimov scenario when a fourth particle is added to the generic three-body problem.
16:00		***Coffee Break***
		Chair: H.-C. Nägerl, Uni Innsbruck
16:30	**108**	**Quantum simulation of the 1+1 dimensional Dirac equation with a single trapped ion** *Rene Gerritsma, Gerhard Kirchmair, Florian Zähringer, Christian Roos, Rainer Blatt* *Institut für Quantenoptik und Quanteninformation, Otto-Hittmair-Platz 1, 6020 Innsbruck, Austria* Crystals of trapped ions form an ideal system for studying fundamental questions in quantum information science. Over recent years special interest has grown in using trapped ions to simulate other quantum mechanical systems that are not readily accessible in experiments. Moreover, the unprecedented control of experimental parameters might make it possible to explore new physical regimes of these systems. In a recent experiment we simulated the 1+1 dimensional Dirac equation using a single trapped ion (based on Lamata et al., PRL 98, 253005 (2007)). Straight-forward adjustment of experimental parameters makes it possible to simulate both mass-less and massive free particles in the relativistic and classical limits. We observe Zitterbewegung in the simulated particle motion and investigate various parameter regimes. Furthermore, we give a detailed analysis of the quantum states involved.

17:00 | **109**

Phase fluctuations in one-dimensional quasi-condensates on an atom chip

Thomas Betz, Stephanie Manz, Christian Koller, Robert Bücker, Aurelien Perrin, Thorsten Schumm, Jörg Schmiedmayer
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The intrinsic elongated geometry of wire traps on an atom chip provides direct access to ultra-cold one-dimensional systems. In contrast to the three-dimensional case, one- dimensional ultra-cold Bose gases do not exhibit long-range order. The respective phase fluctuations are observed in interference experiments with split one-dimensional Bose-Einstein condensates [1, 2], using radio-frequency induced double well potentials [3, 4].
In the presented experiment, we investigate the ground state of two tunnel-coupled one-dimensional Bose gases of ^{87}Rb. The ability to easily change the splitting in the double well potential allows studying the effect of different coupling strength on the relative phase between the atomic clouds. In agreement with theory [3] the experiments verify that in this equilibrium system a finite coherence between the Bose-Einstein condensates depending on the coupling remains.

[1] Hofferberth et al., Nature 449, 324 (2007)
[2] Hofferberth et al., Nature Phys. 4, 489 (2008)
[3] T. Schumm et al., Nature Phys. 1, 57 (2005)
[4] G.-B. Jo et al., PRL 99, 240406 (2007)
[5] N. K. Withlock and I. Bouchoule, PRA 68, 053609 (2003)

17:15 | **110**

Efficient Hidden-Variable Simulation of Measurements in Quantum Experiments

Borivoje Dakic [1], Milovan Suvakov [2], Tomasz Paterek [3], Caslav Brukner [1]
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We prove that the results of a finite set of general quantum measurements on an arbitrary dimensional quantum system can be simulated using a polynomial (in measurements) number of hidden-variable states. In the limit of infinitely many measurements, our method gives models with the minimal number of hidden-variable states, which scales linearly with the number of measurements. These results can find applications in foundations of quantum theory, complexity studies and classical simulations of quantum systems.

17:30 | 111 | Atomic three-body loss as a dynamical three-body interaction

Andrew Daley [1], Sebastian Diehl [1], Mikhail Baranov [2], Jake Taylor [3], Peter Zoller [1]
[1] Institute for Theoretical Physics, Technikerstr. 25/2, 6020 Innsbruck, Austria
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Cold atoms in optical lattices offer new opportunities to probe quantum many-body phenomena. Here we study the effects of atomic three-body loss processes, which are ubiquitous and typically undesirable in experiments. We show that a mechanism related to the continuous quantum Zeno effect means that large losses can dynamically suppress the probability of three particles occupying a single lattice site, giving rise to effective three-body interactions that are otherwise difficult to obtain. This counter-intuitively leads to a predicted decrease in the effective rate of loss as the real collisional loss rate is increased. These three-body interactions have important potential applications in the engineering of many-body states, especially dimer states of bosonic atoms with attractive two-body interactions and colour superfluid states in three-species Fermi mixtures. The loss processes can be described by a many-body master equation, which we simulate in one dimension by combining quantum trajectories methods with the time-dependent density matrix renormalisation group algorithm.

17:45 | 112 | Molecule Interferometry: The influence of molecular properties

Sandra Eibenberger [1], Markus Arndt [1], Tarik Berrada [1], Stefan Gerlich [1], Michael Gring [1], Lucia Hackermüller [1], Klaus Hornberger [2], Marcel Mayor [3], Marcel Müri [3], Stefan Nimmrichter [1], Hendrik Ulbricht [1]
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[2] Arnold Sommerfeld Center for Theoretical Physics Ludwig-Maximilians-Universität, Theresienstrafle 37, 80333 München, Germany
[3] University of Basel, Department of Chemistry, St. Johanns-Ring 19, 4056 Basel, Switzerland

Kapitza-Dirac-Talbot-Lau interferometry (KDTLI) has recently been established as an ideal method to perform quantum matter wave experiments with large, highly polarizable molecules in the so far inaccessible mass range of beyond 1000 atomic mass units [1]. We present new and improved data and high-contrast interference fringes with functionalized organic molecules in the range of 1600-3000 amu [2]. The interference visibility reveals important information about the static and dynamical properties of the diffracted particles and KDTLI turns out to be a potent tool for precision metrology of neutral molecules [3]. Mass, optical and static polarizability as well as electric dipole moments become accessible. They are closely related to the molecular conformation and structure. Here, quantum interferometry offers an interesting solution to a challenge that is not readily met using conventional techniques.

[1] S. Gerlich et al., Nat. Phys. 3, 711-715 (2007)
[2] K. Hornberger et al., New J. Phys. 11, 043032 (2009)
[3] S. Gerlich et al., Angew. Chem. Int. Ed. 47, 6195-6198 (2008)

18:00	**113**	**Generation and measurement of entangled two-qubit states in superconducting electronic circuits** *Stefan Filipp [1], Peter J. Leek [1], Matthias Baur [1], Peter Maurer [1], Romeo Bianchetti [1], Johannes M. Fink [1], Martin Göppl [1], Lars Steffen [1], Jay M. Gambetta [2], Alexandre Blais [3], Andreas Wallraff [1]* *[1] Departement of Physics, ETH Zürich, Schafmattstrasse 16, 8093 Zürich, Switzerland* *[2] Institute for Quantum Computing, University of Waterloo, 475 Wes Graham Way, Waterloo N2L 3G1, Ontario, Canada* *[3] Departement de Physique, Universite de Sherbrooke, 2500, Boul. de l'Université Sherbrooke, Sherbrooke J1K 2R1, Canada* The strong coherent coupling of solid state qubits to a coplanar microwave transmission line resonator forms the basis of the circuit-QED architecture and turns it into a promising choice for quantum information processing. The resonator field can be used both to mediate interactions between two distant qubits and to read out the qubits' state. Here, we demonstrate the generation of Bell states of two qubits by inducing sideband transitions to first entangle a qubit with a single resonator photon and to subsequently transfer the entanglement to a second qubit. The resulting entangled two-qubit state is reconstructed by a quantum state tomography scheme, where the qubit-state dependent transmission of the resonator is analyzed. With this dispersive quantum non-demolition measurement qubit correlations can be extracted directly from an averaged measurement without the need for single-shot measurements of individual qubits.
18:15	**114**	**Wave-particle duality of large molecules revealed** *Philipp Geyer, Thomas Juffmann, Stefan Truppe, Markus Arndt, Hendrik Ulbricht, Sarayut Deachapunya, Andras Major* *University of Vienna, Boltzmanngasse 5, 1090 Wien, Austria* Molecular interferometry has proven to be a suitable tool for testing the wave-particle duality of large, heavy and hot molecules. We report on a new detection scheme for molecular interferometry: the near-field interference pattern is deposited onto a Si(111)7x7 surface, which is subsequently imaged using a scanning tunnelling microscope (STM). STM allows imaging of every single molecule with nanometer resolution within the interference pattern, revealing the wave-particle duality in its clearest form. First interferograms of Fullerenes (C_{60}) deposited onto reconstructed Si(111)7x7 are presented.
18:30		***END***

Thursday, 3. Sept. 2009, Room A

Time	ID	ATOMIC- AND MOLECULAR PHYSICS & QUANTUM OPTICS *Chair: P. Knowles, Uni Fribourg*
09:00		***PLENARY SESSION***
12:40		***Postersession, Lunchbuffet***
14:00	115	**Strongly-correlated states of photons in reduced dimensions.** *Vladimir Gritsev, University of Fribourg, Physics Department, Chemin du Musee 3, 1700 Fribourg, Switzerland* Recent progress in quantum optics allows nowadays to create and to probe many-body strongly correlated states of light. The combined effect of reduced dimensions and strong correlation leads to dramatic change in the properties of photons. In particular, photons in special nonlinear optical fibers can exhibit phenomena of fermionization. This state is reminiscent to the Tonks-Girardeau state of ultracold atoms in one-dimensional traps. I will discuss this and other strongly-correlated states of photons in low-dimensional nonlinear systems.
14:30	116	**Quantification and Detection of Multipartite Entanglement with Covariance Matrices** *Oleg Gittsovich, Otfried Gühne* *Austrian Academy of Sciences, IQOQI, Technikerstr. 21a, 6020 Innsbruck, Austria* In this talk we review some new results on entanglement quantification an detection of multipartite entangled states. For this purpose we use the established tool of covariance matrices (CMs) and show that using CMs it is possible to estimate amount of entanglement in bipartite states. Going beyond the bipartite setting we present a criterion based on CMs that is capable of detecting multipartite entangled states. Moreover we will provide an example of a family of three qubit states, that are separable to any bipartition, but not fully separable and are detected by our criterion.
14:45	117	**Observation of strong coupling between a micromechanical resonator and an optical cavity field** *Simon Gröblacher, Klemens Hammerer, Michael Vanner, Markus Aspelmeyer, Institute for Quantum Optics and Quantum Information, Boltzmanngasse 3, 1090 Wien, Austria* We report the observation of strong coupling between a macroscopic mechanical resonator and an optical field, which is an essential requirement for the preparation of mechanical quantum states.

15:00	**118**	**Separability criteria for genuine multiparticle entanglement** *Otfried Gühne, IQOQI, Technikerstr. 21A, 6020 Innsbruck, Austria* *Michael Seevinck, Institute of History and Foundations of Science, Utrecht University, P.O Box 80.010, 3508 TA Utrecht, Netherlands* We present a method to derive separability criteria for the different classes of multiparticle entanglement, especially genuine multiparticle entanglement. The resulting criteria are necessary and sufficient for certain families of states. Further, the criteria are superior to all known entanglement criteria for many other families; also they allow the detection of bound entanglement. We next demonstrate that they are easily implementable in experiments and discuss applications to the decoherence of multiparticle entangled states.
15:15	**119**	**Realization of a Super-Tonks-Girardeau gas with strong attractive interactions** *Elmar Haller [1], Mattias Gustavsson [1], Manfred Mark [1], Johann G. Danzl [1], Russell Hart [1], Guido Pupillo [2], Hanns-Christoph Nägerl [1]* *[1] Experimentalphysik Universität Innsbruck, Technikerstrafle 25/4, 6020 Innsbruck, Austria* *[2] Institut für Quantenoptik und Quanteninformation, Technikerstrafle 21a, 6020 Innsbruck, Austria* We report on the realization of a highly-correlated, excited many-body state with strong attractive interactions. This novel state of matter in one-dimensional (1D) geometry is known as the super-Tonks-Girardeau gas (sTG) and was predicted in [1]. Counter-intuitively, although bosons strongly attract each other in this phase, they behave similar to repulsively interacting fermions, showing an effective long range interaction. We load a Bose-Einstein condensate of cesium atoms into an array of tube-like 1D traps generated by a 2D optical lattice, and control the interaction strength by means of magnetic Feshbach resonances. When the 3D scattering length is increased towards and beyond the length scale set by the tight transversal confinement, we observe a confinement-induced resonance [2] that allows us to tune the effective 1D-interaction parameter to large positive and large negative values. We realize the crossover all the way from a non-interacting gas, via the 1D mean-field and Tonks-Girardeau regime, to the sTG gas. Despite the fact that the interaction is strongly attractive, we find that the sTG gas is surprisingly stable. [1] G. Astrakharchik et al., Phys. Rev. Lett. 95, 190407 (2005). [2] M. Olshanii, Phys. Rev. Lett. 81, 938-941 (1998)
15:30	**120**	**Beam methods for large metal-organo complexes** *Philipp Haslinger, Markus Marksteiner, Michele Sclafani, Hendrik Ulbricht, Markus Arndt, Uni Wien, Boltzmanngasse, 1090 Wien, Austria* The preparation of cold molecular beams is important for physical chemistry as well as for the emerging field of macromolecular quantum optics [1]. In order to apply de Broglie interference to molecules of biological interest it is necessary to implement a soft volatilization method, an improved velocity selection as well as a stable readout scheme. A pulsed laser desorption source allows us to generate beams of amino acids, nucleotides, polypeptides and recently even large neutral amino acid clusters and metal-organic complexes. The addition of metal

salts to the desorption process leads to the inclusion of metal atoms and the formation of $CaTrp_30$ [2], Na_xTrp_y and Ca_xPhe_y even exceeding masses of 6000 amu.
The scheme permits a good velocity resolution and photoionizaton by two subsequent laser beams permits us to eliminate shot-to-shot signal fluctuations down to 4 %.

[1] B. Brezger et al., Phys. Rev. Lett. 88, 100404 (2002).
[2] M. Marksteiner et al. J. Am. Soc. Mass Spectrom. 2008, 19, 1021–1026

15:45 | **121**

Vibronic spectra predictions for open shell molecules - usefulness and limitations of ab initio calculations, assessed on alkali trimers

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The usefulness of standard ab initio techniques, such as Coupled-Cluster or Multi-Reference approaches, for the prediction of vibronic spectra is discussed using the example of K_3 and Rb_3 alkali-metal clusters. These exotic molecules, can be formed in their lowest-energy spin state (the doublet) by standard molecular beam methods; their weakly bound quartet state is easily stabilized on the surface of cold (0.4 K) helium nanodroplets. Both spin multiplicities have been characterized spectroscopically, and are good candidates to assess the quality of ab initio methods for electronic-structure calculations.
The following characteristics make alkali trimers interesting in this respect: They are multi-electron systems, of moderate size, and include heavy atoms. Correlation energy and relativistic effects thus play an equally essential role for the molecular binding; at the same time, the system remains tractable by computationally-expensive high-level methods.
The symmetry properties of alkali trimers, in either spin multiplicity, makes them prime examples for the E·e Jahn-Teller effect, where a doubly-degenerate electronic state interacts with the doubly-degenerate vibrational mode of the system. By least-squares-fits of the ab initio points we extract parameters for the analytical description of the potential energy surfaces of several electronic states. We calculate vibronic spectra where the Jahn-Teller distortion as well as spin-orbit coupling are accounted for, which we compare with the available experimental data.

16:00 | ***Coffee Break***

Chair: W. Ernst, TU Graz

16:30 | **122**

Controlling the translational motion of Rydberg atoms and molecules using inhomogeneous electric fields

Stephen Hogan, Christian Seiler, Frédéric Merkt, Laboratorium für Physikalische Chemie, ETH Zürich, Wolfgang-Pauli-Strasse, 10, 8093 Zürich, Switzerland

Recent progress in the development of methods by which to decelerate and manipulate the translational motion of Rydberg atoms in the gas phase using static and time-varying inhomogeneous electric fields [1] has led to the experimental realization of Rydberg atom optics elements including a lens [2], a mirror [3] and two- and three-dimensional traps [4,5]. These experiments exploit the very large electric dipole moments associated with Rydberg Stark states, and have demonstrated the possibility to stop a seeded, pulsed, supersonic beam of atomic hydrogen traveling with an initial velocity of 700 m/s within 2 mm and only ~5 microseconds using electric fields of a few kV/cm.

We have now extended these techniques to manipulate the translational motion of molecular hydrogen, for applications in precision spectroscopy and in studies of molecular collisions at low temperature or with a high degree of control over collision energies. The results of recent experiments in which we have loaded hydrogen Rydberg molecules into a three-dimensional electrostatic trap will be presented. These experiments have relied upon the multiphoton excitation of nonpenetrating (l>3) Rydberg-Stark states, with principal quantum number in the range n=20-30, using circularly polarized laser radiation. The method employed to decelerate and load the trap will be discussed along with the loss mechanisms affecting the rate of decay of these states from the trap.

[1] S. R. Procter et al., Chem. Phys. Lett., vol. 374, 667 (2003).
[2] E. Vliegen et al., Eur. Phys. J. D, vol. 40, 73 (2006).
[3] E. Vlegen and F. Merkt, Phys. Rev. Lett., vol. 97, 033002 (2006).
[4] E. Vliegen et al., Phys. Rev. A, vol. 76, 023405 (2007).
[5] S. D. Hogan and F. Merkt, Phys. Rev. Lett., vol. 100, 043001 (2008).

17:00 **123**

A Miniaturized Microwave Paul Trap for Electron Guiding

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We present the current status of an experiment aiming at guiding electrons in an AC quadrupole guide. In order to stably and tightly confine electrons in the transverse direction the guide has to be miniaturized and operated at microwave frequencies. Therefore, we plan to combine a microfabricated microwave guiding structure with the electrode layout of a planar two-dimensional Paul-trap on a chip substrate. With electrons emerging from a high brightness single atom tip direct injection into the transverse ground state of the guide should be feasible. This would lead to a well-defined motional quantum system with potential applications in interferometry and quantum information processing. Here, the numerical and experimental characterization of the guiding-chip layout will be presented.

17:15 **124**

The geometric measure of entanglement for symmetric states

Robert Hübener, Matthias Kleinmann, Otfried Gühne
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We show that the closest product state to any symmetric multipartite pure quantum state is symmetric. This proves an often used conjecture concerning the geometric measure of entanglement. Our results have further applications to the separability of permutationally symmetric states and the injective tensor norm.

17:30 **125**

Solid state quantum memory for photons at telecommunication wavelength

Björn Lauritzen, Jirì Minàr, Hugues de Riedmatten, Mikael Afzelius,
Christoph Simon, Nicolas Gisin
GAP-Optique, Université de Genève, Rue de l'Ecole-de-Médecine 20,
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Quantum memories are the building block of quantum repeaters, which would allow the extension of fiber based quantum communication to very long distances. Some efficient quantum repeater protocols that have been proposed

		require quantum memories at telecommunication wavelength around 1550 nm. We present a proof of principle of the experimental realization of such quantum memory in an Erbium doped solid. Weak pulses of light at the single photon level are stored for up to 600 ns in the crystal and retrieved on demand using a modified photon echo approach based on controlled reversible inhomogeneous broadening (CRIB). The storage and retrieval efficiency is currently limited by the available optical depth and by difficulties in the preparation of the memory by optical pumping. These results provide a proof of principle of the feasibility of a light-matter interface at the quantum level for photons at telecommunication wavelength.
17:45	**126**	**Deriving quantum mechanics from statistical assumptions** *Ulf Klein* *Institut für Theoretische Physik, Universtiät Linz, Altenberger Strasse 69, 4040 Linz, Austria* Quantum *mechanics* is generally considered as a superior version of classical mechanics. This means: (i) it is believed that the proper starting point for quantization is classical mechanics (a deterministic theory), and: (ii) the formalism is used to describe the behavior of single particles. In this communication I try to show that quantum mechanics can be understood in terms of statistical assumptions. These include a conservation law of probability and the postulate of a a complex state variable (see: http://xxx.lanl.gov/abs/0806.4335v3, Found. Phys. accepted). More recently (work in progress) a statistical version of Newtons equations and a principle of maximal Fisher information have been used. One obtains Schrödinger's equation and an explanation of established but nevertheless mysterious quantization rules related to (i). In this approach there are no mysterious results related to (ii) either because a statistical theory cannot be used to make any predictions about individual events.
18:00	**127**	**Test of quantum contextuality incorporating imperfect measurement devices** *Matthias Kleinmann [1], Gerhard Kirchmair [1], Florian Zähringer [1], Rene Gerritsma [1], Otfried Gühne [1], Adan Cabello [2], Rainer Blatt [3], Christian F. Roos [3]* *[1] IQOQI, Technikerstr. 21a, 6020 Innsbruck, Austria* *[2] Departamento de Fisica Aplicada II, Universidad de Sevilla, 41012 Sevilla, Spain* *[3] IQOQI, Otto-Hittmair-Platz 1, 6020 Innsbruck, Austria* We study the influence of imperfect measurement devices on the notion of quantum contextuality. In general, tests of (non-)contextuality require perfectly compatible measurement devices, a requirement that can be neither achieved nor verified in an experimental realization. We propose a modification of a measurement scheme recently proposed [Cabello, Phys. Rev. Lett. 101, 210401]. With this modification, full compatibility is no longer a necessary precondition. This scheme has been experimentally implemented using trapped ions [arXiv:0904.1655] and the experimental results show a clear contradiction to any non-contextual model.

18:15	**128**	**Quantum State Preparation using dissipation** *Barbara Kraus [1], Sebasian Diehl [2], Hans Peter Büchler [3], Adrian Kantian [2], Andrea Micheli [2], Caroline Kruszynska [2], Peter Zoller [2]* *[1] Institute of Theoretical Physics, Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria* *[2] Institute of Quantum Optics and Quantum Information of the Austrian Academy of Sciences, Technikerstr. 21, 6020 Innsbruck, Austria* *[3] Institute of Theoretical Physics, Pfaffenwaldring 57, 70550 Stuttgart, Germany* We investigate the possibility of using a dissipative process to prepare a quantum system in a desired state. We derive for any multipartite pure state a dissipative process for which this state is the unique stationary state and solve the corresponding master equation analytically. For certain states, like the Cluster states, we use this process to show that the jump operators can be chosen quasi--locally, i.e. they act non--trivially only on a few, neighboring qubits. We demonstrate the general formalism by considering MPS--PEPS states. In particular, we show that the ground state of the AKLT-model can be prepared employing a quasi-local dissipative process. Furthermore, we discuss a dissipatively driven Bose-Einstein Condensate, where for non-interacting atoms a pure state exhibiting long range order is generated as the steady state by quasi-local coupling to an environment with finite correlation length. Applying standard linearization schemes in the weakly interacting situations, allows us to determine the solution of the master equation, revealing a steady state with properties similar to bosons in thermal contact to a heat bath. Furthermore, we consider a special class of states, called locally maximally entangleable states and discuss their applications for quantum information tasks. The generation of those states using either dissipative processes, or unitary evolutions is presented.
18:30		***END***
19:30		***Conference Dinner***

Time	ID	ATOMIC- AND MOLECULAR PHYSICS & QUANTUM OPTICS *Chair: P. Moroshkin, Uni Fribourg*
09:00		***PLENARY SESSION***
12:40		***Postersession, Lunchbuffet***
14:00	129	**Measuring the Stark shift of the Cs clock transition frequency** *Paul Knowles, Jean-Luc Robyr, Antoine Weis* *University of Fribourg, Department of Physics, Chemin du Musée 3, 1700 Fribourg, Switzerland* The Stark effect describes atomic energy level shifts caused by external electric fields. In Cs atomic clocks, the AC Stark shift, caused by the ever-present blackbody radiation, is one important instability. Recent measurements of the AC and DC Stark shifts of the Cs clock transition show mutual inconsistency. We propose a new measurement method using a fully-optical Ramsey pump-probe experiment on a thermal Cs atomic beam. We will show measurements of the Ramsey signal already obtained and discuss the technical challenges for calibration of the electric field and expected accuracy of the measurements. Research funded by the Swiss National Science Foundation, 200021-117841.
14:30	130	**Hybrid Quantum Systems:** **Integrating Atomic and Solid-State Qubits** *Johannes Majer [1], Robert Amsüss [1], Stefan Haslinger [1], Nils Lippok [1], Christian Koller [1], Stephan Schneider [1], Jörg Schmiedmayer [1], Kathrin Henschel [2], Hashem Zoubi [2], Helmut Ritsch [2]* *[1] Atominstitut / TU Wien, Stadionallee 2, 1020 Wien, Austria* *[2] Institute of Theoretical Physics, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria* For quantum information to emerge as a valuable technology, it is mandatory to pool the strengths of different systems to bridge their weaknesses. For example solid-state devices allow very fast processing and promise dense integration, but have very short coherence times. Atomic systems are slow, but exhibit very long coherence of quantum states if they are stored in hyperfine states. An ensemble of ultracold atoms would thus be an ideal quantum memory. Placing an ensemble of 10^6 ultracold atoms in the near field of a superconducting coplanar waveguide resonator (CPWR) with $Q{\sim}10^6$ one can achieve strong coupling between a single microwave photon in the CPWR and a collective hyperfine qubit state in the ensemble with $g_{eff}/2\pi{\sim}40$kHz larger than the cavity line width of $\kappa/2\pi{\sim}7$kHz. Integrated on an atomchip such a system constitutes a hybrid quantum device, which interconnects solid-state and atomic qubits.

14:45	131	**Superconducting NbN detector for neutral nanoparticles**

Markus Marksteiner [1], Michele Sclafani [1], Philipp Haslinger [1], Hendrik Ulbricht [1], Markus Arndt [1], Alexander Divochiy [2], Alexander Korneev [2], Gregory Gol'tsman [2]
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[2] Department of Physics, Moscow State Pedagogical University, M. Pirogovskaya Street 1, 119992 Moscau, Russian Federation

A superconducting single photon detector (SSPD) was tested as a detector for neutral large molecules/nanoparticles. The detector, which is made of a meandering nano-structured NbN wire on an area up to 20x20 μm^2, was placed in the beam line of a laser desorbed supersonically cooled molecular beam. Impacting particles destroy the superconductivity of the biased chip resulting in a narrow (about 20 ns) voltage peak. The SSPD chip allowed to retrieve the arrival time distribution of the pulsed molecular beam containing the amino acid tryptophan (204 Da) and the polypeptide gramicidin (1880 Da), which showed good agreement with the arrival time distributions measured via photoionization and time-of-flight mass spectrometry.
We also see good evidence for the detection of higher mass bioparticles like insulin (5800 Da), myoglobin (≈17,000 Da) and hemoglobin (≈64,000 Da) that cannot be detected in the gasphase using standard mass spectrometric tools since photoionization starts to fail in this mass range. The possibility to extend the mass range of detectable neutral molecules beyond 2000 Da would be of interest for gasphase studies of molecules in general and especially in the case of combining it with matter wave interference experiments the wave-particle dualism could be shifted towards high mass molecules.

15:00	132	**High-fidelity multipartite entangled states of $^{40}Ca^+$ ions**

Thomas Monz [1], Michael Chwalla [1], Julio Barreiro [2], Philipp Schindler [1], Markus Hennrich [1], Rainer Blatt [1]
[1] Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria
[2] Institut für Quantenoptik und Quanteninformation, Otto Hittmair-Platz 1, 6020 Innsbruck, Austria

Realizing high fidelity entangling operations poses one of the biggest challenges in experimental quantum information. Currently, trapped ions represent one of the most advanced quantum computational system, as the demonstration of six ions entangled in a GHZ state [1] and eight ions in a W-state [2] until recently marked the state-of-the-art in terms of number of entangled particles. Furthermore, a record fidelity of F=99,3% [4] for two entangled ions has been recently achieved with the robust entanglement scheme of Mølmer and Sørensen [3] on an optical qubit transition (MS).
Here we show the entanglement of a larger number of ions using the MS gate operation. In particular, we will demonstrate the experimental realization of GHZ states with more than 6 ions with high fidelity.

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[2] Häffner, H., Hänsel, W., Roos, C. F., Benhelm, J., Chek-al kar, D., Chwalla, M., Körber, T., Rapol, U. D., Riebe, M., Schmidt, P. O., Becher, C., Gühne, O., Dür, W., and Blatt, R. Nature 438(7068), 643–646 (2005).
[3] Sørensen, A. and Mølmer, K. Phys. Rev. Lett. 82(9), 1971 (1999).
[4] Benhelm, J., Kirchmair, G., Roos, C. F., and Blatt, R. Nat. Phys. 4, 463 (2008).

15:15	**133**	**Single molecule fluorescence detection on functionalized surfaces** *Michael Müllneritsch [1], Thomas Juffmann [1], Agnieszka Dreas [2], Marcel Mayor [2], Markus Arndt [2]* *[1] Quantumoptics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria* *[2] Institute for Nanotechnology, Forschungszentrum Karlsruhe GmbH, P. O. Box 3640, 76021 Karlsruhe, Germany* The immobilization of organic molecules on surfaces is important for various applications in nanolithography and also essential in novel detectors for matter wave interferometry. We use fluorescence imaging up to the single molecule level to study the suppression of long-range surface diffusion of ZnTPP on pyridine functionalized surfaces.
15:30	**134**	**Electron-Spin Resonance and Rabi Oscillations on Helium Nanodroplets** *Martin Ratschek, Markus Koch, Carlo Callegari, Wolfgang E. Ernst* *Institute of Experimental Physics, TU Graz, Petersgasse 16, 8010 Graz, Austria* Superfluid helium nanodroplets provide a versatile substrate for cooling atoms and molecules and, if desired, assemble weakly bound complexes. Electron-spin resonance (ESR) is a versatile probe of the electronic environment in radicals and, via spin tags, in ESR-silent species. We demonstrate the first application of ESR to doped helium nanodroplets and exploit the scheme of optically-detected magnetic resonance (ODMR). We measure sharp, hyperfine-resolved, ESR spectra of single K and Rb atoms isolated on He nanodroplets. The shift of the ESR lines with respect to free atoms directly reflects the distortion of the valence-electron wavefunction due to the He nanodroplet. We are able to follow this change as a function of droplet size. The observation of Rabi oscillations indicates a long decoherence time and demonstrates our ability to perform coherent manipulation of the spin. We are currently constructing a high-temperature pickup source, based on electron bombardment, to extend the method to transition metal atoms with high spin-multiplicity.
15:45	**135**	**Two-step excitation of Rb atoms on He nanodroplets** *Moritz Theisen 1, Florian Lackner [1], Francesco Ancilotto [2], Carlo Callegari [1], Wolfgang E. Ernst [1]* *[1] Institute of Experimental Physics, Graz University of Technology, Petersgasse 16, 8010 Graz, Austria* *[2] Dipartimento di Fisica "G. Galilei", Università di Padova, via Marzolo 8, 35131 Padova, Italy* We present the first sequential excitation of atom-doped helium nanodroplets. Rubidium atoms on the surface of a helium nanodroplet are selectively excited to their $5P_{1/2}$ state so as not to desorb from the droplet. From there they are excited by a laser pulse to their 5D state. The atom's energy levels are calculated as a function of the atom-droplet distance R, and the resulting potential energy curves are compared with the experimental data. We also want to compare the sequential excitation with a direct two-photon one-color excitation from the ground state to the 5D state, which we intend to present at the meeting. In the future the $5P_{1/2}$ state can be used as a springboard to reach high-lying ^2S and ^2D states.
16:00		***Coffee Break***

Time	ID	*Chair: C. Roos, Österreichische Akademie der Wissenschaften*
16:30	**136**	**Entangled qutrit states in a double-loop neutron interferometer** *Katharina Durstberger-Rennhofer* *Atominstitut, TU Wien, Stadionallee 2, 1020 Wien, Austria* The physical system of interest is the (massive) neutron which is a proper object for a study of fundamental quantum mechanical behavior: it allow for rather easy experimental control and the neutron spin is the simplest two-level system with easy manipulation by magnetic fields. In combination with interferometric measurements the system has enough intrinsical richness to show interesting quantum features such as entanglement. The coupling of the neutron to an external magnetic field allows for selective manipulations of the spinor quantum states and their energies. This can be used to create entangled states where the entanglement occurs between different degrees of freedom (e.g., spin and path). We introduce the concept of qutrits for neutrons by considering a double-loop interferometer with three path-states. Entanglement with a second qubit / qutrit can be constructed by manipulating the neutrons energy with rf-spin flippers accordingly. With this arrangement it is possible to investigate questions about entanglement witnesses in 3x2 and 3x3 dimensions and bound entanglement for 3x3 dimensions for massive particles.
17:00	**137**	**Stability of a Three-Component ^{6}Li 40K Fermi Mixture near a ^{6}Li Feshbach Resonance** *Andreas Trenkwalder, Devang Naik, Frederik Spiegelhalder, Gerhard Hendl, Florian Schreck, Rudolf Grimm* *IQOQI, Technikerstrasse 21a, 6020 Innsbruck, Austria* We report on the stability of a three-component Fermi gas consisting of a strongly interacting ^{6}Li two component degenerate mixture near the 834-G Feshbach resonance in the presence of a weakly interacting 40K sample. Despite the presence of three distinguishable particles, we observe stability against three-body recombination both on resonance and on the BCS side. On the molecular side, however, we observe increasing losses due to atom dimer collisions. We have measured the corresponding rate coefficients, along with Li-K thermalization rates, for different magnetic fields around the resonance. The observed stability and thermalization opens up the possibility of using 40K as a probe to study ^{6}Li BEC-BCS crossover dynamics. We also report on the observation of ^{6}Li 40K molecules.
17:15	**138**	**Preparing cold samples of ground state radicals and metastable atoms and molecules by multistage Zeeman deceleration** *Alex Wiederkehr, Stephen Hogan, Hansjürg Schmutz, Markus Andrist, Frédéric Merkt* *Laboratorium für physikalische Chemie, ETHZ, Wolfgang-Pauli-Strasse 10, 8093 Zürich, Switzerland* Multistage Zeeman deceleration exploits the interaction of open shell atoms and molecules with inhomogeneous magnetic fields to manipulate the translational motion of pulsed supersonic beams [1-7]. The cold atomic and molecular samples prepared in this way have relative translational temperatures in the range

of 10-100 mK and are therefore ideally suited for applications in precision spectroscopy and studies of cold reactive collisions. The multistage Zeeman decelerator developed at ETH Zurich requires for its operation the generation of strong magnetic field pulses (> 2T) with rise and fall times of only a few microseconds along with pulse sequences calculated using numerical particle trajectory simulations and optimized for a selected bunch of particles.

We have employed multistage Zeeman deceleration to stop ground state hydrogen atoms in the lab frame and load the atoms into a magnetic quadrupole trap [7]. The implementation of an accurate three-dimensional particle trajectory simulation program has been essential to achieve a complete interpretation of the dynamics of the deceleration and trap loading processes. With this software it is possible to reproduce accurately the spatial and velocity distributions of the decelerated and trapped atoms.

In this contribution we shall also present our latest generation of Zeeman decelerators that is designed in a flexible modular way enabling the slowing and trapping of a broad range of species. This instrument operates with a cooled pulsed valve which can be coupled to an electrical discharge as a source of cold metastable atoms and molecules. The characteristics of the decelerator will be presented and results obtained with a range of atomic and molecular samples will be compared.

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[7] S. D. Hogan et al. , Phys. Rev. Lett. 101 , 143001 (2008).

17:30 **139**

Excitons and Polaritons as a Nondestructive Observation Tool of Quantum Phases in Optical Lattices

Hashem Zoubi, Helmut Ritsch,
Institute for Theoretical Physics, Technikerstrasse 25, 6020 Innsbruck, Austria

For ultracold atoms in an optical lattice we study the quantum phase transition from the superfluid into the Mott insulator phase within a cavity, where we found the Mott insulator to be recovered for deeper optical lattices. We examine the possibility of the formation of collective electronic excitations (excitons) in an optical lattice, and within a cavity we introduce polaritons. Through optical linear spectra we show how polaritons can serve as a non-destructive observation tool for the different quantum phases in an optical lattice. Furthermore, we obtain that the formation of optical lattice molecules can be manifested via photon polarization mixing in the linear spectra. Moreover, we get that the coupling of excitons to vibrational modes of atoms excited to higher Bloch bands in an optical lattice is an important mechanism for excitation and de-excitation of such vibrational modes.

17:45	**140**	**Concatenated tensor network states** *Volckmar Nebendahl, Robert Hübener, Wolfgang Dür* *Institut für Theoretische Physik Innsbruck, Technikerstasse 25, 6020 Innsbruck, Austria* We introduce the concept of concatenated tensor networks to efficiently describe quantum states. We show that the corresponding concatenated tensor network states can very efficiently describe time evolution and can possess arbitrary block-wise entanglement and long-ranged correlations. We illustrate the approach for the enhancement of matrix product states, i.e. 1D tensor networks, where we replace each of the matrices of the original matrix product state with another 1D tensor network. This procedure yields a 2D tensor network, which includes -- already for tensor dimension two -- all states that can be prepared by circuits of polynomially many (possibly non-unitary) two-qubit quantum operations, as well as states resulting from time evolution with respect to Hamiltonians with short-ranged interactions. We investigate the possibility to efficiently extract information from these states, which serves as the basic step in a variational optimization procedure. To this aim we utilize known and improved methods for 2D networks. We generalize the approach to higher dimensional and tree tensor networks.
18:00	**141**	**Second order coherence across the Bose-Einstein condensation threshold** *Aurelien Perrin, Robert Bücker, Stephanie Manz, Thomas Betz, Thorsten Schumm, Jörg Schmiedmayer* *Atominstitut der österreichischen Universitäten, Stadionallee 2, 1020 Wien, Austria* Recently, there has been an increasing interest in performing classical quantum optics experiments in the context of interacting atomic many-body systems. In particular, two-point correlation functions can be used to characterize and identify interesting phases and regimes in quantum atom optics. In that vein, the bunching effect, originally demonstrated for a chaotic light source by Hanbury Brown and Twiss (HBT), has been observed for an expanding Bose gas. In the same direction, it has been shown that the bunching effect disappears below the Bose-Einstein condensation (BEC) threshold. We present a new fluorescence detection scheme that yields spatially resolved single atom sensitivity. This gives us direct access to second-order coherence of expanding Bose gases and allows to measure HBT correlations around the BEC phase transition. We observe significant bunching below condensation in anisotropic (1D) trap geometries that we attribute to the presence of strong phase fluctuations. For more isotropic geometries the bunching effect below the threshold is less pronounced but still present. The talk will introduce the new detection scheme, explain details of the correlations measurements, and compare our observations to theoretical models.

18:15	**142**	**Minimizing the statistical error in measurements of witness operators** *Bastian Jungnitsch, Sönke Niekamp, Matthias Kleinmann, Otfried Gühne* *Institut für Quantenoptik und Quanteninformation, Technikerstraße 21a, 6020 Innsbruck, Austria* Witness operators are a well-established tool for the detection of entanglement in quantum information theory. They can be optimized with respect to the set of entangled states they detect. We consider an experimental situation in which one has some knowledge of the prepared state and wants to ensure that this state is entangled. To detect entanglement in such a case with high certainty, one aims at decreasing the statistical error involved in the measurement of the witness operator. We investigate error models for photonic experiments and show that the Mermin inequality, although leading to a lower violation of local realism than the Ardehali inequality, can detect the entanglement with higher statistical significance.
18:30		***END***
19:30	**21**	***Public Lecture***

ID	Atomic- and Molecular Physics & Quantum Optics Poster
146	**Hypergeometric Function Representation of Relativistic Transition Matrix elements for Hydrogenic Atoms** *Gerhard Adam [1], A. V. Soldatov [2], J. Seke [1], M. Polak [1]* *[1] Institut für Theoretische Physik, TU Wien, Wiedner Hauptstrafle 8-10/136, 1040 Wien, Austria* *[2] Department of Mechanics, 8, Gubkina str., 119991 Moscow, Russian Federation* By using the plane-wave expansion for the electromagnetic-field vector potential, relativistic bound-bound, bound-unbound and unbound-unbound transition matrix elements for hydrogenic atoms are expressed universally in terms of hypergeometric functions. By applying the obtained formulae, these transition matrix elements can be evaluated analytically and numerically with arbitrarily high precision. The newfound representation for the matrix elements is very convenient for direct numerical evaluation of the Lamb shift because of its universality, conciseness and reliance on functions, already built in the standard computational packages All of this being highly favorable for programming of computationally efficient algorithms.
147	**A versatile diode laser system for the production of a Rb-Cs quantum gas mixture** *David Baier [1], Almar Lercher [1], Bastian Schuster [1], Markus Debatin [1], Francesca Ferlaino [1], Rudolf Grimm [1,2], Hanns-Christoph Nägerl [1]* *[1] Institut für Experimentalphysik, Technikerstrasse 25/4, 6020 Innsbruck, Austria* *[2] Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria* We present a homebuilt, high-precision diode laser system, which employs various methods of spectroscopy-based frequency-locking schemes to simultaneously cool, trap, and image a diatomic quantum gas mixture. In our experiment we prepare a double-degenerate mixture of ^{133}Cs and ^{87}Rb in an all-optical way, with the goals of producing a two-species Bose-Einstein condensate and ultracold heteronuclear Feshbach molecules. In order to reach the low temperatures required for quantum degeneracy, cooling techniques such as Zeeman-slowing of atomic beams, magneto-optical trapping of atoms, and two-color Raman sideband cooling are essential tools. We make use of various locking schemes based on modulation-transfer spectroscopy, frequency-modulation spectroscopy, and beat-locking in order to create narrow-band diode-based laser sources, which are highly reliable and stable over extended periods of time.
148	**Quantum Interference of Resonance Fluoeresence Photons** *Sebastian Gerber* *Institut für Experimentalphysik, Technikerstrasse 25, 6020 Innsbruck, Austria* We report measurements of an intensity-field correlation function using single trapped Ba^+ ion. In this setup a homodyne measurement is conditioned on a fluorescence photon detection and we record the regression of the field amplitude of the resonance fluorescence, i.e. a photon detection from the ion starts the measurement in a well defined state that evolves then back to equilibrium in phase with a local oscillator via vacuum Rabi oscillation. Thus, this third-order correlation function g(1.5) can be seen as demonstrating an aspect of wave-particle duality.

149	**Production of Argon Clusters within Helium Clusters and Analysis of the formed Droplets** *Peter Bartl [1], Christian Leidlmair [1], Filipe Ferreira da Silva [1], Stephan Denifl [1], Paul Scheier [1], Olof Echt [2], Tilmann Märk [1]* *[1] Institut für Ionenphysik, Technikerstr. 25/3, 6020 Innsbruck, Austria* *[2] Department of Physics, University of New Hampshire, DeMeritt Hall, Durham NH 03824-3568, United States* In the present study we investigate argon cluster ions Ar^{n+} up to 2400 Thomson. The clusters are formed upon pickup of Ar atoms in helium droplets. The ultra-low temperature (0.38K), superfluidity and high thermal conductivity make He droplets an ideal matrix for this type of experiment. Subsequent electron impact ionization of the droplets allows us to analyze the products in a double-focusing mass spectrometer in reverse BE geometry. The results are compared to earlier measurements which used a conventional argon cluster source. The main interest lies in the effect of the He droplets on the Ar cluster distribution. Even the unique properties of helium droplets cannot quench evaporation processes [1] which are supposed to cause magic numbers in mass spectra. [1] S. Denifl, F. Zappa, A. Mauracher, F. Ferreira da Silva, A. Bacher, O. Echt, T. D. Märk, D. K. Bohme, P. Scheier , ChemPhysChem 9, 1387 (2008).
150	**Quantum computation in correlation space and extremal entanglement** *Jianming Cai [1], Wolfgang Dür [1], Maarten Van den Nest [2], Akimasa Miyake [3], Hans Briegel [1]* *[1] IQOQI, Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, 6020 Innsbruck, Austria* *[2] MPQ, Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 München, Germany* *[3] PI, Perimeter Institute for Theoretical Physics, 31 Caroline St. N., Waterloo ON, N2L 2Y5, Canada* Recently, a framework was established to systematically construct novel universal resource states for measurement-based quantum computation using techniques involving finitely correlated states. With these methods, universal states were found which are in certain ways much less entangled than the original cluster state model, and it was hence believed that with this approach many of the extremal entanglement features of the cluster states could be relaxed. The new resources were constructed as ``computationally universal'' states – i.e. they allow one to efficiently reproduce the classical output of each quantum computation – whereas the cluster states are universal in a stronger sense since they are "universal state preparators". Here we show that the new resources are universal state preparators after all, and must therefore exhibit a whole class of extremal entanglement features, similar to the cluster states.

151	**Classes of multipartite entangled states and applications** *Tatjana Carle, Barbara Kraus, Wolfgang Dür, Hans-Jürgen Briegel, Caroline Kruszynska, Theoretische Physik, Universität Innsbruck, Technikerstrafle 25, 6020 Innsbruck, Austria* One of the challenges in quantum information theory is to get a better understanding of multipartite entangled states, their entanglement properties and their applications. Despite all the results on bipartite entanglement, the properties of multipartite entangled states are far from being completely understood. In order to gain new insight, a new class of multipartite entangled states was recently introduced [1]. It is based on the physical idea of how well the qubits can be locally entangled to an auxillary system (LME – Locally Maximally Entanglable). Prominent examples of this class are stabilizer states, which are used for quantum error correction and one-way computing, and weighted graph states. The aim here is to consider a restricted set of LMEs to generalise the existing description of spin gases using weighted graph states. [1] C. Kruszynska, B. Kraus arXiv:0808.3862 (to appear in PRA)
152	**Analytical Results on Matrix Product States** *Florian Fröwis, Wolfgang Dür* *Inst. f. Theoretische Physik, Technikerstr. 25a, 6020 Innsbruck, Austria* We consider representations of Hamiltonians in terms of matrix product operators (MPOs), following and generalizing the approach presented by Murg et al in arXiv:0804.3976. We show how to efficiently represent arbitrary pairwise interaction Hamiltonians of N d-dimensional systems by a low dimensional MPO of bond dimension D=O(d2 N). We regard special instances as same interaction kind for all pairs, mimicking 2D systems and discuss extensions to k-body interactions and Pair-Entangled Projected Operators.
153	**Generation of an intense and slow caesium atomic beam with a two-dimensional magneto-optical trap (2D-MOT)** *Laurent Devenoges, Gianni Di Domenico, Pierre Thomann* *Université de Neuchâtel, Laboratoire Temps-Fréquence, Avenue de Bellevaux 51, 2009 Neuchâtel, Switzerland* We will present the design and performances of a novel length-tuneable 2D-MOT used to load a continuous atomic fountain clock. The simple optical configuration, using metal-coated retro-reflecting prisms instead of mirrors and quarter-wave plates, saves space and laser power by recycling the cooling beams. The length of the MOT cooling zone can be varied by changing the number of prisms. This source of cold atoms (~25 $m \cdot s^{-1}$) has been characterized on an experimental atomic fountain by measuring the flux of caesium atoms after their ballistic flight for three different lengths of the 2D-MOT cooling zone. For each length of the cooling zone, we optimized the 2D-MOT parameters: magnetic field gradient of the trap, power and frequency detuning of the cooling beams. We obtained the highest fountain flux ($1.2 \cdot 10^{10}$ $at \cdot s^{-1}$ captured by a moving molasses) for a 9 cm long MOT length, an improvement by a factor of three compared to the standard length (12 cm) of the previous 2D-MOT version.

154	**Low-energy electron damage to dipyrimidines**

154 Low-energy electron damage to dipyrimidines

Achim Edtbauer [1], Christian Mitterdorfer [1], Lukas An der Lan [1], Erna Schuhfried [1], Stephan Denifl [1], Tilmann D. Märk [1], Jörg Taubitz [2], Linda Feketeova [2], Richard O'Hair [2], Paul Scheier [1]
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The increase of ultraviolet radiation reaching the earth's surface, caused by the depletion of the stratospheric ozone layer shows the importance of investigating the effects of UV-induced DNA damage. DNA is very sensitive to UV radiation since the absorption maximum of DNA is in the UV region. UV-radiation is known to induce mutagenic and cytotoxic DNA lesions: e.g. the cyclobutane –pyrimidine dimers. DNA damage is then also induced by secondary processes which occur after irradiation, their nature is either physical or chemical. Among them the action by low energy electrons turned out be highly relevant. This secondary species interact with molecules by DEA (Dissociative Electron Attachment).
Here we study DEA to a 1,2-dimethylcyclobutane pyrimidine dimer methylated at the nitrogen atoms. The apparatus used for the presented measurements is a crossed electron/molecule beams-instrument consisting of a neutral molecular beam source, a Nier-type ion source and a double-focusing two sector instrument in reverse BE-geometry with high sensitivity. The electron attachment measurements show a surprising fragmentation pattern at electron energies only slightly above 0eV. The mass spectra reveal that the highest anion fragment is mass 139 which corresponds to a symmetric cleavage minus one methyl group. This fragmentation pattern which reminds of fragmentation patterns of explosives like TNT could perhaps be one reason for the DNA damage caused by these molecules.

Acknowledgement
This work has been supported by the FWF, Wien, Austria and the European Commission, Brussels. S.D. gratefully acknowledges an APART-fellowship from the Austrian Academy of Sciences.

155 Selective depletion of excited states of Si^- in a gas filled rf quadrupole ion cooler

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For precision experiments with negative ions, e.g. the accurate determination of the electron affinity, sufficient knowledge about the fraction of possible excited states in the beam is required. This is even more critical in molecular anions for an experimental determination of the adiabatic electron affinity. In our experiments Si^- was chosen as it is one of the few atomic anions with well known excited states.
The cooling of excited states was studied at the ion source test facility of the HRIBF at the Oak Ridge National Laboratory. 5 keV negative ions are injected into an ion cooler and afterwards analyzed by selective laser photodetachment. Nd:YAG lasers have been used for studying the photodetachment of silicon anions. The energy of the 1064 nm photons is sufficient to detach electrons from either excited state but not from the ground state. In this way the fraction of excited states in a Si^- beam with and without the quadrupole cooler in operation could be measured.

156	**Vlasov approach to particle dynamics in resonators** *Tobias Griesser* *Institut für theoretische Physik, Technikerstrasse 25, 6020 Innsbruck, Austria* We investigated the dynamics of particles coupled to two counter propagating modes of a ring resonator, both in a CARL as well as a transversally pumped setup. In the limit of large particle numbers and small coupling constants we found a Vlasov type kinetic model to be an adequate description of the system. As an application of the latter we investigated the instability threshold of homogeneous steady states, leading to corrections as well as extensions of the results obtained by a mean field approach. Finally, the Vlasov equations were solved numerically, showing qualitative as well as quantitative agreement with the results from particle simulations.
157	**Towards a degenerate Bose-Fermi Mixture on an Atomchip** *Michael Gring, Maximilian Kuhnert, Tim Langen, Matthias Schreitl, David A. Smith, Jörg Schmiedmayer* *Atominst. der Österreichischen Universitäten, TU-Wien, Stadionallee 2, 1020 Wien, Austria* We present the progress in setting up a new atomchip experiment to realize a degenerate Bose-Fermi Mixture of bosonic ^{87}Rb and fermionic 40K. Recently, a BEC of ^{87}Rb was realized in this setup and the work in adding the second component is in progress. The new apparatus will allow the imaging of structures down to at least 2.5 μm. Our new atomchip should provide very tight elongated static traps which will allow us to study the crossover regime between 3D and 1D of this Bose-Fermi system.
158	**Dynamic Entanglement in Oscillating Molecules and Potential Biological Implications** *Gian Giacomo Guerreschi [1], Jian-Ming Cai [1], Sandu Popescu [2], Hans Briegel [1]* *[1] IQOQI, Technikerstrasse 21a, 6020 Innsbruck, Austria* *[2] H. H. Wills Physics Laboratory, University of Bristol, Tyndall Avenue, Bristol BS8-1TL, United Kingdom* We demonstrate that entanglement can persistently recur in an oscillating two-spin molecule that is coupled to a hot and noisy environment, in which no static entanglement can survive. The system represents a non-equilibrium quantum system which, driven through the oscillatory motion, is prevented from reaching its (separable) thermal equilibrium state. Environment noise, together with the driven motion, plays a constructive role by periodically resetting the system, even though it will destroy entanglement as usual. As a building block, the present simple mechanism supports the perspective that entanglement can exist also in systems which are exposed to a hot environment and to high levels of de-coherence, which we expect e.g. for biological systems.
159	**Light-Induced Charging Effects in Microscopic Ion Traps** *Wolfgang Hänsel, Max Harlander, Michael Brownnutt, Rainer Blatt* *Institut für Experimentalphysik, Technikerstr. 25, 6020 Innsbruck, Austria* Microfabricated ion traps are discussed as one of the most promising candidates for a quantum mechanical computer. By bringing the electrodes close to the ions a rich selection of trapping potentials can be created and many traps can, in principle, be operated in parallel. However, the proximity of the electrodes and other surfaces poses strong constraints on

the materials used. In particular, near-by glass surfaces that may be used for high-finesse cavities around the ions or for light collection represent a challenge, since the dielectric surfaces may charge up and perturb the trapping potential.
By bringing a glass substrate close to a surface ion trap, the charging can be studied in a controlled manner. Two distinct mechanisms of charging have been observed, both being light-induced with different wavelength dependence. The results allow an estimate of the rate of charge production and may be prove useful for the design of new integrated microscopic ion traps.

160 Few-body physics and ultracold chemistry with Cs atoms and molecules

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An ultracold atomic gas of cesium is a versatile system to study few-body-physics, providing the possibility of magnetically tuning the strength of interaction over a large range. Starting with atoms in the lowest hyperfine state A, we produce molecules AA by means of Feshbach association. We experimentally explore three-body phenomena by investigating ultracold A+AA collisions. We observe a resonant enhancement in atom-dimer relaxation, giving clear evidence of the existence of a universal Efimov trimer state AAA. By transferring atoms from state A to a different hyperfine state B, we find a resonantly enhanced exchange of molecule constituents, according to the reaction B + AA → A + AB, where the final products remain being trapped. This magnetically tunable reaction process provides a striking example of ultracold controllable chemistry.

161 Investigation of superfluid-insulator transitions with one dimensional ultracold atomic gase

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One dimensional (1D) systems of ultracold atomic gases offer a unique possibility to investigate many-body systems. In 1D, the interplay between interactions and confinement induces strong particle correlations and increases phase fluctuations. We investigate the behavior of this system with an additional shallow lattice potential along the free dimension. Specifically, we examine the conductance of the gas along the tube as a function of particle interaction and strength of longitudinal lattice and find evidence for negative differential conductance. That is, counterintuitively, particle scattering supports conduction. Similarly, we show that the interactions themselves can turn off conduction between the tubes in a self-trapping effect. Finally, in the Tonks-Girardeau (TG) regime, we investigate the phase diagram of the 1D gas with additional lattice. Correlations in the TG gas should enhance the onset of a 1D Mott insulator if the particle separation induced via interactions is commensurate with the separation induced by the lattice.

162	**Hybrid Quantum Systems: Integrating Atomic and Solid-State Qubits**

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Hybrid Quantum Systems: Integrating Atomic and Solid-State Qubits

Stefan Haslinger [1], Robert Amsüss [1], Christian Koller [1], Nils Lippok [1], Johannes Majer [1], Stephan Schneider [1], Hashem Zoubi [2], Jose Verdu [3], Helmut Ritsch [2], Jörg Schmiedmayer [1]
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For quantum information to emerge as a valuable technology, it is mandatory to pool the strengths of different systems to bridge their weaknesses. For example solid-state devices allow very fast processing and promise dense integration, but have very short coherence times. Atomic systems are slow, but exhibit very long coherence of quantum states if they are stored in hyperfine states. An ensemble of ultracold atoms would thus be an ideal quantum memory. placing an ensemble of 10^6 ultra-cold atoms in the near field of a superconducting coplanar waveguide resonator (CPWR) with a quality-factor of $Q = 10^6$, one can achieve strong coupling between a single microwave photon in the CPWR and a collective hyperfine qubit state in the ensemble with an effective coupling rate larger than the cavity line width. Integrated on an AtomChip such a system constitutes a hybrid quantum device, which interconnects solid-state and atomic qubits.
We present theoretical results concerning the coupling of a Bose-Einstein condensate (BEC) to a single photon stored in a CPWR on an AtomChip. Starting from the analytical expression for the quasi-TEM odd mode of the field generated by the photon in the CPWR, we construct the full quantum mechanical Jaynes-Cummings model of the system BEC + CPW photon. The Rabi-Splitting of the resonance curve of the CPW-cavity is calculated analytically as a function of several parameters, like the number of atoms in the BEC, the position and the distance of the atom-cloud above the chip's surface, the geometry and the capacitive coupling of the CPWR, etc. We demonstrate the experimental accessibility of the strong coupling regime for the system BEC + CPWR with current available technologies. Further we present our ongoing experimental efforts on both the technology of CPW resonators as well as the experimental insertion/creation of a cloud of cold atoms in a dilution fridge at a temperature of 20mK.

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Superradiance of an ultracold gas coupled to a microwave cavity

Kathrin Henschel [1], Hashem Zoubi [1], Helmut Ritsch [1], Robert Amsüss [2], Nils Lippok [2], Stefan Haslinger [2], Christian Koller [2], Jose Verdu [2], Stephan Schneider [2], Johannes Majer [2], Jörg Schmiedmayer [2]
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So-called Dicke states or superradiant states describe an ensemble of two-level systems that are confined to a volume small compared to the emission wavelength. This confinement leads to a strong modification of the radiative properties of the atoms. The collection of atoms starts to radiate spontaneously much faster and stronger than the emission of independent atoms, in a well defined direction depending upon the geometry of the sample. Analogous effects can be observed if the atoms are dominantly coupled to a single resonator mode. In extension of standard optical implementation we study here superradiance effects in the context of an ensemble of ultracold atoms, which are magnetically coupled to a microwave cavity mode. Despite the minuteness of magnetic coupling the strong confinement of the field and the large number of particles in the mode should allow to reach the superradiant regime. In contrary to optical setups, the effects of a finite thermal occupation number of the resonator mode cannot be neglected here down to temperatures well below 1K and we investigate their influence on the properties of superradiance.

164	**Two computable sets of multipartite entanglement measures** *Marcus Huber, Beatrix Hiesmayr, Philipp Krammer* *Vienna University, Boltzmanngasse 5, 1090 Vienna, Austria* We present two sets of computable entanglement measures for multipartite systems where each subsystem can have different degrees of freedom (so-called qudits). One set, called 'separability' measure, reveals which of the subsystems are separable/entangled. For that we have to extend the concept of k-separability for multipartite systems to a novel unambiguous separability concept which we call γ_k-separability. The second set of entanglement measures reveals the 'kind' of entanglement, i.e. if it is bipartite, tripartite, ..., n-partite entangled and is denoted as the 'physical' measure. We show how lower bounds on both sets of measures can be obtained by the observation that any entropy may be rewritten via operational expressions known as m-concurrences. Moreover, for different classes of bipartite or multipartite qudit systems we compute the bounds explicitly and discover that they are often tight or equivalent to positive partial transposition (PPT).
165	**Towards time-bin entangled photon pairs from a quantum dot** *Harishankar Jayakumar [1], Christophe Couteau [2], Gregor Weihs [1]* *[1] Institute for Experimental Physics, Technikerstrafle 25, 6020 Innsbruck, Austria* *[2] Laboratoire de Nanotechnologie et d'Instrumentation Optique, 12, rue Marie Curie, 10000 Troyes, France* Quantum dots are attractive sources for deterministic generation of entangled photon pairs. It has been showed theoretically by Simon and Poizat [PRL, 94,030502 (2005)] that biexciton-exciton cascade emission from single quantum dots can be used to generate time-bin entangled photon pairs. This requires coherent excitations that results in the emission of exciton-biexciton at two well-defined times. Preliminary measurements of photon statistics showing photon antibunching, and cross-correlations of exciton- biexciton cascade from single quantum dot emissions and the future directions towards realization of time-bin entanglement will be presented.
166	**New Odd Parity levels in Neutral Praseodymium** *Shamim Khan, Syed Tanweer Iqbal, Imran Siddiqui, Laurentius Windholz* *Institute Of Expermental Physics, Petersgasse 16, 8010 Graz, Austria* Extensive experimental work has been done in past on the investigation of hyperfine splitting of praseodymium atom and at the moment our level data base on Pr contains more than 2000 levels of even and odd parity, but still a large number of fine structure levels are yet to be discovered. We recorded characteristic hyperfine patterns for the transitions under investigation by using laser induced fluorescence spectroscopy in a hollow cathode discharge. The spectral region covered during these investigations lie in the spectral range of R6G and Keton Red Dyes. A fitting program is used to determine J-values and magnetic dipole interaction constants for the combining levels. Using these constants and excitation and fluorescence wavelengths, we are able to find the energies of the new, up to now unknown energy levels. We present the data of the discovered 30 odd parity levels (energy, angular momenta, and magnetic hyperfine constant).

167	**Holographically prepared diffraction gratings for use in neutron interferometry**

167 Holographically prepared diffraction gratings for use in neutron interferometry

Jürgen Klepp [1], Martin Fally [1], Mostafa Ellabbaan [1], Irena Drevensek Olenik [2], Y. Tomita [3], T. Nakamura [3], Martin Bichler [1], Romano Rupp [1], H. Eckerlebe [4]
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We report coherent elastic diffraction of cold neutrons from gratings holographically prepared in nanoparticle dispersed polymers. In contrast to a previously designed LLL-interferometer from polymethylmethacrylate based gratings [1] or holographically dispersed liquid crystals [2] these media offer a big variety of possibilities to optimize the diffraction properties for beam splitters and mirrors [3]. Thus nanoparticle dispersed polymers prove to be ideal materials for implementation as gratings in a neutron interferometer.

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168 Investigations on Coherent Population Trapping Resonances in lin || lin configuration

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We present our studies on the behavior of Coherent Population Trapping (CPT) resonances in Rubidium (^{87}Rb Isotope) due to the interaction of a linear polarized dichromatic laser light (lin || lin CPT) in presence of longitudinal magnetic fields. In this configuration the coherence has a quadrupol like nature and is strongly influenced by the hyperfine structure of the excited state.
We investigate the lin || lin CPT signal depending on the ratio between the pressure broadening and laser line width obtained by use of Rb-vapor cells with different puffer gas pressures. The case of high puffer pressures, where the lin || lin CPT signal becomes more and more suppressed, is investigated by a special contrast measurement method with high dynamic range. Based on our experiments, conditions of optimal performance for compact atomic clocks based on lin || lin CPT are outlined.

169	**Atomic and molecular spectroscopy of transition metals in condensed helium**

169 Atomic and molecular spectroscopy of transition metals in condensed helium

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We investigated laser induced fluorescence spectra of copper and gold atoms and dimers thereof isolated in solid and liquid ^{4}He. Among the atomic spectral lines the most interesting ones are forbidden transitions that involve electrons from inner d-shells which are screened from the surrounding He atoms by the outer s-shell and are therefore much less affected by the interaction with the He matrix. Indeed, the observed spectral lineshapes are much narrower than those of transitions involving outer shell electrons. Another important result is the observation of well resolved vibrational structures in five molecular bands of the Au_2 and Cu_2 dimers. We expect that the analysis of those spectra will significantly advance our understanding of impurity atoms and molecules in condensed He.
Work funded by the Swiss National Science Foundation, #200020-119786.

170 Towards a double-species Bose-Einstein condensate of ^{87}Rb and ^{133}Cs

Almar Lercher, Bastian Schuster, Markus Debatin, David Baier, Francesca Ferlaino, Rudolf Grimm, Hanns-Christoph Nägerl
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Quantum gas mixtures with tunable interspecies interaction promise the observation of novel quantum gas phases and are expected to serve as a starting point for the production of quantum degenerate samples of polar molecules. In our experiment we prepare an ultracold Bose-Bose mixture of ^{133}Cs and ^{87}Rb in an all-optical way with the goal of producing a double species Bose-Einstein condensate. We first load the atoms into a two-color magneto-optical trap from a Zeeman slowed atomic beam. The mixture is then further cooled and spin-polarized by applying two-color Raman sideband cooling. Finally, we load the sample into a levitated optical dipole trap. In a first set of experiments we have observed interspecies Feshbach resonances, which will allow us to characterize the Rb-Cs scattering properties [K. Pilch et al., Phys. Rev. A 79, 042718 (2009)]. We currently investigate potential pathways towards obtaining a doubly-degenerate bosonic quantum gas. As a benchmark of the apparatus we already achieved Bose-Einstein condensation of Cs atoms. Our task is now to assure favourable conditions for simultaneous condensation of both species.

171 Tunable quantum gases in optical lattices

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We discuss a series of recent experiments with tunable Bose-Einstein condensates (BEC) of Cs atoms loaded into optical lattice potentials. In the first experiment, we examine the dephasing of Bloch oscillations in the presence of interactions. We observe a fully coherent evolution in momentum space as manifested by a regular time-varying interference pattern. Coherence of the dephasing process is demonstrated by reversing the time evolution in a matter wave spin echo experiment.

In the non-interacting case, we observe long-lasting Bloch oscillations and, when an external potential is applied, observe pronounced matter wave Talbot interferences with repeated revivals. For a 3D-lattice configuration, we present results on the effect of variable interaction strength on the superfluid-to-Mott-insulator phase transition.

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Quantum optics with quantum gases: controlled state reduction by designed light scattering

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Cavity enhanced light scattering off an ultracold gas in an optical lattice constitutes a quantum measurement with a controllable form of the measurement back-action. Time-resolved counting of scattered photons alters the state of the atoms without particle loss implementing a quantum nondemolition (QND) measurement. The conditional dynamics is given by the interplay between photodetection events (quantum jumps) and no-count processes. The class of emerging atomic many-body states can be chosen via the optical geometry and light frequencies. Light detection along the angle of a diffraction maximum (Bragg angle) creates an atom-number squeezed state, while light detection at diffraction minima leads to the Schrödinger cat states of different atom numbers in the cavity mode. A measurement of the cavity transmission intensity can lead to atom-number squeezed or macroscopic superposition states depending on its outcome.

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AC Stark shift and temperature shift in laser pumped Rubidium frequency standards

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We report our study on the light-shift (AC-Stark effect) and buffer-gas induced effects (e.g. temperature effect) on the ground-state ("clock") transition of Rubidium atoms contained in cm-scale glass cells. Rb atoms are optically pumped by radiation from a DFB laser diode (@ 780nm). Microwave radiation resonant with the clock transition frequency is applied via a resonator cavity, and the clock transition is detected in the light transmission. Narrow double resonance linewidths are obtained by adding buffer gases (Dicke narrowing). Control of the buffer-gas mixture allows reducing the temperature coefficient. By adjusting the total buffer-gas pressure, we are able to adjust the pump optical frequency to the point of the zero light-shift. We have successfully produced cells that simultaneously show a low intensity light-shift ($\delta f/f \approx 1x10^{-12}$ cm /uW) as well as a small temperature coefficient ($\delta f/f < 9x10^{-12}$ /K), and pave the way for improved Rb atomic frequency standards.

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CPT spectroscopy on miniature rubidium vapour cells

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We report our measurements of ^{85}Rb $\sigma+$ CPT resonance in miniature (glass-blown and MEMS-fabricated) vapour cells containing natural rubidium and buffer gas. The resonance is recorded on the rubidium D1-line (795 nm) using a circular polarized and current modulated VCSEL. Some measurements have been done on MEMS vapour cells sealed at high temperature (>300 °C), using anodic bonding technique. We have also recently developed a low temperature (~ 150 °C) sealing technique with fast process time (< 1 min) based on soldering. We record the resonance shift, linewidth and amplitude as a function of several experimental parameters such as light intensity, cell-temperature, and buffer gas pressure- and mixture. By using a 4 mm long cell with 70 mbar of nitrogen buffer gas we measure a contrast of 1.8 % and linewidth of 1.55 kHz. With these results we predict a clock stability of 2×10^{-11} @ 1 second.

175	**Mesoscopic Physics with Ultracold Fermions** *Torben Müller, Bruno Zimmermann, Jakob Meineke, Henning Moritz, Tilman Esslinger* *ETH Zürich, Institute of Quantum Electronics, ETH Hönggerberg, 8093 Zürich, Switzerland* The recent years have seen tremendous progress in the manipulation and control of ultracold quantum gases, e.g. in the context of optical lattices entering the regime of strongly correlated quantum systems. Here, we reach out for a new level of control over the quantum gas by trapping it in variable optical potentials which can be patterned and shaped on the length scale of one micrometer. Starting point of our experiments is a BEC of ^{6}Li Feshbach molecules sandwiched between two microscope objectives enabling us to create arbitrary potentials and to locally probe the sample. We present first results obtained with our new experimental setup. Due to the achieved optical resolution of 700 nm, mesoscopic physics with strongly correlated fermions is within reach. As a first example, we realized a 2x2 array of micro-traps spaced by one micrometer. In this basic plaquette-type trapping potential, we were able to load and detect a very small number of atoms. Further experimental progress will be presented.
176	**Cavity nonlinear optics with few photons and ultracold quantum particles** *Wolfgang Niedenzu, András Vukics, Helmut Ritsch, Institut für Theoretische Physik,* *Universität Innsbruck, Technikerstrafle 25, 6020 Innsbruck, Austria* The light force on particles trapped in the field of a high-Q cavity mode depends on the quantum state of field and particle. Different photon numbers generate different optical potentials and different motional states induce different field evolution. Even for negligible internal particle excitation, which yields linear polarizability, the quantum character of particle motion generates nonlinear field dynamics. We derive a corresponding effective field Hamiltonian containing all the powers of the photon number operator, which predicts nonlinear phase shifts and squeezing even at the few-photon level. Simulations of the full particle-field dynamics confirm this and show significant particle-field entanglement.
177	**Towards Cryogenic Surface Ion Traps.** *Michael Niedermayr [1], Muir Kumph [1], Michael Brownnutt [1], Rainer Blatt [1,2]* *[1] Institut für Experimentalphysik, Uni. Innsbruck, Technikerstr. 25,, 6020 Innsbruck, Austria* *[2] Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Otto-Hittmair-Platz 1, 6020 Innsbruck, Austria* One promising approach for scalable quantum information processing (QIP) architectures is based on miniaturised surface ion traps. Traps with dimensions in the sub-100 μm range can be fabricated by photolithographic techniques. The ion-heating rate has been shown increases strongly with decreasing trap dimensions, though this can be reduced by several orders of magnitude when the trap electrodes are cooled from room temperature to 4 K. We present the characterisation of a gold-on-sapphire surface microtrap suitable for use at cryogenic temperatures. The development of the cryostat and appropriate systems for ablation-based photoionisation loading of cryo-traps are also discussed. Such traps will ultimately be used for quantum simulations, fundamental investigations of large-scale entanglement, and entanglement-enhanced precision measurements.

178	**Detection of entanglement with high statistical significance** *Sönke Niekamp, Bastian Jungnitsch, Matthias Kleinmann, Otfried Gühne* *Institute for Quantum Optics and Quantum Information, Technikerstrafle 21 a, 6020 Innsbruck, Austria* A witness operator is an observable which allows to verify whether a given state is entangled. In a typical experiment, only a limited number of copies of the entangled state is available for this task. In order to detect entanglement with high certainty, it is therefore of advantage to decrease the statistical error involved in the measurement of the witness. We demonstrate that the variance of a witness operator can always be minimized for a given state by adding a positive operator. Apart from witness operators, we also consider Bell-like inequalities and present an example in which an inequality with lower violation leads to a higher statistical significance.
179	**Creating and Verifying a Quantum Superposition in an Optomechanical System** *Igor Pikovski [1], Dustin Kleckner [2], Evan Jeffrey [3], Luuk Ament [3], Eric Eliel [3], Jeroen van den Brink [3], Dirk Bouwmeester [2,3]* *[1] Universität Wien, Boltzmanngasse 5, 1090 Wien, Austria* *[2] University of California, Department of Physics, Santa Barbara, CA 93106, United States* *[3] Universiteit Leiden, PO Box 9504, 2300 Leiden, Netherlands* Micro-optomechanical systems have become increasingly important in the study of quantum effects in relatively massive systems. Here we review the experiment as proposed by Marshall et al. (2003) which aims to demonstrate a quantum superposition of a mesoscopic cantilever. We analyze in detail the effects of finite temperature on the interpretation of the experiment, and obtain a lower bound on the degree of non-classicality of the cantilever. Although it is possible to measure the quantum decoherence time when starting from finite temperature, an unambiguous demonstration of a quantum superposition requires the mechanical resonator to be in or near the ground state. We also calculate the rate of environmentally induced decoherence and provide a rough estimate of the gravitationally induced collapse as proposed by R. Penrose and L. Diosi.
180	**The SECOQC Quantum Key Distribution Network in Vienna** *Andreas Poppe, Momchil Peev, Thomas Lorünser, Oliver Maurhart* *Austrian Research Centers GmbH, Department Safety&Security, Donau-City-Straße 1 / Tower, 1220 Vienna, Austria* We present the Quantum Key Distribution (QKD) network designed and implemented by the European project SECOQC (2004-2008, http://www.secoqc.net/), unifying the efforts of 41 research and industrial organizations. This contribution discusses the architecture and functionalities of the SECOQC trusted repeater prototype, which has been put into operation in Vienna in 2008. The features of the QKD-network has been publicly shown during a live demonstration by following tests and experiments: One Time Pad telephone communication, a secure (AES encryption protected) video-conference with all deployed nodes and a number of rerouting experiments, highlighting basic mechanisms of the SECOQC network functionality. Besides the explanation of benefits by extending single QKD-links to QKD-networks, this contribution gives an overview of the implemented point-to-point QKD-links and their underlying technology. The average link length of the fibre based systems was between 20 and 30 kilometers, the longest link being 83 kilometers.

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Towards Bose-Einstein condensation of rovibronic ground state molecules

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High phase-space density samples of molecules in the rovibronic ground state are ideal systems to address a variety of fundamental questions in physics and chemistry. Our aim is to fully control all molecular degrees of freedom and to produce a BEC of ground state molecules. We load a BEC of Cesium atoms into an optical lattice, maximizing the number of doubly occupied sites and produce weakly bound Feshbach molecules. These are subsequently transferred to the rovibronic ground state by STIRAP transfer.
We discuss recent progress in the optimization of the molecule production and state transfer. This is instrumental for state selective scattering experiments and for the production of a BEC of ground state molecules when melting the lattice. Furthermore, the prospects for direct imaging of ground state molecules and improved lattice loading by means of a bichromatic lattice are examined.

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An integrated atom detector: Single atoms and photon statistics

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We present recent experiments with our integrated single atom detector [1]. It consists of a tapered lensed single-mode fiber for precise delivery of excitation light and a multimode fiber to collect the flourescence photons and transmit them to a Hanbury Brown - Twiss setup with two detection APDs. The fibers are mounted in lithographically defined SU-8 holding structures on an atom chip. Rubidium 87 atoms propagating freely in a magnetic guide are detected with an efficiency of up to 66% with a signal-to-noise ratio in excess of 100.
The setup allows us to study the interplay between atom and photon statistics [2]. For small atom flux, the photon count distribution reflects the instantaneous photon emission of the detected (single) atoms at short times and the statistical atomic distribution at long time scales.

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Time-dependent Many-body Dynamics with Long-Range Interactions in 1D Optical Lattices

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There have recently been several important developments in realising systems with long-range interactions in cold quantum gases, particularly with developments in controlled Rydberg excitations, and in the realisation of an ultracold gas of dipolar molecules. Atoms in excited Rydberg states interact strongly over a long range and have therefore become interesting in the context of engineering fast quantum gates. Here we study dynamics in a system of up to 50 laser excited Rydberg atoms, which are confined in a 1D optical lattice

potential. Employing time-dependent calculations we present a scheme to adiabatically prepare crystalline states depending on an appropriate variation of the laser parameters with time. For the simulation of this system we adapt a very successful numerical method, the time-evolving block decimation algorithm (TEBD), to treat long-range interactions. We also discuss progress in treating long-range interactions with matrix product operators, which are capable of simulating systems with interactions over many sites. These new algorithms could also be applied to a confined 1D gas with long-range interactions that is not trapped along the axial direction.

184 Stark deceleration and trapping of hydrogen Rydberg molecules

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Recent progress in the development of methods to decelerate and manipulate the translational motion of Rydberg atoms and molecules in the gas phase using inhomogeneous electric fields [1,2] has led to the experimental realization of Rydberg atom optics elements including a lens [3], a mirror [4] and two- and three-dimensional traps [5,6]. These experiments make use of the very large electric dipole moment of Rydberg Stark states and have demonstrated the possibility to stop a pulsed supersonic beam of seeded atomic hydrogen traveling with an initial velocity of 700 ms^{-1} within a distance of 2 - 3 mm and within ~ 5 μs using electric fields with a strength of a few $kVcm^{-1}$.
We have extended these methods to control the translational motion of molecules and present the results of recent experiments in which we have decelerated and loaded hydrogen Rydberg molecules into a three-dimensional electrostatic trap. The experiments use a multiphoton excitation sequence to excite nonpenetrating ($l \geqslant 3$) Rydberg-Stark states with principal quantum number in the range n=20-35 using circularly polarized laser radiation. These states are long-lived and the avoided crossings between Stark states are reduced to the extent that they are traversed diabatically during deceleration. We discuss the method employed to decelerate and load the Rydberg molecules into the trap along with trap loss mechanisms including predissociation, fluorescence and collisional processes.

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185 Discovery of new energy levels in Praseodymium with large angular momentum

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Using the method of laser induced fluorescence spectroscopy in a hollow cathode discharge we investigated the spectral lines in Pr I atom and discovered new, up to now unknown, energy levels with high angular momentum values, namely 17/2, 19/2, 21/2. As an example a transition at line 5752.83 ≈ is discussed. From the determined J-values, magnetic interaction constants A and from observed fluorescence wavelengths for the recorded structure the lower level was identified in the list of known levels, as 11483.45 cm^{-1}, even parity, J = 7.5 and A = 987.3(1) MHz. Using the center of gravity excitation wavelength, the energy of upper level was determined to be 28861.373 cm^{-1}. It has odd parity, J = 8.5, A = 450(3) MHz. We present here the data of 30 new energy levels with J = 17/2, 19/2, 21/2, the energies of all these levels were confirmed by a second excitation.

186	**Testing Born's Rule in Quantum Mechanics for Three Mutually Exclusive Events**

186 Testing Born's Rule in Quantum Mechanics for Three Mutually Exclusive Events

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In spite of the success of Quantum Mechanics there still remains a lot we do not understand about the Theory. Therefore it is important to have empirical verification of the fundamental postulates of Quantum Mechanics. In this experiment we have set out to test Born's Rule, which interprets probability as the modulus squared of the wavefunction. This has been indirectly verified. Yet, to our knowledge, this is the first proposed experiment directly testing this postulate of Quantum Mechanics.
Analogous to how Youngs double slit experiment expresses a deviation from the classical additivity of the probabilities of two mutually exclusive events. This experiment looks for deviations from the quantum mechanical triadditivity of three mutually exclusive events. This means we are looking for a "three-path interference" that can not be explained by Born’s Rule, and we hope to put an upper bound on any such possible deviation from Born's Rule.

187 High-resolution spectroscopy of high *n*p Rydberg states of the helium dimer

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Metastable $^4He_2$ (a $^3\Sigma_u^+$) was produced in a supersonic beam expansion of neat helium atoms using a pulsed discharge. The third harmonic of the output of a 16-stage pulsed titanium-doped sapphire (Ti:Sa) amplifier was used to excite high *n*p Rydberg states of the helium dimers. 2 μs after laser excitation, a pulsed electric field with an amplitude of 12.8 V/cm was applied. It was used to field-ionize the excited helium dimers and to accelerate the released electrons towards a multi-channel plate detector. The electron signal produced by the extraction field was integrated and monitored as a function of the laser wave number. The spectra reveal a dense structure of very sharp features that can be attributed to high *n*p Rydberg series (*n*=85-150) converging to the first three rotational levels of the ground ionic state (rotational quantum number N^+=1,3,5). In addition, Rydberg states (*n*=23-39) of rotationally excited levels of the ion core (N^+=3,5,7) are observed within the field-lowered ionization continua associated with the N^+ -2 and N^+ -4 ionization channels. The mechanism making the observation of these states possible was attributed to forced rotational autoionization. Multichannel quantum defect theory was applied to study the rotational autoionzation dynamics and to extrapolate the ionization energy of the a $^3\Sigma_u^+$ state (N^+=1 - N''=1) to a value of 34 301.2025 ± $(0.0006)_{statistical}$ ± $(0.006)_{systematic}$ cm^{-1}. An interpretation of the effects of an electric field on the autoionzation dynamics is proposed.

188	**Towards a BEC of Strontium** *Simon Stellmer [1,2], Meng Khoon Tey [2], Rudolf Grimm [1,2], Florian Schreck [2]* *[1] University of Innsbruck, Technikerstrasse 21a, 6020 Innsbruck, Austria* *[2] IQOQI Innsbruck, Technikerstrasse 21a, 6020 Innsbruck, Austria* Atomic Strontium as an alkaline earth metal shows some remarkable atomic properties owing to its electronic configuration. Very long-lived metastable states, narrow intercombination lines, and zero magnetic moment for the bosonic isotopes offer unique possibilities for optical clocks, employment of optical Feshbach resonances, quantum computation and quantum simulation. Cooling of Strontium into either bosonic or fermionic quantum degeneracy will be the first step towards quantum computation with neutral atoms.
189	**New Even Parity Levels in Neutral Praseodymium** *Syed Tanweer Iqbal, Shamim Khan, Imran Siddiqui, Zaheer Uddin, Laurentius Windholz, Institute of Experimental Physics, Graz University of Technology, Petersgasse 16, 8010 Graz, Austria* In this investigation of the hyperfine structure of the praseodymium atom in a hollow cathode discharge using laser induced fluorescence spectroscopy, we present the discovery of eight newly found even parity levels by investigation of spectral lines in the region 5700 Å to 6200 Å. J-quantum numbers and magnetic dipole interaction constants A for upper and lower levels have been determined from the recorded hyperfine structure. Energies of the new, up to now unknown, levels were obtained by using these constants, excitation and fluorescence wavelengths. Levels confirmed by a second laser excitation are given in the following table.
190	**Femto-Tesla Cs magnetometer arrays** **for biomagnetic measurements and fundamental research** *Antoine Weis, Natascia Castagna, Malgorzata Kasprzak, Anatoly Pazgaleav, Paul Knowles, Physics Department, Université de Fribourg, Chemin du Musée 3, 1700 Fribourg, Switzerland* We have developed scalar magnetometers using laser-driven and -detected magnetic resonance in paraffin-coated Cs vapor cells. A single laser can drive up to several hundred sensor heads, where each requires only a few micro-Watt of light for optimal performance, thus allowing operation of multi-sensor arrays. The individual sensor heads are fiber-coupled compact structures (few cm^3) reaching a (close to) shot-noise limited sensitivity of a few 10 $fT/Hz^{1/2}$. We have solved the problems of cell mass production (300 excellent cells produced so far), light delivery to the sensor heads, and digital control using FPGA electronics. We will report on magneto-cardiographic measurements using a 19 channel second order gradiometry scheme with 25 sensors and will outline prospects for the use of sensor arrays in a new search for a permanent electric dipole moment of the neutron. Work supported by the Velux Foundation and the Swiss National Science Foundation.

191 Asymmetry and time-resolved features beyond the Landau Zener problem

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The tunneling problem of a quantum particle through the energy gap at an avoided crossing between two energy levels of the system has been studied from the simple picture of the Landau Zener theory. We present experimental and numerical results for deviations from this simple theory in the case of asymmetric tunneling in the presence of interactions as well as for "interrupted" tunneling events representing a time resolved measurement of the Landau-Zener process.
The nonlinearity introduced by the interactions leads to an asymmetric tunnelling rate (probability of tunnelling from one band to another) [1]. An enhancement of the tunnelling probability occurs when the atoms tunnel from the lower to the upper band while tunnelling is suppressed in the opposite direction.
The time resolved experiments were performed in both the diabatic and adiabatic bases of the problem, i.e., in the basis of the free particle states and in the band structure, respectively. The aim was to investigate the survival probability of a BEC initially loaded into the lowest band of the 1D optical lattice as a function of its final position in the Brillouin zone [2]. In both bases we could observe a step-like discontinuous decay of the population in the ground state after part of them had tunnelled to the upper band. Moreover the measurements in the diabatic basis also showed strong oscillations in the survival probability.

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192 Toward quantum networks: integrating fiber cavities and ion traps

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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 hope to 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. Our approach is twofold: first, we are investigating the perturbation of ions in a linear segmented trap by the presence of an optical fiber. This experiment provides a testbed for us to explore little-understood factors such as acceptable ion-fiber distances and the effects of fiber coatings. Second, we are developing and testing curved, coated fiber mirrors and designing an integrated ion-trap cavity setup.

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An Ion in a sea of ultracold neutral atoms

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We report on the status of our new hybrid ion/atom trap experiment where a single trapped Ba^+ ion will be immersed into a Bose-Einstein condensate of ^{87}Rb atoms. First experiments will focus on the investigation of the interaction between the ion and the sea of ultracold neutral atoms. We plan to study elastic as well as inelastic scattering processes, e.g. charge transfer and molecule formation. We describe in detail our setup which will feature an optical transport of a Rb BEC into a linear Paul trap, where the Barium ion is stored.

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Interference of Two Molecular Bose-Einstein Condensates

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Interference of Bose-Einstein condensates (BECs) strikingly demonstrates the wave nature of matter. Here, we present the observation of interference of BECs made of molecules. The molecules are weakly bound dimers consisting of fermonic lithium atoms close to the 834-G Feshbach resonance. We condense these molecules in a double well potential. After release, the clouds overlap and we record interference fringes by absorption imaging. We explore different scenarios that affect the contrast of the interference fringes. (1) As expected, the fringes vanish above the critical temperature for BEC. (2) Contrast is also reduced with further increasing the interaction strength between the molecules. (3) The contrast changes periodically in time when we excite collective modes along the direction of imaging.

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Entanglement detection with bounded reference frames

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Quantum experiments usually assume the existence of perfect, classical, reference frames, which allow for the specification of measurement settings (e.g. orientation of the Stern Gerlach magnet in spin measurements) with arbitrary precision. If the reference frames are ``bounded'' (i.e. are quantum systems themselves, with a finite number of degrees of freedom), only limited precision can be attained. Using spin coherent states as bounded reference frames we have found the minimal size needed to violate local realism for entangled spin systems. For composite systems of spin-1/2 particles reference frames of very small size are sufficient for the violation; however, to see this violation for macroscopic entangled spins, the size of the reference frame must be at least quadratically larger than that of the spins. This gives a possible explanation for the non-observance of entanglement at macroscopic scales, that is, the emergence of classicality.