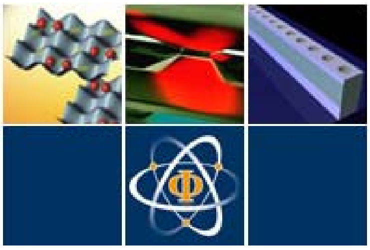
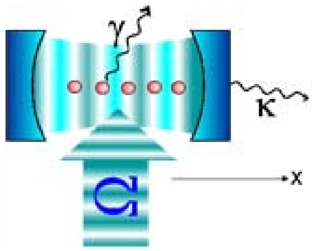
International Conference on

Quantum Optics 2014

Obergurgl, February 23 - March 01





Book of Abstracts

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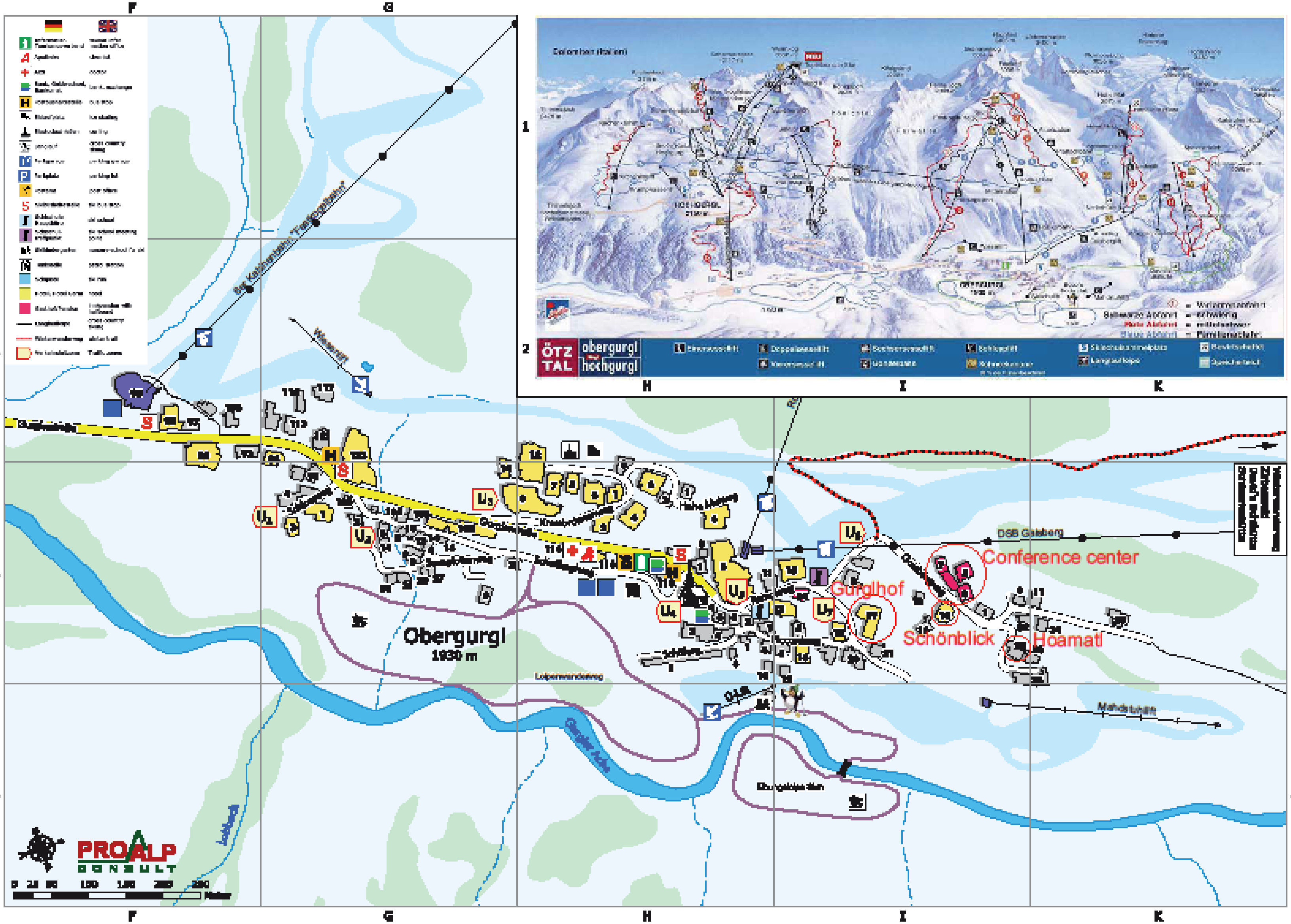
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	Sunday 23.02	Monday 24.02	Tuesday 25.02	Wednesday 26.02	Thursday 27.02	Friday 28.02	Saturday 01.03
8.20		Welcome					
8.30-9.00		Salomon	Polzik	Schmidt-Kaler	Roos (HT)	Rigol	return bus
9.00-9.30		Köhl	Rempe	Bollinger	Klempt (HT)	Kosloff	return bus
9.30-10:15		Coffee break					
10.15-10.45		Grimm	Rauschenbeutel	Northup	Dür	Wester	return bus
10.45-11.15		Oberthaler	Arndt	Dürr (HT)	Clausen (HT)	Ferlaino (HT)	return bus
11.15-12.00		Discussions					
12.00-15.30		Lunch + Discussions					
15.30-16.00		Coffee + Cake					
16.00-16.30		Gross	Kollath	Mølmer	Brune	Fallani	
16.30-17.00		Hemmerich (HT)	Simon	Taminiau	Romero-Isart	Campbell (HT)	
17.00-17.30	registration	Landig (HT)	Meinert (HT)	Bushev (HT)	Zimmermann (HT)	Törmä (HT)	
17.30-18.00	registration	Coffee break					
18.00-18.30	registration	Langen	Läuchli		Genes	Lesanovsky (HT)	
18.30-19.00	registration	Lechner	Chin		Gasenzer	Dalmonte (HT)	
19.15-20.30	Dinner	Dinner	Dinner	Conference Dinner	Dinner	Dinner	
20.30-22.00		Posters	Posters		Posters	Posters	

List of contributions

Talks

Experimental explorations towards quantum interference in the regime of ultrahigh masses

Markus Arndt, *Faculty of Physics, University of Vienna, Boltzmanngasse 5, Vienna, Austria*

Quantum superposition is at the heart of quantum physics but matter wave interference at ultrahigh (10^7-10^{10} u) masses is still an open experimental challenge [1]. The Kapitza-Dirac-Talbot-Lau scheme [2] has seen quantum interference of tailor-made molecules composed of more than 800 atoms [3], with a total mass beyond 10.000 amu. A recent extension to interferometry with pulsed laser gratings [4] currently allows addressing de Broglie wavelengths down to 10^{-4}…10^{-6} of the particle size. A key challenge for further progress is the development of ultracold nanoparticle sources. We discuss recent advances in cavity cooling of dielectric nanoparticles of about 10^{10} amu [5].

[1] M. Arndt and K. Hornberger, Nature Physics (2014)
[2] S. Gerlich et al., Nature Physics 3, 711 (2007)
[3] S. Eibenberger, S. Gerlich, M. Arndt, M. Mayor, and J. Tüxen, Phys. Chem. Chem. Phys. 15, 14696 (2013)
[4] P. Haslinger, N. Dörre, P. Geyer, J. Rodewald, S. Nimmrichter, and M. Arndt, Nature Physics 9, 144 (2013)
[5] P. Asenbaum, S. Kuhn, S. Nimmrichter, U. Sezer, and M. Arndt, Nature Communications 4, 2743 (2013)

Quantum control and simulation with 2-dimensional arrays of trapped ions

John Bollinger, *National Institute of Standards and Technology, 325 Broadway Boulder, CO USA*

Trapped ions, when cooled to sufficiently low temperatures form crystalline arrays. I will describe our efforts to extend the quantum control techniques developed with small linear chains of ions in rf traps to larger two-dimensional crystals of hundreds of ions formed in a Penning trap. Our qubit is the 124 GHz electron spin-flip transition in the ground state of Be^+ in the 4.5 T magnetic field of the Penning trap. We control the spins with an effective transverse magnetic field generated with 124 GHz microwaves. Spin-dependent optical dipole forces are used to engineer long range Ising interactions between the ion qubits and to characterize the motional degrees of freedom of the trapped ions.

Confined quantum Zeno dynamics of a watched angular momentum

Michel Brune, *LKB, ENS, 24 rue Lhomond, Paris, France*

Repeatedly asking a quantum system "are you still in your initial state?"' blocks its coherent evolution through the Quantum Zeno effect. Quantum Zeno Dynamics (QZD) leaves more freedom to the system. Repeatedly asking it "are you beyond this limit?"' sets an impenetrable, tailorable border in its Hilbert space. We report the observation of QZD in the Hilbert space of a large angular momentum J=25 implemented in the Stark manifold of a Rydberg level. This confined dynamics leads to the production of non-classical `Schrödinger cat' states, quantum superpositions of angular momentums pointing in different directions. State tailoring via QZD is promising for quantum information tasks.

Hybrid quantum systems with rare-earth spin ensembles

Pavel Bushev, *Universität des Saarlandes, Campus E 26, Saarbrücken, Germany*

Interfacing photonic and solid-state qubits within a hybrid quantum architecture offers a promising route towards large scale distributed quantum computing. Ideal candidates for coherent qubit interconversion are optically active spins, magnetically coupled to a superconducting resonator. I will report on our recent circuit QED, on-chip ESR and optical experiments with erbium doped crystals at millikelvins.

Making the best atomic clock and applying it to quantum many-body physics

Sara Campbell, *JILA, 440 UCB Boulder, Colorado, USA*

We bring a many-particle clock to the frontier of atomic clock accuracy, achieving a new record of 6^{-18}. A laser with record 10^{-16} stability allows the clock to benefit from many particles, reaching a stability at its accuracy level in 3000 s. The future of stable lasers includes novel crystalline mirror coatings and a technique that uses ^{87}Sr atoms to measure laser linewidth. The latest developments in stability enable new explorations of collective interactions in ultracold gases.

Universality in quantum quenches and quantum transports

Cheng Chin, *University of Chicago, 929 E. 57th St Chiago, IL USA*

We demonstrate a new scheme to extract particle and energy flows induced by temperature gradients; equivalent to thermoelectricity in electronic materials. We determine the thermopower and Lorenz number, both showing intriguing behavior: a sign change of the thermopower suggests the emergence of superfluid counterflow; the Lorenz number approaches zero, contrasting with the universal Wiedermann-Franz law in electron systems.

Quantum teleportation from a telecom-wavelength photon to a solid-state quantum memory

Christoph Clausen, *TU Wien - Atominstitut, Stadionallee 2 Wien, Austria*

In quantum teleportation, a shared entangled state and classical communication is all that is required to transfer an arbitrary quantum state between two distant locations. Quantum teleportation plays an essential part in quantum communication and computation. We have experimentally demonstrated the teleportation of a polarization qubit at a telecommunications wavelength, into a solid-state quantum memory. Subsequent quantum state tomography revealed teleportation fidelities of 80 to 90%.

A case for quantum Ice and frustrated magnetism with Rydberg-dressed atoms in optical latt

Marcello Dalmonte, *Institute for theoretical physics, IBK, Technickerstrasse 25 Innsbruck, Austria*

The concept of gauge symmetry permeates through many branches of our understanding of physical phenomena, ranging from fundamental interactions in particle physics, to frustrated magnetism and spin models. In this talk, we will discuss how some simple instances of gauge theories relevant for the study of condensed matter problems can be realized in ultra-cold atom gases in optical lattices. In particular, the case of quantum Ice, a paradigmatic toy model for frustrated magnetism, will be discussed.

Measurement-based quantum information processing with high error thresholds

Wolfgang Dür, *Inst. for Theoretical Physics, Innsbruck, Technikerstrasse 25 Innsbruck, Austria*

We investigate the usage of measurement-based elements in quantum information processing, including entanglement purification, error correction and fault-tolerant quantum computation. We construct optimal resource states of minimal size, and report on first experimental implementations with trapped ions and photons. We find that such schemes show a remarkable robustness against noise and imperfections on resource states. For measurement-based entanglement purification up to 24% local noise per particle is tolerable, while for fault-tolerant quantum communication and computation this value is still above 10%.

Single-Photon Switch Based on Rydberg Blockade

Stephan Dürr, *Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1 Garching, Germany*

All-optical switching is a technique in which a gate light pulse changes the transmission of a target light pulse without the detour via electronic signal processing. We take this to the quantum regime, where the incoming gate light pulse contains only one photon on average. The gate pulse is stored as a Rydberg excitation in an ultracold atomic gas using electromagnetically induced transparency. Rydberg blockade suppresses the transmission of the subsequent target pulse.

Multi-component one-dimensional liquids of fermions

Leonardo Fallani, *University of Florence & LENS, Via Nello Carrara 1, Sesto Fiorentino, Italy*

We report on the realization of multi-component 1D liquids of ultracold ^{173}Yb fermions. These atoms are characterized by a large nuclear spin and highly-symmetric interactions, allowing quantum simulations of systems with SU(N) interaction symmetry. By controlling the number of spin components N, we have studied how static and dynamic properties of strongly-correlated 1D fermions change with N, evidencing intriguing effects caused by the interplay between interactions and quantum statistics.

Breaking dogmas with ultracold erbium atoms

Francesca Ferlaino, *Institute for Experimental Physics, Technikerstrasse 25 Innsbruck, Austria*

Non-alkali-metal atoms have recently proved to be fascinating systems to explore novel lands in ultracold quantum physics. Here, we present recent results with ultracold dipolar gases of erbium atoms. As a consequence of the strong dipole-dipole interaction and of the large anisotropy in the dispersion potential, Er shows a spectacularly high number of Fano-Feshbach resonances both in the fermionic and bosonic isotopes. The complex Er scattering behavior escapes to traditional scattering models and requires novel approaches based on statistical analysis. Following the powerful toolset provided by Random-Matrix theory, we elucidate the chaotic nature of the scattering. Finally, we report on the first degenerate Fermi gas of Er, which is realized by direct cooling of identical fermions based on dipole-dipole interaction [1,2].

[1] A. Frisch, M. Mark, K. Aikawa, F. Ferlaino, J. L. Bohn, C. Makrides, A. Petrov, S. Kotochigova, arXiv: 864076 (2013)
[2] K. Aikawa, A. Frisch, M. Mark, S. Baier, R. Grimm, and F. Ferlaino, Phys. Rev. Lett. 112, 010404 (2014)

Non-thermal fixed points: Universality, topology and turbulence in Bose systems

Thomas Gasenzer, *Universität Heidelberg, Philosophenweg 16 Heidelberg, Germany*

Non-thermal fixed points are proposed which are, for generic cases, related to the presence and turbulent dynamics of (quasi-)topological defects in the Bose field, which are manifestly far from equilibrium. Our results establish a link between kinetic wave turbulence and topological excitations of superfluids. They open a path to explore a new class of universal far-from-equilibrium dynamics accessible in ultracold gas experiments and are of importance beyond the realm of these systems.

Protected state enhanced quantum metrology with ensembles of interacting two-level systems

Claudiu Genes, *institute for theoretical physics, technikerstrasse 25 Innsbruck, Austria*

Ramsey interferometry is routinely used in quantum metrology for the most sensitive measurements of optical clock frequencies. Spontaneous decay to the electromagnetic vacuum ultimately limits the interrogation time and thus sets a lower bound to the optimal frequency sensitivity. In dense ensembles of two-level systems the presence of collective effects such as superradiance and dipole-dipole interaction tends to decrease the sensitivity even further. We show that by a redesign of the Ramsey-pulse sequence to include different rotations of individual spins that effectively fold the collective state onto a state close to the center of the Bloch sphere, partial protection from collective decoherence is possible.

Efimov and beyond: New twists in three-body physics with ultracold bosons and fermions

Rudolf Grimm, *Institute for Experimental Physics, Technikerstrasse 25 Innsbruck, Austria*

Ultracold quantum gases provide unique experimental access to the bizarre physics of resonantly interacting three-body systems. We report on novel results in two different situations. In the paradigmatic three-boson system, we have observed the second triatomic resonance, which is a striking signature of an excited Efimov state. The experiments are carried out in extremely cold samples (few nK) of Cs atoms at extremely large values of the s-wave scattering length (about 20000 times the Bohr radius). For a mass-imbalanced fermion system (^{6}Li-^{40}K mixture), we study near-resonant interactions of atoms and dimers using radio-frequency spectroscopy. We find that the three-body physics leads to a strong attraction, having no counterpart in the well-investigated mass-balanced Fermi systems.

Dynamical Crystallization Of Rydberg Excitations

Christian Groß, *MPQ, Hans-Kopfermann-Str. 1 Garching, Germany*

Ultracold Rydberg atoms offer the possibility to realize effectively long-range interacting quantum gases. The ground state of an atomic many-body system continuously coupled to a Rydberg state is paramagnetic or crystalline depending on the detuning of the electromagnetic coupling. Here we report on the observation of dynamical crystallization of Rydberg excitations in one-dimensional systems. Using optimized control of the detuning and power of the coupling we drive the system into the crystalline phase. We observe the characteristic staircase of excitation numbers and simultaneously measure the spatial distribution of the excitations.

Atom-cavity physics with recoil resolution

Andreas Hemmerich, *Universität Hamburg, Luruper Chaussee 149 Hamburg, Germany*

I will summarize our recent observations of non-linear dynamics, cooling with sub-recoil resolution, Bloch-Oscillations and other related phenomena in an atom-cavity system operating in the intersection of the regimes of cavity dominated scattering, strong cooperative coupling, and sub-recoil momentum resolution.

Classification of the entanglement depth near a Dicke state

Carsten Klempt, *Leibniz Universität Hannover, Welfengarten 1 Hannover, Germany*

Spin dynamics in BECs allows for the production of many thousands of neutral atoms with entangled spins. Here, we present a novel method to classify the entanglement depth near Dicke states by measuring the components of the total spin. Our limits for the spin variances predict how many atoms are at least in the largest nonseparable subset. For our experimentally created states, we conclude that these subsets consist of a minimum of 30 entangled atoms.

Single Ion Coupled to an Optical Fiber Cavity

Michael Köhl, *Uni Bonn, Wegelerstrasse 8 Bonn, Germany*

We present the realization of a combined trapped-ion and optical cavity system, in which a single Yb^{+} ion is confined by a micron-scale ion trap inside a 230 micron-long optical fiber cavity. We characterize the spatial ion-cavity coupling and measure the ion-cavity coupling strength using a cavity-stimulated Lambda-transition. Owing to the small mode volume of the fiber resonator, the coherent coupling strength between the ion and a single photon exceeds the natural decay rate of the dipole moment. We demonstrate the generation of single photons form the coupled ion-cavity system as well as observing correlations between the spin-state of the ion and the polarization state of the photons. This system can be integrated into ion-photon quantum networks and is a step towards cavity quantum electrodynamics based quantum information processing with trapped ions. We demonstrate the feasibility of this ion-cavity system for hybrid quantum networking by interfacing the ion-cavity system with an InGaAs semiconductor quantum dot. Communication between the two system is achieved by the exchange of single photons.

Unconventional dynamics of ultracold bosons in optical lattices

Corinna Kollath, *University of Bonn, Nussallee14-16 Bonn, Germany*

Atomic gases cooled to Nanokelvin temperatures are a new exciting tool to study a broad range of quantum phenomena. In particular, an outstanding degree of control over the fundamental parameters, such as interaction strength, spin composition, or dimensionality has been achieved. This has facilitated access to strongly correlated quantum many body physics in exceptionally clean samples. For example, artificial periodic structures for the atomic gas can be created using laser light to mimic condensed matter systems. Further, the outstanding tunability of cold gases allows to rapidly change the system parameters or to induce a coupling to an environment and to observe the subsequent quantum evolution. This ability poses new challenges for the understanding of quantum dynamics in correlated many-body systems. I will report on recent progress on investigating bosonic and fermionic gases in optical lattices coupled to dissipative light fields described by Markovian Master equations. In particular, we point out unconventional dynamical regimes for bosonic gases reaching from an algebraic decay of correlations to a stretched exponential decay. We analyze the origin of this unconventional dynamics. The algebraic behavior is related to the continuum spectrum of the bosonic gas and we develop a classical diffusion equation description for the dynamics. In contrast, the stretched exponential dynamics can be traced back to the existence of rare states with increasingly long time scales. In fermionic gases in contrast we show that purely local dissipation can even create metastable pair correlations.

The Dynamical Versions of the III-law of Thermodynamic reflected in quantum refrigerators.

Ronnie Kosloff, *Hebrew University, Institute of Chemistry Jerusalem, Israel*

Quantum thermodynamics addresses the emergence of thermodynamical laws from quantum mechanics. The III-law of thermodynamics has been mostly ignored. There are seemingly two independent formulation of the third law. The first, known as the Nernst heat theorem, implies that the entropy flow from any substance at absolute zero temperature is zero: $\dot{S} = J_c/T_c \rightarrow 0$ when $T_c \rightarrow 0$ and *cal* J_c is the heat current. In order to insure the fulfillement of the second law when $T_c \rightarrow 0$ it is necessary that the entropy production scales as $\dot{S} \sim T_c^{\alpha}$ with $\alpha \geq 0$. The third low impose $\alpha > 0$ guaranteeing that at the absolute zero $\dot{S} = 0$. As a result $J_c \sim T_c^{\alpha+1}$.
The second formulation of the III-law is a dynamical one, known as the unatinability principle: *No refrigerator can cool a system to absolute zero temperature at finite time*. This formulation is more restrictive, imposing limitations on the on the spectral density and the dispersion dynamics of the heat bath. We quantify this formulation by evaluating the characteristic exponent ζ of the cooling process

$$dT(t)/dt \sim -T^{\zeta},\ T \rightarrow 0$$

Namely for $\zeta < 1$ the system is cooled to zero temperature at finite time. We relate the III-law to a generic quantum refrigerator model which is a nonlinear device merging three currents from three heat baths: a cold bath to be cooled, a hot bath as an entropy sink, and a driving bath which is the source of cooling power. A heat-driven refrigerator (absorption refrigerator) is compared to a power-driven refrigerator related to laser cooling. When optimized, both cases lead to the same exponent ξ, showing a lack of dependence on the form of the working medium and the characteristics of the drivers. The characteristic exponent is therefore determined by the properties of the cold reservoir and its interaction with the system. Two generic heat bath models are considered: a cold bath composed of harmonic oscillators and a cold bath composed of ideal Bose/Fermi gas. The restrictions on the interaction Hamiltonian imposed by the third law will be addressed. [1-3].

[1] Amikam Levy and Ronnie Kosloff, Phys. Rev. Lett. 108, 070604 (2012).
[2] Amikam Levy, Robert Alicki, and Ronnie Kosloff, Phys. Rev. E 85, 061126 (2012).
[3] Amikam Levy, Robert Alicki, and Ronnie Kosloff, Phys. Rev. Lett. 109, 248901 (2012).

One-Dimensional Bose Gases Out of Equilibrium

Tim Langen, *Atominstitut, TU Wien, Stadionallee 2 Wien, Austria*

We study the non-equilibrium dynamics of a 1D Bose gas by splitting it coherently into two parts. The time evolution following this quench leads to the establishment of a quasi-steady prethermalized state. Time-resolved measurements reveal that the thermal correlations of this state first emerge locally and then spread through the system in a light-cone-like evolution. Finally, we report on the current progress in the study of thermalization beyond the transient prethermalized state.

New States of Quantum Matter in Static Gauge Fields

Andreas Läuchli, *Theoretical Physics, Innsbruck, Technikerstr. 25 Innsbruck, Austria*

Recent experimental progress has demonstrated that it is possible to engineer various lattice models with static abelian gauge fields. In this talk we discuss various novel states of quantum matter which now become within experimental reach. We report the appearance of fractional Chern insulators, Meissner phases and floating vortex lattices among other phases in phase diagrams of Fermi- or Bose-Hubbard models and discuss their unique experimental signatures.

Exploring the driven-dissipative Dicke phase transition with a Bose-Einstein condensate

Renate Landig, *ETH Zurich, Schafmattstr. 16, HPF D22 Zurich, Switzerland*

We investigate the influence of dissipation on the driven Dicke quantum phase transition, realized by Raman coupling motional degrees of freedom of a Bose-Einstein condensate to the quantized field of an optical cavity. By monitoring the cavity output field, we observe the fluctuation spectrum in real time. The observed critical behavior is in quantitative agreement with a theoretical model including the dissipation channel of the cavity as well as an atomic dissipation channel.

Quantum Glass and the Quantum Hexatic Phase with Cold Polar Molecules

Wolfgang Lechner, *IQOQI, Technikerstrasse 21a Innsbruck, Austria*

The realization of cold ensembles of polar molecules has opened a new pathway to explore the dynamics of quantum many body systems with strong, long-range and anisotropic dipolar interactions. I will focus in my talk on non-equilibirum dynamics in the regime where quantum and thermal fluctuations are of the same order of magnitude. The talk covers i.) a study on the glass transition in the presence of quantum fluctuations and ii.) a study on quantum fluctuations in the hexatic phase. i.) I will show, how the glass phase can be prepared in a bilayer system of ultracold dipolar molecules and present results on classical and quantum glassy behavior, characterized by long tails in the relaxation time and dynamical heterogeneity. I will also present experimental accessible order parameters based on marker molecules, distinguished by properly chosen internal levels, and find quantum features of dynamical heterogeneity. ii.) The hexatic phase is an intermediate phase in two dimensional systems between the crystal to the liquid phase. I will present results on the influence of quantum fluctuations on the nature of the hexatic phase and methods that allow one to measure these effects in a setup with polar molecules.

Onset of glassiness in strongly interacting and dissipative Rydberg gases

Igor Lesanovsky, *University of Nottingham, School of Physics, University Park Nottingham, UK*

We demonstrate the usefulness of Rydberg systems for studying soft-matter phenomena. In particular we show that the dynamics of a laser driven Rydberg gas in the limit of strong dephasing is described by a master equation with manifest kinetic constraints. The equilibrium state of this system is uncorrelated but the constraints in the dynamics lead to spatially correlated collective relaxation. Such intricate dynamics in the presence of trivial thermodynamics is typical for glassy systems.

Quantum Quench in an atomic one-dimensional Ising chain

Florian Meinert, *Universität Innsbruck, Technikerstrasse 25/4 Innsbruck, Austria*

We study correlated tunneling dynamics for an ensemble of tilted 1D Mott chains after a quench to the vicinity of the Ising paramagnetic to antiferromagnetic phase transition point. The quench results in coherent oscillations for the orientation of effective Ising spins. We characterize the quench by varying the system parameters and report on collective effects. When the tilt is tuned to integer fractions of the Mott gap, we observe higher-order many-body tunneling over up to 5 lattice sites.

Quantum trajectories making use of all the information in measurement records.

Klaus Mølmer, *Aarhus University, Department of Physics and Astronomy Aarhus C, Denmark*

The evolution of a continuously probed quantum system is referred to as a quantum trajectory. We discuss how to infer unknown parameters, and we derive resolution limits by detection of, e.g., light emitted by atomic systems. Probing affects not only the current state but also the quantum state of a system in the past and we discuss how a theory of past quantum states may yield useful information in precision metrology [1-3].

[1] PRA 87, 032115 (2013)
[2] arXiv:1310.5802
[3] PRL 111, 160401 (2013)

Entangled ions in an optical cavity

Tracy Northup, *Institut für Experimentalphysik, Technikerstrasse 25/4 Innsbruck, Austria*

Optical cavities provide a coherent interface between light and matter that can be used to link remote quantum systems. With such an interface, quantum information can be mapped from a single atom onto a photon for long-distance transport, and an atom can be entangled with a cavity photon as a resource for teleportation. However, in a quantum network, it would be advantageous for each cavity to contain not just a single atom, but rather several. Multiple atoms within a cavity could be used for local quantum information processing, error correction between network nodes, and improved quantum memories, among other tasks.
I will describe the coupling of two calcium ions to the mode of a high-finesse optical cavity and how the interaction strength of each ion within the cavity can be controlled. When both ions are coupled with near-maximum strength, we entangle the ions with one another: each ion generates a cavity photon, and the measurement of two orthogonally polarized photons heralds entanglement. Parity oscillations of the ions are used to bound the entanglement fidelity. I will then discuss applications of entangled ions in a cavity for both quantum information tasks and the investigation of open quantum systems.

Entanglement of non-gaussian atomic states generated with bifurcation squeezing

Markus Oberthaler, *Kirchhoff Institut für Physik, Im Neuenheimer Feld 227 Heidelberg, Germany*

We report on the generation of spin squeezed states by employing the quantum dynamics close to an unstable fixed point of the underlying classical dynamics. This new method allows the generation of 6dB spin squeezed states on a short time scale. In the later evolution the states loose coherent spin squeezing and thus entanglement cannot be flagged by a mere variance analysis. Therefore we implemented a novel method based on distances of distribution functions for the extraction of the Fisher information of mesoscopic ensembles. With that we have confirmed that entanglement is still present.

Room temperature atomic ensembles: from deterministic teleportation to single photon networks

Eugene Polzik, *Niels Bohr Institute, Blegdamsvej 17 Copenhagen, Denmark*

Room temperature atomic ensembles in spin protecting environment have proven to be a fruitful platform for quantum networks [1]. In a recent experiment we have demonstrated deterministic teleportation of atomic spin states between two remote ensembles [2]. Due to the deterministic character of the protocol, teleportation of spin dynamics becomes possible [3]. The experiments so far have been conducted with ensembles contained in rather large cells and have been limited to operation on Gaussian states. In order to extend room temperature quantum networks to non-Gaussian states we have developed a new technology of fabrication of atomic microcells having dimensions compatible with transverse dimensions of an optical resonator mode. With the coherence time approaching 10 milliseconds and the optical depth exceeding one hundred such ensembles become promising candidates for scalable quantum networks and simulators [4].

[1] Quantum interface between light and atomic ensembles. K. Hammerer, A. Sørensen, and E.S. Polzik. Reviews of Modern Physics. 82, 1041–1093 (2010).
[2] Deterministic quantum teleportation between distant atomic objects. H. Krauter, D. Salart, C. A. Muschik, J. M. Petersen, Heng Shen, T. Fernholz, and E. S. Polzik. Nature Phys., 9, 400 (2013).
[3] Quantum Teleportation of Dynamics and Effective Interactions Between Remote Systems. C. A. Muschik, K. Hammerer, E. S. Polzik, and I. J. Cirac. Phys. Rev. Lett., 111, 021103 (2013)
[4] M. Zugenmaier, J. Borregaard, A. S. Sørensen, J. Appel and E. S. Polzik. In preparation.

Coupling, controlling, and processing non-transversal photons with a single atom

Arno Rauschenbeutel, *Vienna Universtiy of Technology, Stadionallee 2 Wien, Austria*

I will report on the interaction of single rubidium atoms and a whispering-gallery-mode (WGM) bottle microresonator. We discovered that the non-transversal polarization of WGMs fundamentally alters the physics of light-matter interaction. Taking advantage of this effect, we demonstrated switching of signals between two distinct optical fibers controlled by a single atom. Furthermore, we implemented a single-atom-controlled polarization flip of the light and realized an optical Kerr nonlinearity that leads to a pi nonlinear phase shift for single fiber-guided photons.

Cavity QED with photons outside the cavity

Gerhard Rempe, *Max Planck Insitute of Quantum Optics, Hans-Kopfermannstr. 1 Garching, Germany*

The coherent control of flying photons with single atoms requires a large optical nonlinearity which so far has only been achieved in cavity quantum electrodynamics (QED). However, cavity QED usually deals with photons trapped between highly reflecting mirrors, a situation which is not readily compatible with photons flying outside the cavity. The solution is to implement an asymmetric Fabry-Pérot cavity in which the higher-transmission mirror serves as an input/output coupler. With a single atom trapped inside the cavity, we have used such setup to efficiently detect a flying photon without destroying it [1]. We have also employed it to demonstrate for the first time protocols of scalable quantum computation and quantum communication based on photonic links between remote quantum processors. These protocols include the first implementation of a quantum gate between an atom and a photon, initially separated and finally entangled, and the first generation of a nonlocal three-particle state with one atom and two photons.

[1] A. Reiserer, S. Ritter, and G. Rempe, Science 342, 1349 (2013)

Fluctuation-dissipation relations in isolated quantum systems after a quench

Marcos Rigol, *Penn State, 104 Davey Lab, PMB #109 University Park, PA USA*

Recent studies have shown that observables in isolated quantum systems far from equilibrium relax to the predictions of traditional statistical ensembles [1,2], which is a result of eigenstate thermalization [1-4]. In integrable systems, on the other hand, observables relax to nonthermal values that can instead be described by generalized Gibbs ensembles (GGEs) [5]. We review some of the early results on this topic and examine whether standard fluctuation dissipation relations apply after relaxation following a quantum quench. We focus on the dynamics of trapped hard-core bosons in one-dimensional lattices with dipolar interactions [6].

[1] M. Rigol, V. Dunjko, and M. Olshanii, Nature 452, 854 (2008)
[2] M. Rigol, Phys. Rev. Lett. 103, 100403 (2009)
[3] J. M. Deutsch, Phys. Rev. A 43, 2046 (1991)
[4] M. Srednicki, Phys. Rev. E 50, 888 (1994)
[5] M. Rigol, V. Dunjko, V. Yurovsky, and M. Olshanii, Phys. Rev. Lett. 98, 050405 (2007)
[6] E. Khatami, G. Pupillo, M. Srednicki, and M. Rigol, Phys. Rev. Lett. 111, 050403 (2013)

Superconducting Vortex Lattices for Ultracold Atoms

Oriol Romero-Isart, *IQOQI & UIBK, Technikerstr. 21a Innsbruck, Austria*

We propose and analyze a nanoengineered vortex array in a thin-film type-II superconductor as a magnetic lattice for ultracold atoms. This proposal addresses several of the key questions in the development of atomic quantum simulators. By trapping atoms close to the surface, tools of nanofabrication and structuring of lattices on the scale of few tens of nanometers become available with a corresponding benefit in energy scales and temperature requirements. This can be combined with the possibility of magnetic single site addressing and manipulation together with a favorable scaling of superconducting surface-induced decoherence.

Light-cone like spreading of entanglement

Christian Roos, *IQOQI Innsbruck, Botanikerstrasse 19 Innsbruck, Austria*

In quantum-many body systems with finite-range interactions a maximum speed exists at which quantum correlations can propagate. I will present experiments with up to 15 ions realizing an Ising model with variable range spin-spin interactions. After a local quench, we observe the light-cone like ejection of entangled quasi-particles. By local measurements we demonstrate the quantum nature of the correlations and investigate the breakdown of the light-cone picture for long-range interactions.

Strongly Correlated Bose and Fermi Gases

Christophe Salomon, *ENS, 24 rue LHOMOND Paris, France*

In the recent years, ultra-cold atoms have established a very fruitful connection with condensed matter physics, nuclear physics, and astrophysics. Thanks to the tunability of the atomic interactions offered by magnetic Feshbach resonances, atomic lithium 7 and lithium 6 gases can be brought to the strongly correlated regime. In this talk, we will present recent results on strongly correlated Fermi and Bose gases. For a system in thermal equilibrium, the thermodynamic equation of state (EoS) is a central quantity for describing macroscopic properties of the system. Expressing the EoS in the grand canonical ensemble enables a very simple connection with experimental quantities such as the in-trap position distribution [1]. Precision measurements of the Equation of State of a tunable Fermi gas in the crossover between Bose Einstein condensation of strongly bound pairs and traditional Cooper pairing for weak attractive interactions reveal several properties of the gas such as the superfluid phase transition, the Lee-Yang and Lee-Huang-Yang (LHY) beyond mean field effects or the properties of Fermi polarons. Quantitative comparisons with advanced many-body theories developed for a uniform gas can now be made a the few percent level.
The EoS of low temperature bosons for large repulsion between particles also reveals the LHY quantum corrections [2]. However, unlike fermions, strongly interacting bosons suffer from large inelastic losses due to three-body recombination. We have measured the lifetime of a tunable Lithium 7 Bose gas at and around unitarity. Good agreement is found with an exact theory valid for arbitrary temperature and negative scattering length in the non-degenerate regime [3]. Our theory also predicts that new Efimov resonances in Lithium 7 and Cesium 133 should be observable.
Finally we will present recent results on the production of mixtures of superfluid bosons and strongly interacting fermions.

[1] S. Nascimbène *et al.*, Nature 463, 1057 (2010)
[2] N. Navon *et al.*, Phys. Rev. Lett. 107, 135301 (2011)
[3] B. Rem *et al.*, Phys. Rev. Lett. 110, 163202 (2013)

Fast ion transports and splitting operations in a segmented trap and the deterministic extraction of single ions for nm-microscopy and doping

Ferdinand Schmidt-Kaler, *Univ. Mainz, Ermlandstr. 14 Neu-Ulm, Germany*

Ions confined in a Paul trap arrange in linear crystals and allow for a unique control and analysis. Segmented traps provide the promising architecture for a future quantum computer, supposed that transport and the splitting of ion crytsals can be performed faster than quantum logic gate operations while the ion's motional state still allows for high-quality gates. I report experiments of ultra-fast transport [1], theory and experiments of fast splitting operations [2]. The ions may be transported inside the trap, or even extracted in free space via pierced endcap electrodes, focused by a electrostaic Einzel lens and used for single-ion microscopy. We observe a 8.6nm focal spot which we scan over transmission objects (see Fig) [3]. Further applications such as deterministic doping at a nm scale or ion interferometry are also discussed.

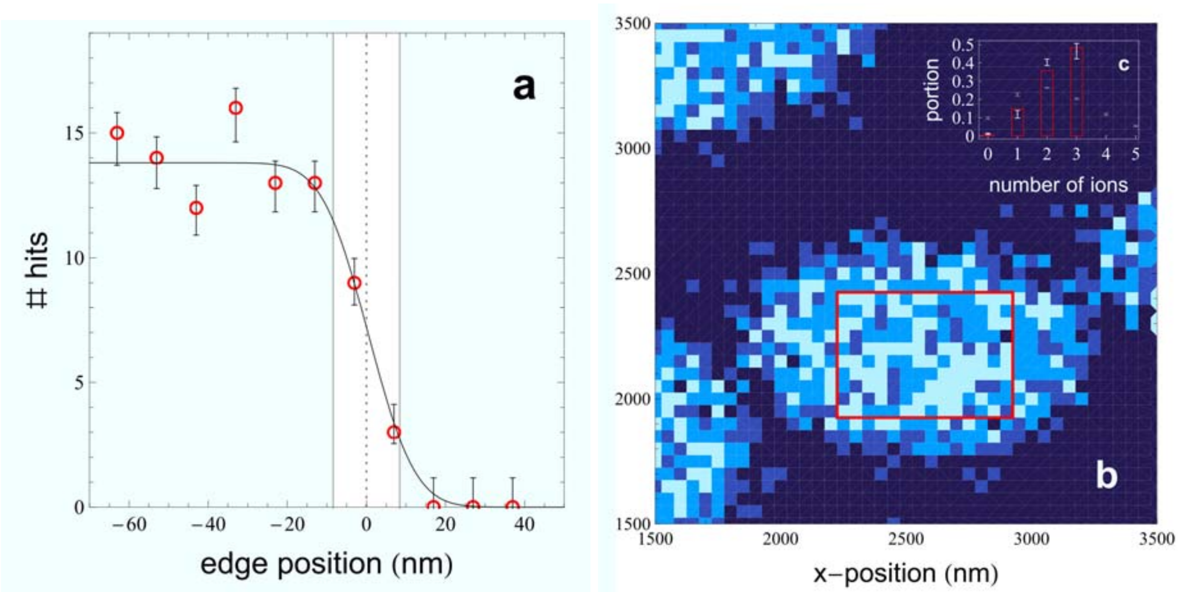

Figure: a) 8.6nm single ion waist determination with a knife edge b) single ion transmission microscopy of 1µm diam. holes, using a pixel size 50nm x 50 nm and 3 ion shots per pixel, c) histogram of strongly sub-Poisson counting statistics (red) as compared with the expected Binomial and the much broader Poisson statistics.

[1] A. Walther, et al, "Controlling fast transport of cold trapped ions",
Physical Review Letters 109, 080501 (2012). F. Ziesel, T et al, "Experimental creation and analysis of displaced number states", Journal of Physics B 46, 104008 (2013).
[2] H. Kaufmann et al, T. Ruster et al, to be published
[3] G. Jakob et al, to be published.

From Optical Lattice Gases towards Photonic Quantum Fluids

Jonathan Simon, *University of Chicago, 929 East 57th St. GCIS E207 Chicago, Illinois USA*

Low dissipation, strongly interacting material systems are an exciting frontier in condensed matter physics. Building upon lattice microscopy techniques successfully applied to atomic gases, my group is working to engineer photonic quantum fluids in a strongly interacting, topologically non-trivial regime that is compatible with particle-resolved imaging. To this end, I will present our ongoing efforts to realize 2D photonic gases in high-finesse optical resonators, and techniques to mediate inter-particle interactions via Rydberg-dressing. I will then describe several approaches we are investigating to realize synthetic spin-orbit coupling of photons, as well as a promising method to break time-reversal symmetry and realize a single lowest-Landau level for photons. Such a system will enable high-resolution, time-resolved studies of emergent crystallization and fractional quantum hall physics.

Quantum networks and quantum information with spins in diamond

Tim Hugo Taminiau, *Kavli Institute of Nanoscience, PO Box 5046 Delft, Netherlands*

The nitrogen vacancy (NV) center in diamond is a promising candidate to realize quantum networks consisting of multi-qubit nodes optically linked over large distances. In this talk, I will present our recent progress towards this goal. First, I will present the control and entanglement of multi-qubit nodes of nuclear spins in the NV environment, including the realization of a quantum error correction protocol. Second, I will discuss our recent demonstrations of entanglement and deterministic teleportation between remote NV centers.

Critical velocity in 1D optical lattices, and strong coupling in plasmonic nanoparticle arrays

Päivi Törmä, *Aalto University, P.O.Box 15100 Aalto, Finland*

We simulate dynamics of fermions in a 1D lattice in a critical velocity scenario. The results are in striking contrast to higher dimensions: superfluidity is broken for slow velocities of the perturbation and preserved for fast ones. As a second topic, we present our experimental demonstration of strong coupling between molecules and plasmonic lattice resonances in metal nanoparticle arrays.

Temperature diagnostics of cold trapped molecular ions

Roland Wester, *University of Innsbruck, Technikerstr 25 Innsbruck, Austria*

This talk will discuss cooling and heating of molecular ions trapped in radiofrequency multipole ion traps filled with cold buffer gas. Bound-bound, bound-free and evaporative loss measurements have been used to determine translational and rotational temperatures of the trapped ions. These data are important to improve the internal cooling and provide optimal starting conditions for high resolution spectroscopy of low-lying rovibrational levels.

Dicke Quantum Phase Transition with a BEC in a Ring Resonator

Claus Zimmermann, *Universität Tübingen, Auf der Morgenstelle 14 Tübingen, Germany*

We experimentally investigate the dynamical instability of a Bose Einstein condensate in an optical ring resonator for various cavity detuning and pump powers. The resulting phase diagram is asymmetric with respect to the cavity detuning and can be described by the coupling of two atomic modes with one optical mode. For positive and negative pump cavity detuning diferent coupling mechanisms are identifed.

Posters

Braiding of Atomic Majorana Fermions and Implementation of the Deutsch-Jozsa Algorithm

Mikhail Baranov, *ITP, University of Innsbruck, Technikerstr. 21a Innsbruck, Austria*

We propose an efficient protocol for braiding atomic Majorana fermions in wire networks based on the possibility of local site addressing available in current AMO experiments, and demonstrate its robustness against experimentally relevant errors. As an application of this protocol we implement the Deutsch-Jozsa algorithm for two qubits in a topologically protected way.

Verification of quantum computation

Stefanie Barz, *University of Vienna, Boltzmanngasse 5 Vienna, Austria*

The concept of quantum computation opens up fundamental questions, among them the issue of whether quantum computations can be certified by entities that are inherently unable to compute the results themselves. Here we present the first experimental verification of quantum computation. We show, in theory and experiment, how a verifier with minimal quantum resources can test a significantly more powerful quantum computer.

Preading of correlations at finite temperatures

Lars Bonnes, *ITP / University of Innsbruck, Technikerstr. 25 Innsbruck, Austria*

We study the quench dynamics in finite-temperature states using METTS. The velocity of the light-cone in the spreading of correlations in the XXZ chain strongly depends on the initial temperature and nature of the quench. We provide numerical evidence that the velocity, however, is solely determined by the amount of excess energy put into the system. This observation is thus highly relevant with respect to current out-of-equilibrium experiments in cold atomic gases.

Dicke Quantum Spin and Photon Glass in Optical Cavities

Michael Buchhold, *ITP University of Innsbruck, Technikerstraße 25 Innsbruck, Austria*

Stimulated by recent studies of strongly interacting atoms and photons in optical cavities, we analyze the dissipative multi-mode Dicke model and identify a spin glass as a possible steady state of the system. The glassy system shows low frequency thermalization, unusual spectral behavior of the atoms and strong competition between relaxational and reversible dynamics. Mapping the spin glass physics onto the cavity photons makes the glass physics detectable via photon output measurements.

Heralded Entanglement of Two Ions in an Optical Cavity

Bernardo Casabone, *Institut für Experimentalphysik, technikerstrasse 25/4 Innsbruck, Austria*

We show precise control of the coupling of each of two trapped ions to the mode of an optical resonator. When both ions are coupled with near-maximum strength, we generate ion-ion entanglement heralded by the detection of two orthogonally polarized cavity photons. The entanglement fidelity with respect to the Bell state Ψ^+ reaches $F \geq 91.9 \pm 2.5$ %. This result represents an important step toward distributed quantum computing with cavities linking remote atom-based registers.

Photonic tuning of viscosity in a superfluids

Peter Domokos, *Wigner Research Centre for Physics, Konkoly Thege Miklós u. 29-33 Budapest, Hungary*

We show that the damping of a selected collective excitation mode of a homogeneous Bose superfluid can be tuned by means of a designed interaction with the electromagnetic radiation field sustained by an optical cavity. We find that the ultimate quantum friction of the collective mode in the superfluid, which does not vanish even at zero temperature, can be made arbitrarily small. This phenomenon is in accordance with recent experimental observations.

Cooperative effects between three-level systems in two-photon and scattering resonances

Nicolae Enaki, *IFA, ASM, MD, Academiei Str. 5, IFA, Chisinau, R. Moldova*

The collective decay effects between the dipole active three-level subsystems in the nonlinear interaction with dipole forbidden transitions is proposed, taking into consideration the cooperative scattering and two-photon resonances through vacuum field. One of them corresponds to the situation when the total energy of the emitted two photons by the three-level radiator in the cascade configuration enters into the two-photon resonance with the dipole-forbidden transitions.

Quantum Entanglement of Complex Photon Polarization Patterns in Vector Beams

Robert Fickler, *Uni Wien/ IQOQI Wien, Boltzmanngasse 5 Vienna, Austria*

We efficiently create hybrid entanglement between vector photons with arbitrary complex polarization patterns and polarization encoded photons. With our recently developed coincidence-imaging technique we investigate the resulting complex entanglement patterns. Hereby, we are able to visualize the different strengths of three popular entanglement tests and demonstrate a novel feature: vector photons are entangled and separable in polarization dependent on the transverse spatial position.

Composite pulses and interferometric cooling in a cold atom cloud

Tim Freegarde, *University of Southampton, Highfield Southampton, Hampshire United Kingdom*

Large-area atom interferometers require fidelity to be maintained throughout a sequence of pulsed interactions despite a variety of inhomogeneities and dephasing processes. We have applied NMR composite-pulse techniques to velocity-sensitive Raman transitions in atomic Rb, and find significantly improved fidelity and fine agreement of temporal and spectral characteristics with simple theoretical models. A first application to interferometric cooling appears to halve the cold atom temperature.

Multistage Temporal Accelerating Beams

Moti Fridman, *Bar Ilan University, Building 1104 room 442 Ramat Gan, Israel*

We will present experimental results of novel accelerating beams in the time domain where the acceleration is performed in two stages rather than one. This enables us to break the limit of acceleration which is determined by the finite aperture.

Spin Ice with Rydberg dressed atoms

Alexander Glätzle, *IQOQI, Technikerstrasse Innsbruck, Austria*

We present a discussion of quantum spin ice, which represents a paradigmatic example on how the physics of frustrated magnets is related to gauge theories. The goal is to assemble a system of cold Rydberg atoms and to design interactions that realize a toy model of quantum spin ice on a two-dimensional checkerboard lattice. In particular, we exploit the strong angular dependence of Van-der-Waals interactions between high angular momentum Rydberg states.

Two-Photon Rydberg Excitation of Trapped Strontium Ions

Markus Hennrich, *University of Innsbruck, Technikerstr. 25 Innsbruck, Austria*

Trapped Rydberg ions are a novel approach for quantum information processing. This idea will join the advanced quantum control of trapped ions with the strong dipolar interaction between Rydberg atoms. It promises to speed up entangling interactions and to make such operations possible in larger ion crystals. We will present our progress to realise such a system of trapped Rydberg ions. In particular, this includes a two-photon excitation scheme of Sr^{+} ions into the Rydberg state.

Entanglement Swapping over a 143 km free-space link

Thomas Herbst, *Universität Wien, Boltzmanngasse 3 Vienna, Austria*

Entanglement swapping is a quintessential prerequisite of many quantum-information protocols as it can be used to create entanglement between formally completely independent particles. Our work proofs the feasibility of ground-based free-space entanglement swapping. We achieved coincidence production rates and fidelities to cope with the optical link attenuation, which will arise in a quantum transmission between a ground-based transmitter to a low-earth-orbiting satellite receiver.

Double-loop microtrap array for ultracold atoms

Bin Jian, *York University, 4700, Keele Street Toronto, Canada*

A linear microtrap array was developed where each microtrap consists of two concentric loops carrying oppositely oriented currents [1]. About 10^5 ^{87}Rb atoms were loaded into each microtrap from a surface MOT or alternatively using a FORT. The position of the microtrapped atom cloud could be precisely adjusted using a bias magnetic field over a distance of 350 to slightly less than 50 µm from the atom chip surface.

[1] Applied Physics B: Lasers & Optics. DOI 10.1007/s00340-013-5573-4, 2013

Spin-orbit coupling for cold atoms without light

Gediminas Juzeliunas, *Vilnius University, A. Gostatuto 12 Vilnius, Lithuania*

We a analyse a method of producing the Rashba-type spin-orbit coupling (SOC) for ultra cold atoms without involving light [1]. The method relies on a sequence of magnetic pulses imprinting phase gradients in different directions at specified times. This can generate not only a conventional two-dimensional Rashba SOC, but also its three-dimensional counterpart which has no analogue for electrons in solids.

[1] B. M. Anderson, I. B. Spielman and G. Juzeliunas, Phys. Rev. Lett. 111, 125301 (2013)

Nonthermal Fixed Points and Superfluid Turbulence in Ultracold Bose Gases

Markus Karl, *Heidelberg University, Philosophenweg 16 Heidelberg, Germany*

Turbulence appears in situations in which, e.g., an energy flux goes from large to small scales where finally the energy is dissipated. As a result the distribution of occupation numbers of excitations follows a power law with a universal critical exponent. The situation can be described as a nonthermal fixed point of the dynamical equations. We present numerical and analytical studies thereof. Specifically, in spinor gases we discuss the phenomenon in presence of a quantum phase transition.

Early Universe Dynamics with Cold Atoms

Valentin Kasper, *ITP Heidelberg, Philosophenweg 16 Heidelberg, Germany*

The decay of the inflaton field leads to an explosive particle production in many cosmological models. This effect is usually explained by parametric resonance of the inflaton. On the other hand, recent atomic twin-beam experiments showed parametric matter wave amplification. These similar resonance phenomena hint at a related underlying mechanism. The following work investigates possible mappings of inflation models to atomic systems, which would allow studying the dynamics of the early universe with ultra-cold atomic experiments.

Measuring higher-order interferences with a five-path interferometer

Thomas Kauten, *Inst. for Exp.phys./Innsbruck University, Technikerstraße 25 Innsbruck, Austria*

I will present results of a five-path interferometer experiment with the goal of putting a bound on the potential magnitude of higher order interference. This experiment was first proposed for three paths by Sorkin in 1994. Our experiment expands this to five paths, which not only allows us to measure third and fourth order interference terms but also allows testing for the possibility of quantum mechanical wavefunctions based on quaternions or octonions rather than complex numbers.

A novel experiment for coupling quantum gases with two crossed cavity modes

Julian Leonard, *ETH Zurich, Schafmattstrasse 16, IQE HPF D18 Zurich, Switzerland*

We present a novel experimental system for coupling quantum gases to optical cavities by means of an interchangeable science platform to switch between different cavity setups while maintaining ultra-high vacuum conditions. This highly flexible approach allows to study various cavity geometries, such as crossed cavities, multimode cavities or setups involving mechanical membranes, with a single apparatus. Using this system, we present our progress in coupling a BEC with two crossed cavity modes.

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

Rianne Lous, *IQOQI, Technikerstraße 21a Innsbruck, Austria*

We investigate a mixture of ultracold fermionic ^{40}K atoms and weakly bound ^{6}Li-^{40}K dimers on the repulsive side of a heteronuclear atomic Feshbach resonance. By radio-frequency spectroscopy we demonstrate that the normally repulsive atom-dimer interaction is turned into a strong attraction. The phenomenon can be understood as a three-body effect in which two heavy ^{40}K fermions exchange the light ^{6}Li atom, leading to attraction in odd partial-wave channels (mainly p-wave).

Coherent Oscillations in the Strong Coupling Regime of Cavity QED

Johannes Majer, *TU Wien/Atominstitut, Stadionallee 2 Wien, Austria*

Hybrid quantum systems and circuit QED have been a promising candidate in building robust experiments for exploring cavity quantum electro dynamics and developing future technologies such as quantum information. We demonstrate the strong coupling of an ensemble of nitrogen vacancy spins to a superconducting resonator. Furthermore we study coherent oscillations and the transition between the non- and markovian regime. Additionally we couple two distant ensembles via the resonator.

Doublon stability and decay mechanisms

Manfred J. Mark, *Universität Innsbruck, Technikerstr. 25/4 Innsbruck, Austria*

We prepare and study doublons formed by two bosons in an optical lattice at attractive or repulsive interactions. Around zero interactions we observe a rapid decay of doublons as the binding energy vanishes. For large repulsive interactions a decay of doublons is observed, whereas such a decay is absent for attractively bound doublons. Analysing the loss of doublons and the total atom number reveals off-resonant three-body loss as one decay mechanism for large repulsive interactions.

Quantum walks in an arrays of optical waveguides

Alexey Melnikov, *IQOQI, Technikerstraße 21a Innsbruck, Austria*

The structures of optical waveguides are considered. Waveguides are coupled through tunneling and can be fabricated in fused silica by femtosecond laser pulses. The relation between the probability of photon tunneling and the waveguides configuration was analytically obtained. We studied the decoherence process and calculated the waveguides length on which the quantum effects are preserved. Entanglement dynamics for distinguishable and indistinguishable photons was computed.

Exceptional Point Phenomena in Optomechanical Systems

Thomas Milburn, *Atominstitut, TU Wien, 22/25 Haberlgasse, Vienna, Austria*

Dissipative optomechanical (OM) systems may be described by a non-Hermitian dynamical matrix. For example, two mechanical oscillators coupled via a driven cavity. The spectrum of such a matrix is in general complex and may therefore exhibit branch points. In the literature such branch points are called exceptional points (EPs). EPs give rise to many interesting phenomena; most notably, PT symmetry breaking and diode behaviour. We investigate EP phenomena for OM systems and present new insights.

Operations on an encoded 7-qubit quantum-register

Thomas Monz & Daniel Nigg, *Institute for Experimental Physics, Technikerstr. 25 Innsbruck, Austria*

Every quantum processor is affected by noise from the environment and imperfections of the gate operations. The essential method to correct for these errors and therefore enabling fault tolerant quantum computation is known as quantum error correction. Here we report on the experimental realization of a quantum error correcting code, where a logical qubit is encoded within 7 ion-qubits. This corresponds to the minimal instance of a topological stabilizer code as well as the Steane code. We demonstrate the capability of detecting arbitrary single qubit errors by measuring the full syndrome table. Additionally, we show the application of multiple instances of all single-qubit Clifford operations on the logical qubit, which is the basic requirement for fault tolerant quantum computation.

Quantum interference of photons from single Rb87-atoms for long distance quantum communication

Norbert Ortegel, *Fakultät für Physik, LMU München, Schellingstraße 4/III München, Germany*

Two-photon interference is a key ingredient for many protocols in quantum communication such as quantum teleportation or entanglement swapping. We present results on quantum interference of single photons emitted by two independently trapped ^{87}Rb-atoms and examine which effects limit the interference contrast. This technique allowed us to successfully demonstrate quantum teleportation of the polarization state of photons from weak coherent laser pulses onto the spin state of a single atom.

Scattering approach to multicolour light forces and self-ordering of polarizable particles

Stefan Ostermann, *Institut für Theoretische Physik, Technikerstr, Innsbruck, Austria*

Collective coherent scattering of laser light by polarizable point particles creates long range interactions, whose properties can be tailored by choice of injected laser powers, frequencies and polarizations. We use a transfer matrix approach to study the forces induced by non-interfering pump fields of orthogonal polarization or different frequencies and find long range ordering of particles. Adjusting laser frequencies and powers then allows to tune inter-particle distances and dynamics.

Chiral system-reservoir interaction using spin orbit coupled cold atoms

Hannes Pichler, *Institut für Theoretische Physik, Technikerstr 21a Innsbruck, Austria*

We study the possibility to engineer exotic types of reservoirs for cold atoms in optical lattices. In particular we are interested in engineering a cascaded quantum system in a cold atom setup. The key ingredient in our proposal to realise a unidirectional system-reservoir interaction is to use a 1D spin-orbit coupled quasi-BEC as a reservoir for a second species of atoms moving in the lowest two Bloch bands of a 1D optical lattice. The chiral nature of this reservoir allows us to find a regime such that the system couples only to excitations moving along one direction, but not the other.

PT-symmetry breaking transitions in coupled phonon-laser arrays

Peter Rabl, *Atominstitut, TU Wien, Stadionallee 2 Vienna, Austria*

We describe the dynamics of a PT-symmetric coupled phonon lasers array with alternating gain and loss of equal strength. The different phases in such a system are described for small and large arrays and a possible implementation using NV centers in diamond nanostructures is discussed.

Towards a Fermi-Fermi mixture of dysprosium and potassium

Cornee Ravensbergen, *IQOQI, Technikerstr. 21a, Innsbruck, Austria*

Ultracold Fermi-Fermi mixtures with tunable interactions represent an intriguing test bed for exploring the physics of strongly interacting many-body quantum systems and few-body quantum states. Two-species Fermi gases extend the variety of phenomena thanks to mass imbalance. This motivates us to construct a dysprosium – potassium experiment exploiting the favorable mass ratio of 4. The two naturally abundant fermionic dysprosium isotopes offer an additional degree of freedom to our system.

Nondestructive Detection of an Optical Photon

Andreas Reiserer, *Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1 Garching, Germany*

We demonstrate a robust photon detector which does not rely on photon absorption. Instead, impinging light is reflected off an optical resonator containing a single atom in a superposition of two states. Upon reflection of a single photon, the phase of the superposition state is flipped, which unambiguously allows us to nondestructively detect the photon. The presented single-photon nonlinearity paves the way towards photonic quantum gates and the preparation of novel quantum states of light.

Superradiant clock laser in a magic wavelength lattice

Helmut Ritsch, *Universität Innsbruck, Technikertsr. 25 Innsbruck, Austria*

An ideal superradiant laser operating on an optical clock transition of a noninteracting ensemble of cold trapped atoms is predicted to exhibit extreme frequency stability and acurracy far below mHz linewidth. In any concrete setup a sufficiently large number of atoms have to be confined and optically pumped within an optical cavity and will also interact directly via dipole-dipole coupling. Collective spontaneous emission suppression can lead to sub-radiant line narrowing in such a laser.

A universal matter wave interferometer in the time-domain

Jonas Rodewald, *University of Vienna, Boltzmanngasse 5 Vienna, Austria*

We demonstrate an optical time-domain matter-wave interferometer (OTIMA) for atoms, clusters and molecules which utilizes three pulsed optical gratings. Operating the interferometer in the time-domain brings a decisive gain in count rate, visibility and measuring precision. The OTIMA promises to be a powerful tool to probe quantum theory on an increasingly large mass scale in the quest for novel decoherence effects, such as continuous spontaneous localization (CSL).

Scaling of phonons and shortcuts to adiabaticity in a one-dimensional quantum system

Wolfgang Rohringer, *Atominsititut / TU Wien, Erdbergstraße 30/6 Wien, Wien Austria*

For a certain class of quantum many-body systems, nonequilibrium states after a quench have been conjectured to be connected to the initial equilibrium state by a scale transformation. We present temperature measurements on quasi-1d Bose gases after a quench of the trapping potential, finding a power law dependence on the spatial extension of the cloud, as predicted by the scaling law. Further, we present an optimal control scheme to implement shortcuts to adiabaticity for quasi-1d Bose gases.

Heralded Entanglement of Widely Separated Atoms

Wenjamin Rosenfeld, *Faculty of Physics, University of Munich, Schellingstr. 4/III Munich, Germany*

We present our progress on establishing entanglement of two single trapped ^{87}Rb atoms over a distance of 400 meters. For this we combine atom-photon entanglement with the entanglement-swapping protocol, as recently demonstrated. Implementation of a fast detection of the atomic state will enable space-like separated measurements on the entangled atoms paving the way for new applications like a loophole-free test of Bell's inequality and, potentially, device-independent quantum key distribution.

Chain Bell Inequality violation for bright squeezed vacuum

Krzysztof Rosołek, *University of Gdańsk, Wita Stwosza 57 Gdańsk, Poland*

Quantum correlations manifest themselves in violation of Bell inequalities. We consider entangled bright squeezed vacuum a macroscopically populated superposition of light easily produced in laboratories and investigate the violation of Bell inequalities in a chain form. Here two observers, Alice and Bob subsequently apply one of the L measurement settings. The observables for the measurement are intensity differences in polarization modes. Our proposal is feasible within the current technology.

Sweeps to ordered states in a two-dimensional Rydberg gas

Peter Schauß, *MPQ, Hans-Kopfermann-Str. 1 Garching bei München, Germany*

Here we extend the ideas of coherent control and adiabatic passage to strongly interacting collective states of Rydberg atoms. We prepare a two-dimensional system of ground state atoms and couple them to a Rydberg state. The Rydberg atoms interact via the van der Waals force extending over half the system size, thereby leading to strong correlations. Guided by numerical optimization we found laser sweeps that created self-organized many-body states with spatially ordered Rydberg excitations.

On the increasing fragility of quantum superpositions of easily distinguishale states

Pavel Sekatski, *Innsbruck University, Institut für Theoretische Physik ,Innsbruck, Austria*

We consider the pairs of states which can be distinguished with measurement devices lacking of microscopic accuracy, suffering from coarse-gaining or limited sensitivity. We show that in order to prove that a superposition of such states is not a statistical mixture one has to fulfill severe requirements on the control of the measurement setup. The more distinguishable are the two states, the more demanding are the requirements.

Nanoparticle sources for quantum interference and cavity cooling experiments

Ugur Sezer, *University of Vienna/ Faculty of Physics, Boltzmanngasse 5, Vienna, Austria*

Neutral and slow nanoparticle beams are essential for novel cooling and quantum experiments in the regime of high mass (10^4-10^6 u) and ultrahigh mass (10^7-10^{10} u). We present a series of experiments characterizing different laser desorption and evaporation sources in combination with UV (266 nm) and VUV (157 nm) photoionization. Our recent successes have been the intact photoionization of organic molecules beyond 24000 u and transverse cooling of free silicon nanoparticles in a cavity.

Two dimensional superfluidity in driven systems requires strong anisotropy

Lukas Sieberer, *University of Innsbruck, Technikerstr. 25 Innsbruck, Austria*

We show that driven two dimensional Bose systems can not exhibit algebraic superfluid order unless the underlying microscopic system is strongly anisotropic. Our result implies, in particular, that recent apparent evidence for Bose condensation of exciton-polaritons in semiconductor quantum wells must be an intermediate scale crossover phenomenon, while the true long distance correlations fall off exponentially.

Attractive optical forces from blackbody radiation

Matthias Sonnleitner, *Institut für Theoretische Physik, Technikerstraße 25, Innsbruck, Austria*

Thermal radiation around hot objects induces AC Stark shifts of the energy levels of nearby atoms and molecules. These shifts are roughly proportional to the fourth power of the temperature and induce a dipole force. Using the generic example of a ground state hydrogen atom interacting with a hot sphere we show that this force can surpass the repulsive radiation pressure and pull the atoms towards the surface with a small force.

Chip Integrated Nano-Fiber Atom-Photon Interface

Florian Steiner, *Atomic Institute, Stadionalle 2 Wien, Austria*

The combination of Atoms being magnetically trapped on atom-chips in a one dimensional fashion and nanofiber based (FBG) elongated cavities constitutes a unique platform to probe atom-photon interactions.Appl.: Strong nonlinear interactions between individual photons; Quantum Phase transitions; Fermionization of Photons;

Topological phases on optical flux lattices

Antoine Sterdyniak, *Institüt für Theoretische Physik - UIBK, Technikerstr. 25 Innsbruck, Austria*

Optical flux lattices models allow to realize artificial magnetic field in cold atom gases. In these models, the tight-binding model is realised in reciprocal space and leads to flat bands with non-zero Chern Number. We investigate in detail how these bands can lead to the emergence and stability of fractional quantum Hall states, like the Laughlin and Moore-Read states. We also show that novel topological phases could be observed in these systems as the Chern number can be greater than 1.

Ultracold RbCs

Tetsu Takekoshi, *IQOQI, Inst. für Experimentalphysik Innsbruck, Austria*

We give an update on ground state RbCs collision measurements and ongoing enhanced molecule production using an optical lattice.

Observation of optical nonlinearities at the single photon level

Jürgen Volz, *Atominstitut, TU Vienna, Stadionallee 2 Vienna, Austria*

In our experiment, we couple single ^{85}Rb atoms to a whispering-gallery-mode microresonator. Light propagating through a nanofiber coupled to the resonator acquires a photon number dependent phase shift with a phase-difference close to 180° between the one and two photon case. Combined with small optical losses, this allows the generation of high fidelity photon-photon interactions. We quantitatively investigate the performance of our system and its suitability for future quantum applications.

Numerical modeling of polaritonic BEC using Gross-Pitaevskii

Oksana Voronych, *University of Gdansk, Wita Stwosza 57 Gdansk, Poland*

The goal of this work is to deepen our understanding of the polaritonic Bose-Einstein Condesate (BEC), confined in a microcavity. Polaritons are short-living quasiparticles resulting from coupling photons with excitons. For mathematical description we use the Gross-Pitaevskii equation with spin. The Runge-Kutta method of fourth oder used for numerical calculations. Computations are performed for different parameters of the system.

A continuous centrifuge decelerator for polar molecules

Xing Wu, *Max-Planck-Institut für Quantenoptik, Has-Kopfermann-Str. 1 Garching, Germany*

Producing large samples of slow molecules from thermal-velocity ensembles is a formidable challenge. Here we employ a centrifugal force to produce a continuous molecular beam with high flux at near-zero velocities. We demonstrate deceleration of three electrically guided molecular species, from about 200m/s down to below 15m/s with intensities of several $10^9/(\mathrm{s \cdot mm^2})$. The centrifuge decelerator has the potential to become a standard technique for continuous deceleration of molecules.

Hybrid architecture for encoded measurement-based quantum computation

Michael Zwerger, *Universität Innsbruck, Technikerstrasse 21a Innsbruck, Austria*

We present a hybrid scheme for quantum computation that combines the modular structure of elementary building blocks used in the circuit model with the advantages of a measurement-based approach to quantum computation. The performance of the scheme is determined by the quality of the resource states, where within this error model we find a threshold of the order of 10% local noise per particle for fault-tolerant quantum computation and quantum communication.

Program Quantum Optics Conference Obergurgl 2014

	Sunday 23.02	Monday 24.02	Tuesday 25.02	Wednesday 26.02	Thursday 27.02	Friday 28.02	Saturday 01.03
8.20		Welcome					
8.30-9.00		Salomon	Polzik	Schmidt-Kaler	Roos (HT)	Rigol	return bus
9.00-9.30		Köhl	Rempe	Bollinger	Klempt (HT)	Kosloff	return bus
9.30-10:15		Coffee break					
10.15-10.45		Grimm	Rauschenbeutel	Northup	Dür	Wester	return bus
10.45-11.15		Oberthaler	Arndt	Dürr (HT)	Clausen (HT)	Ferlaino (HT)	return bus
11.15-12.00		Discussions					
12.00-15.30		Lunch + Discussions					
15.30-16.00		Coffee + Cake					
16.00-16.30		Gross	Kollath	Mølmer	Brune	Fallani	
16.30-17.00		Hemmerich (HT)	Simon	Taminiau	Romero-Isart	Campbell (HT)	
17.00-17.30	registration	Landig (HT)	Meinert (HT)	Bushev (HT)	Zimmermann (HT)	Törmä (HT)	
17.30-18.00	registration	Coffee break					
18.00-18.30	registration	Langen	Läuchli		Genes	Lesanovsky (HT)	
18.30-19.00	registration	Lechner	Chin		Gasenzer	Dalmonte (HT)	
19.15-20.30	Dinner	Dinner	Dinner	Conference Dinner	Dinner	Dinner	
20.30-22.00		Posters	Posters		Posters	Posters	