Oral Presentations

Thursday, December 15th

12:15 - 12:30:
The Austrian Quantum Initiative ESQ: Goals and Perspectives
Markus Arndt, University of Vienna, Speaker of the Erwin-Schrödinger-Center for Quantum Science and Technology

12:30 - 13:00
Preparing a Quantum Technologies European Flagship
Tommaso Calarco, University of Ulm

14:00 - 14:50
Quantum optimal control for quantum technologies, Invited talk
Tommaso Calarco, University of Ulm

14:50 - 15:15
Quantum optical networks with chiral couplings
Benoit Vermersch, IQOQI Innsbruck

We present new results on quantum optical networks with chiral couplings. A quantum network consists of nodes connected by quantum channels. In a quantum optical setup, the nodes are represented by two-level atoms (qubits) coupled to cavities, which in turn are coupled to 1D photonic waveguides as quantum channel with chiral (i.e. unidirectional) emission of photons.

In this talk I will focus on new results on quantum state transfer with chiral networks where the aim is a faithful transmission of states of a qubit from a first to a second node in the presence of a noisy (imperfect) quantum channel. We will demonstrate that a quantum protocol and corresponding cavity QED setup can be developed, which is a priori immune to noise injected into the quantum channel (waveguide), and we show a quantum error correction scheme which corrects for random photon loss and photon additions [1].

[1] B. Vermersch, P.O. Guimond, and P. Zoller, unpublished

16:10 - 17:00, Invited talk
An information-theoretic view on the foundation of quantum theory
Renato Renner, ETH Zürich

Information theory, apart from its many technological implications, also provides a novel view on the foundations of quantum mechanics. In this talk I will present a thought experiment motivated by information theory. The idea is to consider the consistency between the predictions made by different agents, who have access to different pieces of information. Under the assumption that any measurement has a single outcome (from the viewpoint of the agent who performs the measurement) this reasoning leads to a logical contradiction. This shows that various standard interpretations of quantum theory are not self-consistent.

17:00 - 17:25

Cavity-mediated effects in transport

Claudiu Genes, Max Planck Institute for the Science of Light (Erlangen, Germany), University of Innsbruck

Transport properties of materials (transport of charge, energy, correlations, etc.) can be considerably altered in the presence of strong light-matter interactions manifested in the strong coupling regime of cavity quantum electrodynamics. Recent experiments show that enhanced charge transport in organic semiconductor materials can occur [3] that can be simulated via a two-band model where the inter-band transitions are coupled to the confined light modes of a micro-cavity and consequent delocalized hybrid light-matter states participate in the transport.

In a simplified quantum optical model, where a single cavity light mode is equally coupled to a chain of two-level systems, we study the modification of the typical nearest neighbor hopping transport below and inside the strong coupling regime. We find in [1] (in agreement with [3]) that the polariton-enhanced transport can show polynomial instead of exponential suppression with the system size in the presence of disorder.

[1] J. Schachenmayer, C. Genes, E. Tignone and G. Pupillo, Phys. Rev. Lett., 114, 196403 (2015).
[2] J. Feist and F. J. Garcia-Vidal, Phys. Rev. Lett., 114, 196402 (2015).
[3] E. Orgiu, J. George, J.A. Hutchison, E. Devaux, J.F. Dayen, B. Doudin, F. Stellacci, C. Genet, J. Schachenmayer, C. Genes, G. Pupillo, P. Samorì, T.W. Ebbesen, Nat. Mat. 14, 1123 (2015).

Friday, December 16th

09:30 - 10:20, Invited talk

The Schrödinger Zoo

Klaus Mølmer, Aarhus University

With his famous cat paradox Erwin Schrödinger illustrated his deep frustration by the apparent quantum jumps and collapses in quantum systems subject to measurement, and as late as in 1952, he declared the mere idea of doing experiments with single quantum particles “as absurd as the one of raising Ichtyosauria in the Zoo”. On this subject Schrödinger was wrong, and a variety of single quantum systems are now available for experimental investigation.

Schrödinger may have been terrified to know that these systems are now candidates for applications in crucial technologies such as quantum information and quantum metrology. In this talk, I shall review theoretical methods to describe, control and understand the behavior of the cats and the Ichtyosauria in the quantum laboratory and show examples of how we can even benefit from their random quantum jump behavior.

10:25 - 10:45

A Superradiant Topological Peierls Insulator inside an Optical Cavity

Farokh Mivehvar, University of Innsbruck

We consider a spinless ultracold Fermi gas tightly trapped along the axis of an optical resonator and transversely illuminated by a laser closely tuned to a resonator mode. At a certain threshold pump intensity, the homogeneous gas density breaks a Z2 symmetry towards a spatially periodic order, which collectively scatters pump photons into the cavity. In this talk, we show that this known self-ordering transition also occurs for low field seeking fermionic particles when the laser light is blue-detuned to an atomic transition. The emergent superradiant optical lattice in this case is homopolar and possesses two distinct dimerizations. Depending on the spontaneously chosen dimerization the resulting Bloch bands can have a non-trivial topological structure characterized by a non-vanishing Zak phase. In the case the Fermi momentum is close to half the cavity-mode wavenumber, a Peierls-like instability here creates a topological insulator with a gap at the Fermi surface, which hosts a pair of edge states. The topological features of the system can be non-destructively observed via the cavity output: the Zak phase of the bulk coincides with the relative phase between laser and cavity field, while the fingerprint of edge states can be observed as additional broadening in a well-defined frequency window of the cavity spectrum.

10:45 - 11:10

A universal method of modeling thermal correlations of one-dimensional classical fields

Igor E. Mazets, Atominsitut (TU Wien)

A novel universal method for numerical simulation of correlations of interacting multi-component classical fields at thermal equilibrium in one dimension (1D) is developed. It is a generalization of our previously developed method to simulate thermal fluctuations of bosons in 1D in the harmonic approximation by the Ornstein-Uhlenbeck stochastic process. By invoking the equivalence between the classical transfer matrix approach, the Fokker-Planck equation, and the stochastic Ito equation, we developed a general way to simulate the classical thermal correlations of bosonic mean fields in 1D beyond the harmonic approximation by means of a stochastic process with a known diffusion coefficient and a regular "friction force" that can be determined from the ground-state solution of an auxiliary Schrödinger-type equation. We discuss the application of the method to the analysis of the equilibrium properties of two tunnel-coupled 1D quasicondensates, as well as its other future applications and extensions.

11:40 - 12:05

Flexible resources for quantum metrology

Nicolai Friis, University of Innsbruck

Quantum metrology offers a quadratic advantage over classical approaches to parameter estimation problems by utilizing entanglement and nonclassicality. However, the hurdle of actually implementing the necessary quantum probe states and measurements, which vary drastically for different metrological scenarios, is usually not taken into account. We show [1] that for a wide range of tasks in metrology, the 2D cluster state can serve as a flexible resource that allows one to efficiently prepare any required state for sensing, and perform appropriate (entangled) measurements using only single qubit operations. Crucially, the overhead in the number of qubits is less than quadratic, thus preserving the quantum scaling advantage. This is ensured by using a compression to a logarithmically sized space that contains all relevant information for sensing. We specifically demonstrate how our method can be used to obtain optimal scaling for phase and frequency estimation in local estimation problems, as well as for the Bayesian equivalents with Gaussian priors of varying widths.

[1] N. Friis, D. Orsucci, M. Skotiniotis, P. Sekatski, V. Dunjko, H. J. Briegel, and W. Dür, arXiv: 1610.09999 [quant-ph]

12:05 - 12:30

Atom-photon interactions at the speed of light

Giuseppe Calajo, Atominstitut (TU-Wien)

We analyze the coupling between moving atoms and photons inside a one dimensional waveguide in a regime, where the atomic velocities are comparable to the effective speed of light. Such conditions can be achieved, for example, in photonic crystals and coupled resonator arrays, where the maximal group velocity of the photons is bounded by the width of the propagation band, and can therefore be considerably lower than in free space. We show that the interplay between a velocity-induced directionality and the emergence of effective divergences in the photonic density of states gives rise to a range of intriguing phenomena in the emission of photons or in the exchange of photons between moving atoms. Apart from nanophotonic waveguides, we identify Rydberg atoms flying above a coupled array of superconducting microwave resonators as a promising experimental platform for exploring this new regime of pseudo-relativistic atom-light interactions.

12:30 - 12:55

Relations between bipartite entanglement measures

Katharina Schwaiger, University of Innsbruck

Entanglement is the resource to overcome the natural limitations of spatially separated parties restricted to local operations assisted by classical communication (LOCC) and hence, an entanglement measure is a function that is nonincreasing under LOCC. The source and the accessible entanglement are two operational entanglement measures, that are applicable for arbitrary multipartite (pure or mixed) states. Whereas the accessible entanglement characterizes the potentiality of a state to generate other states via LOCC, the source entanglement characterizes the simplicity of generating the state at hand. Here, we consider pure bipartite states and investigate the behavior of the source and accessible entanglement in terms of each other and also in terms of other well-known bipartite measures. For this we use a central theorem from real algebra, namely the Positivstellensatz, that gives a necessary and sufficient condition for when a system of polynomial equations and inequalities is empty. For instance, this method can be used to determine all possible values of the source and accessible entanglement that correspond to a physical state. Furthermore, with the Positivstellensatz we can prove for low-dimensionial bipartite states, that the source entanglement and certain generalizations of it (which are also valid entanglement measures) completely characterize the entanglement of these states.

12:55 - 13:20

Zizhu Wang, IQOQI Vienna

Entanglement and Nonlocality of 1D Macroscopic Systems

Abstract: We consider the problem of certifying entanglement and nonlocality in one-dimensional macroscopic systems when just averaged near-neighbor correlators are available. We map this question to the characterization of the set of all quantum states (distributions) which admit a separable (classical) Translation-Invariant (TI) extension to infinitely many sites. We advance the first problem by constructing a family of witnesses which can detect entanglement in infinite TI states from the nearest-neighbor reduced density matrix. Along the way, we identify a set of separable two-qubit states which only admit entangled TI extensions. For nonlocality detection, we show that the set of classical TI boxes forms a polytope and devise a general procedure to generate all Bell inequalities which characterize it. Through a Matrix Product State-based method, we show how some of them can be violated by distant parties conducting identical measurements on an infinite TI quantum state.

Poster Presentations

In-situ charge control of a silica optical nanofiber in an ion trap
Benjamin Ames, University of Innsbruck

A trapped ion confined within the evanescent field of an optical nanofiber could be a novel ion-photon interface for networking quantum information between registers. However, achieving the sub-micron ion-fiber distance required to observe coupling to the evanescent field remains problematic due to charges on the nanofiber surface. We report on in-situ techniques developed to mitigate the charge of the nanofiber. Using photoemission and anomalous field emission we are able to charge the fiber positively, while both positive and negative states can be obtained by means of electron flooding at different energies. These results can be applied to a variety of AMO experiments where charge control of dielectrics is desired.

Applications of states in the maximally entangled set
Yaiza Aragonés-Soria, University of Innsbruck

In the bipartite setting, the maximally entangled state is the Bell state. In the multipartite case, in contrast, there is no such unique state. However, the notion has been generalized by introducing the Maximally Entangled Set (MES) [2]. Its elements cannot be reached from any other state via LOCC and any state outside the MES can be obtained via LOCC from one state in the MES. For state transformation, the most relevant states in the MES are the convertible states, i.e., states that can be transformed to some other fully entangled state by deterministic LOCC. Here, we study these states to find an easy characterization and look into some applications. In particular, we work with the Choi-Jamiolkowski isomorphism to investigate the maps associated to the convertible states in the MES. For example, one potential application is their concatenation to build a network which can be used to create a multipartite entangled state."

Tomography of time-bin entangled photon pairs from a quantum dot
Philipp Aumann, University of Innsbruck

A quantum dot can be used as a source for time-bin entangled photon pairs [1]. The photons are detected and a post-selection scheme is applied together with a tomographic method [2,3] to reconstruct the photon's density matrix. We examine this system from a theoretical point of view using a quantum optical model that includes dissipation. With this we can predict the reconstructed density matrix and find an optimal choice for the system parameters in order to optimize the state of the emitted photons.

[1] T. Huber, et al., Phys. Rev. B 93, 201301(R) (2016)
[2] Hiroki Takesue and Yuita Noguchi, Opt. Express 17, 10976-10989 (2009)
[3] D. James, et al., Phys. Rev. A 64, 052312 (2001)

Entanglement Capabilities of Stabilizer States
Raphael Brieger, University of Innsbruck

Stabilizer states have a wide range of applications, they are used for example in quantum error correction, quantum-secret sharing and as initial resource for one-way quantum computing. Therefore, it is of practical interest to characterize their general usefulness as a resource for separated parties, that can manipulate their state only by local operations assisted by classical communication (LOCC). To this end we use the recently introduced accessible entanglement, which measures how many states can be reached by LOCC. We start by investigating the case of

2, 3 and 4 qubits, while our aim is to extend the analysis to more parties, in order to set a foundation for the discovery of further applications."

Dynamics of quantum causal structures
Esteban Castro Ruiz, University of Vienna

The process matrix formalism is an extension of the quantum framework that allows for the description of local experiments on indefinite causal structures. The process matrix, central object of the formalism, specifies possible signaling correlations between local observers, and includes quantum channels and quantum states as particular cases. Here we introduce a framework for the dynamics of process matrices, that is, for transformations of process matrices into process matrices. We show how these transformations generalize the concept of a process matrix itself. Furthermore, we explore the possibility of obtaining processes with an indefinite causal structure from processes with a definite causal structure via continuous, reversible transformations."

Randomized benchmarking of one-qubit and two-qubit operations in an ion-trap quantum computer
Alexander Erhard, University of Innsbruck

Randomized benchmarking provides a platform independent approach to characterize the performance of a quantum computer. Large scale quantum computers require quantum error correction, which can be realized using operations from the Clifford group. Hence we investigate the fidelity of one-qubit gates using operations from the Clifford group. For two-qubit gates we use operations from the Dihedral group. In both schemes we estimate the fidelity of a single gate from the decay of the fidelity with increasing gate sequence length.

Quantum mechanics in quantum reference frames
Flaminia Giacomini, University of Vienna

We are used to the picture that a quantum particle can be in a superposition of different states and entangled with other particles, showing striking differences to the classical world. But how does the world look like as seen by a quantum particle? The relational approach to physics suggests that the particle sees exactly the opposite: while for itself it appears classical; it is the world that is in quantum superposition for it. We develop quantum theory from within quantum reference frame (QRF), including the notion of state and measurement. We analyze how one can change the perspective from the classical external reference frame to a QRF, generalizing the coordinate transformation that we use for classical reference frames.

SLOCC hierarchy of generic 2 x m x n states
Martin Hebenstreit, University of Innsbruck

In [1] three-partite entanglement for the dimensions 2 x m x n has been studied and a connection to linear matrix pencils has been drawn. The SLOCC class of an arbitrary pure state in 2 x m x n can be found by calculating the Kronecker Canonical Form (KCF) of the corresponding matrix pencil. Furthermore, a full characterization of the SLOCC classes for 2 x m x n can be performed by considering all possible different KCFs of matrix pencils corresponding to these dimensions. Also, statements about non-invertible transformations can be made using the mapping from states to matrix pencils. In [1], the derived methods have been applied to fully characterize the hierarchy of SLOCC classes for 2 x 3 x n systems.

We recently developed the tools further and our goal is to explicitly characterize SLOCC classes for all generic 2 x m x n states. We find evidence indicating that for m = n, greater than, or equal to 4, generic states belong to one family of infinitely many SLOCC classes, while for m different from n, all generic states belong to one SLOCC class only, i.e., all generic states are equivalent under SLOCC. Furthermore, we derive the hierarchy of SLOCC classes for generic states. Interestingly, it turns out, that any generic state can be transformed to any other generic state of smaller dimension.

[1] Chitambar, E., Miller, C. A., and Shi, Y., J. Math. Phys. 51, 072205 (2010).

Ultrastrong coupling phenomena beyond the Dicke model

Tuomas Jaako, Atominstitut (TU-Wien)

We study effective light-matter interactions in a circuit QED system consisting of a single *LC*-resonator, which is coupled symmetrically to multiple superconducting qubits. Starting from a minimal circuit model, we demonstrate that in addition to the usual collective qubit-photon coupling the resulting Hamiltonian contains direct qubit-qubit interactions, which have a drastic effect on the ground and excited state properties of such circuits in the ultrastrong coupling regime. In contrast to a superradiant phase transition expected from the standard Dicke model, we find an opposite mechanism, which at very strong interactions completely decouples the photon mode and projects the qubits into a highly entangled ground state. These findings resolve previous controversies over the existence of superradiant phases in circuit QED, but they more generally show that the physics of two- or multi-atom cavity QED settings can differ significantly from what is commonly assumed."

Quantum measurement with a single ion and single optical photons

Moonjoo Lee, University of Innsbruck

We report the nondestructive reconstruction of the photon number in an optical cavity using a quantum decoherence effect. We employ a single 40Ca+ ion that is dispersively coupled to a high-finesse cavity. While the cavity is populated with weak coherent states, Ramsey spectroscopy is performed on the qubit transition to identify the shift and the broadening of the atomic energy levels. The shift is due to the ac Stark effect induced by cavity photons, and the broadening is attributed to the photon-number fluctuations of the cavity field. Taking advantage of the maximum-likelihood method, we reconstruct individual cavity photon number components up to four. This work represents an important step to create and manipulate nonclassical cavity-field states in the optical domain.

BEC of 41K in a Fermi Sea of 6Li

Fabian Lehmann, IQOQI Innsbruck

We report on the production of a double-degenerate, mass-imbalanced Fermi-Bose mixture of 6Li and 41K. In our experimental sequence the potassium atoms are sympathetically cooled by the lithium atoms, which are evaporatively cooled in an optical dipole trap at a magnetic field of 1190 G. We obtain ten to the fourth power 41K atoms with a BEC fraction close to 1 and a T/TF of about 0.05 with ten to the fifth power 6Li atoms in each spin state. To measure the temperature of our fermionic sample we use the 41K BEC as a tool for thermometry. As the system is in thermal equilibrium we evaluate the condensed fraction of our 41K atoms and extract the temperature of the atoms. To investigate the properties of the 6Li-41K mixture near the inter-species Feshbach resonance at 335.8 G we use another scheme of evaporation around 300 G which enables us to have similar results as when evaporating at high field. Currently, we are exploring the repulsive side of the 335.8 G Feshbach resonance and see evidence for a phase separation between 6Li and 41K at strong repulsive interactions.

Cooling phonons with phonons: acoustic reservoir-engineering with silicon-vacancy centers in diamond

Marc-Antoine Lemonde, Atominstitut (TU-Wien)

What can Leggett-Garg Inequalities tell us about Quantum Tunneling?

Yuri Minoguchi, Atominstitut (TU-Wien)

Estimation of Coherent Errors from Stabilizer Measurements

Davide Orsucci, University of Innsbruck

In the context of Measurement-Based Quantum Computation (MBQC) a way to maintain the coherence of the *Graph State* is given by measuring stabilizer operators. Aside from performing Quantum Error Correction (QEC), it is possible to exploit the information gained from these measurements to characterize a coherent source of errors; that is, an error channel that applies a fixed -- but unknown -- unitary operation. Specifically, we study the case in which the error channel acts differently on each qubit of the graph state, and is given by a rotation of the Bloch sphere around either the $\hat{x}$, $\hat{y}$, or $\hat{z}$ axis. The possibility to reconstruct the channel for each qubit depends non-trivially on the topology of the graph state.

The theory of many-body systems is remarkably successful in describing the properties of equilibrium quantum matter.

Jurcevic Petar, IQOQI Innsbruck

In recent years, pioneering experiments have achieved to create novel quantum states beyond this conventional equilibrium paradigm. This makes it now possible to study phenomena such as many-body localization, prethermalization, particle-antiparticle production in the Schwinger model, and light-induced superconductivity.

However, understanding general and universal properties of such nonequilibrium quantum states provides a significant challenge because conventional concepts of equilibrium quantum theory are not applicable. This calls for new approaches that are capable to lift important principles such as universality to the nonequilibrium realm.

In this experiment we show that the theory of dynamical quantum phase transitions (DQPTs) provides a promising concept towards achieving this goal. The theory of DQPTs represents a general approach to extend the notion of phase transitions to the nonequilibrium dynamical regime.

We report on the first direct observation of a DQPT in a system of trapped ions simulating long-range transverse-field Ising models. Utilizing the full control and local addressability of this experimental platform we show that a systematic understanding of the nonequilibrium dynamics in this system can be achieved by understanding the nature of the observed underlying DQPT. In particular, this allows us to unravel a connection between DQPTs and entanglement production which we monitor experimentally using a spin squeezing parameter."

Experimental Verification of an Indefinite Causal Order

Giulia Rubino, University of Vienna

Abstract: Investigating the role of causal order in quantum mechanics has recently revealed that the causal distribution of events may not be a-priori well-defined in quantum theory. While this has triggered a growing interest on the theoretical side, creating processes without a causal order is an experimental task. Here we report the first decisive demonstration of a process with an indefinite causal order. To do this, we quantify how incompatible our set-up is with a definite causal order by measuring a *causal witness*. This mathematical object incorporates a series of measurements which are designed to yield a certain outcome only if the process under examination is not consistent with any well-defined causal order. In our experiment we perform a measurement in a superposition of causal orders *without destroying the coherence* to acquire information both inside and outside of a *causally non-ordered process*. Using this information,

we experimentally determine a causal witness, demonstrating by almost seven standard deviations that the experimentally implemented process does not have a definite causal order.

Scalable Quantum Computation - Keeping a qubit alive
Martin van Mourik, University of Innsbruck

Trapped ion-based qubits provide a promising platform for quantum computation. Using trapped ions, it has been shown that the basic sets of quantum gates necessary for performing any logical algorithm are fully reachable. However, when realizing the scale of full algorithms, two obvious obstacles are present: 1) the current trapping architectures are mechanically limited to containing -at best- tens of qubits, as opposed to the hundreds needed to outperform classical computers, and 2) a qubit's fundamental limit in lifetime requires the use of non-invasive error correction protocols. The eQual project uses an in-cryostat planar trapping architecture to demonstrate the that quantum computation can also be achieved in a fully scalable fashion. Much attention has been paid in the design of the setup to limit harmful vibrations and magnetic field fluctuations, its performance having been confirmed by measurements. Recently, the quality of the trap has been characterized by determining ion phonon numbers, heating rates, coherence times, and addressability. In the future, our setup will be used to show the feasibility of (multi-species) quantum error-correction protocols.

Quantum optical circulator controlled by a single chirally coupled atom
Elisa Will, Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien

Integrated optical circuits for information processing promise to outperform their electronic counterparts in terms of bandwidth and energy consumption. However, such circuits require components that control the flow of light. Here, a particular important class are nonreciprocal devices.

Recently, we realized a quantum optical circulator. For this purpose, we strongly couple a single 85Rb atom to a special type of whispering-gallery-mode resonator - a so-called bottle microresonator [1] - in which photons exhibit a chiral nature: their polarization is inherently linked to their propagation direction [2]. Interfaced by two optical nanofibers, the system forms a 4-port device. The chirality of the photons together with the atom exhibiting polarization-dependent transition strengths leads to a direction-dependent atom-photon interaction. As a consequence, we observe a nonreciprocal behaviour, where photons are directed from one to the adjacent fiber-port [3]. We also show that the internal quantum state of the atom controls the operation direction of the circulator [3]. This working principle is compatible with preparing the circulator in a coherent superposition of its operational states. It thus may become a key element for routing and processing quantum information in scalable integrated optical circuits.

[1] C. Junge et al., Phys. Rev. Lett. 110, 213604 (2013)
[2] P. Lodahl et al., arXiv:1608.00446v1
[3] M. Scheucher et al., arXiv:1609.02492v1

Intra-city quantum communication via thermal microwave channels
Zeliang Xiang, Atominsitut (TU-Wien)

Communication over proven-secure quantum channels is one of the most wide-ranging applications of currently developed quantum technologies. It is generally envisioned that in future quantum networks, separated nodes containing stationary solid-state or atomic qubits are connected via the exchange of optical photons over large distances. Here we explore an intriguing alternative for quantum communication over microwave networks. To make this possible, we describe a general protocol for sending quantum states through noisy channels, even when the number of thermal photons in the channel is much larger than one. The proposed protocol can be implemented with state-of-the-art superconducting circuits and thereby enables the transfer of quantum states over distances of approx. 100 m via microwave transmission lines cooled to only T=4K. This opens up a completely new way for quantum communication within and across buildings, and the implementation of intra-city quantum networks based on microwave technology only.

Quantum annealing with ultracold atoms in a multimode optical resonator
Valentin Torggler, University of Innsbruck

A dilutely filled N-site optical lattice near zero temperature within a high-Q multimode cavity can be mapped to a spin ensemble with tailorable interactions at all length scales. The effective full site to site interaction matrix can be dynamically controlled by the application of up to N(N+1)/2 laser beams of suitable geometry, frequency and power, which allows for the implementation of quantum annealing dynamics relying on the all-to-all effective spin coupling controllable in real time. Via an adiabatic sweep starting from a superfluid initial state one can find the lowest energy stationary state of this system. As the cavity modes are lossy, errors can be amended and the ground state can still be reached even from a finite temperature state via ground state cavity cooling. The physical properties of the final atomic state can be directly and almost non-destructively read off from the cavity output fields. As example we simulate a quantum Hopfield associative memory scheme.

Optical transport and a highly tunable dipole trap for a Er-Dy mixture
Claudia Politi, University of Innsbruck, IQOQI Innsbruck

Strongly magnetic atoms enable the study of few- and many-body effects arising from long-range and anisotropic dipole-dipole interaction (DDI). The anisotropic character of the DDI naturally yields to quantum effects dictated by the underlying geometry of trapping potential. We will present a scheme to create optical dipole traps for Erbium and Dysprosium atoms that feature a high tunability of ellipticity and size. To tune the trapping potential, we will implement a scanning system using an acousto-optic modulator and a cylindrical lens system. This system will be combined with focus tunable lenses to enable the transport of the cloud along a distance of up to 350mm, from the main chamber to either a Rydberg spectroscopy chamber or to a second chamber prepared for high resolution imaging.

Towards spin manipulation in dipolar quantum gases
Gabriele Natale, University of Innsbruck, IQOQI Innsbruck

Over the last decade, dipolar quantum gases became an ideal system to study novel few- and many-body phenomena in ultracold quantum physics. Strongly magnetic species open fascinating possibilities to investigate dipole-dipole interaction (DDI) and its impact on many-body quantum phases and spin physics.
In our experiment in Innsbruck, we work with either bosonic or fermionic erbium atoms. The ground state of Erbium has a total angular momentum J=6 (F=19/2) giving rise to 13 (21) different spin states for bosons (fermions). We here explore an optical scheme to create spin systems starting from spin-polarized ultracold atoms.
At our typical magnetic field strength, the Zeeman splitting between adjacent spin states is equal, hence a deterministic preparation of one particular spin state is not possible with standard methods such as RF transitions. Here, we present a method that exploits the tensorial AC-Stark Shift, which will allow us to populate any spin state deterministically.
For this we employ a home-made External Cavity Diode Laser (ECDL), emitting close to a 28-kHz-wide transition at a wavelength of 631.04nm. The laser light will be locked to an Ultra Low Expansion (ULE) cavity. We slightly detune the laser from resonance, to induce a different Ac-Stark Shift on different Zeeman sublevels. This will allow to selectively populate the different spin states and hence opens the door to study spin dynamics with erbium in a well-controlled manner.