SFB Meeting. Vienna, Austria
December 11-12, 2014

Titles and Abstracts

1. TALKS

Mateus Araújo, MSc
Universität Wien
Title: Computational advantage from quantum-controlled ordering of gates

Abstract:
It is usually assumed that a quantum computation is performed by applying gates in a specific order. One can relax this assumption by allowing a control quantum system to switch the order in which the gates are applied. This provides a more general kind of quantum computing, that allows transformations on blackbox quantum gates that are impossible in a circuit with fixed order. Here we show that this model of quantum computing is physically realizable, by proposing an interferometric setup that can implement such a quantum control of the order between the gates. We show that this new resource provides a reduction in computational complexity: we propose a problem that can be solved using O(n) blackbox queries, whereas the best known quantum algorithm with fixed order between the gates requires $O(n^2)$ queries. Furthermore, we conjecture that solving this problem in a classical computer takes exponential time, which may be of independent interest.

Prof. Dr. Jean Dalibard
Collège de France and École normale supérieure
Title: Gauge fields in an optical lattice: when topology meets with experimental physics

Abstract:
Ultracold atoms constitute a promising physical platform for the preparation and the exploration of novel states of matter. In particular, non-trivial topological fluids such as topological insulators (a material that, irrespective of its shape, always exhibits the same protected current on its edges) are certainly fascinating objects that one try to reproduce with cold atom setups.
In this lecture I will discuss how the notion of topology can emerge in the context of cold quantum matter, taking as a paradigm example particles moving in a square periodic lattice penetrated by a magnetic flux. I will explain how the topology of a given energy band in this periodic potential can be characterized by an integer, the so-called Chern number. I will also present practical implementations of such topological features in the cold-atom context, using in particular time-dependent Hamiltonians and shaken lattices.

Valentin Torggler, BSc
Institut für Theoretische Physik, Innsbruck
Title: Adaptive multifrequency light collection by self-ordered mobile scatterers in optical resonators

Abstract:
Photons carry momentum and thus their scattering not only modifies light propagation but at the same time induces forces on particles. Confining mobile scatterers and light in a closed volume thus generates a complex coupled nonlinear dynamics. As a striking example, one finds a phase transition from random order to a crystalline structure if particles within a resonator are illuminated by a sufficiently strong laser. This phase transition can be simply understood as a minimization of the optical potential energy of the particles in concurrence with a maximization of light scattering into the resonator. Here we generalize the self-ordering dynamics to several illumination colors and cavity modes. In this enlarged model particles adapt dynamically to current illumination conditions to ensure maximal simultaneous scattering of all frequencies into the resonator as a sort of self-optimizing light collection system with built-in memory. Such adaptive self-ordering dynamics in optical resonators could be implemented in a wide range of systems from cold atoms and molecules to mobile nanoparticles in solutions.

Dr. Maria Chekhova
Max Planck Institute for the Science of Light
Title: Giant twin-beam generation along the pump energy propagation

Abstract:
Walk-off effects, originating from the difference between the group and phase velocities, limit the efficiency of nonlinear optical interactions. While transverse walk-off can be eliminated by proper medium engineering, longitudinal walk-off is harder to avoid. In particular, ultrafast twin-beam generation via pulsed parametric down-conversion and four-wave mixing is only possible in short crystals or fibres or in double-path schemes. Here we show that in high-gain parametric down-conversion, one can overcome the destructive role of both effects and even turn them into useful tools for shaping the emission. In our experiment, one of the twin beams is emitted along the pump Poynting vector or its group velocity matches that of the pump. The result is dramatically enhanced generation of both twin beams, with the simultaneous narrowing of angular and frequency spectrum. The effect will enable efficient generation of ultrafast twin photons and beams in cavities, waveguides, and whispering-gallery mode resonators.

Dr. Michael Trupke
Atominstitut, Wien
Title: Sub-nanotesla quantum magnetometry with a single spin

Abstract:
Diamond defects have risen to prominence in the last decade, both as sensors and as qubits. After a brief outline of the activities with diamond defects at ATI, projects will be presented in which the nitrogen-vacancy sensor is implemented as a sensitive

magnetic field probe. Using isotopically purified diamond and carefully tuned control parameters we have been able to significantly extend the range of measurable magnetic fields for both periodic and arbitrary magnetic fields. The findings and methods used will be of interest both for diamond-based sensing and for applications in quantum information.

Prof. Dr. Miles Padgett
University of Glasgow
Title: Photons that travel in free space slower than the speed of light

Abstract: Tba

Prof. Dr. Ad Lagendijk
University of Twente, FOM-Institute AMOLF, University of Amsterdam
Title: Wave Front Shaping: a revolution in optics

Abstract: Studying light propagation in matter that is strongly coupled to light is of much current interest.
When the interaction strength exceeds a certain threshold fascinating phenomena as Anderson localization and a full photonic bandgap are encountered.
The invention of Wave Front Shaping (wfs) has brought a new dimension to this field. Suddenly an experimentalist has millions of control parameters at hand to tailor optical wave fronts. Wave fronts can be optimized for propagation through opaque random materials, for focusing inside opaque materials, for optimizing or minimizing absorption and for many more desired behaviors.
In this talk we will introduce wave front shaping and report on a number of applications in optics. These applications not only refer to classical optics, but we will also describe quantum secure authentication and a quantum credit card. Studying light propagation in matter that is strongly coupled to light is of much current interest.
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In this talk we will introduce wave front shaping and report on a number of applications in optics. These applications not only refer to classical optics, but we will also describe quantum secure authentication and a quantum credit card.

Christine Maier, MSc
IQOQI Innsbruck
Title: Engineering and observation of interacting quasiparticles in a qunatum many-body system

Abstract:
The key to explaining and controlling a range of quantum phenomena is to study how information propagates around many-body systems. This quantum dynamics can be described by particle-like carriers of information that emerge in the collective behaviour of the underlying system, so called quasiparticles. We engineer such quasiparticles in a quantum many-body system of trapped atomic ions, whose interactions are determined by a transverse-field Ising Hamiltonian [1]. In my talk, I will present how we approximately construct the Eigenstates of the system, perform spectroscopy on low lying energy levels and observe signatures of quasiparticle interactions in our system [2].
[1] P. Jurcevic et al., Nature, 511, 202-205 (2014).
[2] P. Jurcevic et al., in preparation.

2. POSTERS

Gabriel Araneda, MSc
Institut für Experimentalphysik, Uversität Innsbruck
Title and Abstract: Tba

Veronika Baumann, MSc
Universität Wien
Title: Measurement-and-Repreparation Operations and Causal Separability for Two Laboratories

Abstract:
In their paper ”Quantum correlations with no causal order” (Nature Communications, 3:1092, 2012) O. Oreshkov et. al. show that the most general quantum correlations between two closed laboratories allow for in- definite global causal structures. The two closed laboratories are described by standard quantum mechanics and therefore correspond to sets of quan- tum instruments. Global causal structures into which the two laboratories are embedded are encoded in so called process matrices. Causally separable process matrices are always compatible with the concept of a definite global causal structure. If the two laboratories are restricted to classical operations the process ma- trices of interest are all diagonal. In this case one can proof (see supple- mentary information of Oreshkov's paper) that they are causally separable. Hence, correlations between two classical laboratories can always be under- stood in terms of a definite global causal structure, such as spacetime. As it turns out this proof can be extended to certain process matrices, which are only partially diagonal, which means diagonal in certain subspaces. Partially diagonal process matrices correspond to so called semiquantum laboratories and correlations. They are compatible with a definite global causal struc- ture, if and only if the information gained from the input in both laboratories can be understood classically.

Walter Boyajian, MSc
IQOQI Innsbruck
Title: Compressed Simulation and Computation of 1D Spin Chains

Abstract:
We derive a quantum circuit processing 'log(n)' qubits which simulates the 1D XY-model describing 'n' qubits. We demonstrate how the adiabatic evolution can be realized on this exponentially smaller system and how the magnetization, which witnesses a quantum phase transition can be observed. We analyse several dynamical processes, like quantum quenching and finite time evolution and derive the corresponding compressed quantum circuit. Using an alternative approach we allow the possibility to simulate the evolutions of excited and thermal states.

Matthias Brandl, Dipl. Ing.
Institut für Experimentalphysik, Uversität Innsbruck
Title: The "Scalable Quantum Information Processing" Project

Abstract: Tba

Katharina Schwaiger; MSc, David Sauerwein, BSc; Dr. Marti Cuquet
Institut für Theoretische Physik, Innsbruck
Title: Operational characterization of few-body entanglement

Abstract:
We present a new approach of characterizing the entanglement contained in few-body systems via new operational entanglement measures. One of them characterizes the potentiality of a state to generate other states via local operations and classical communication (LOCC) and the other the simplicity of generating the state at hand via LOCC. We identify the GHZ- and the W-state as those 3-qubit states that can be used to reach the largest sets of other states.

Adrien Feix, MSc
Universität Wien
Title: Superposition of causal orderings as a resource for communication complexity

Abstract: Tba

Dr. Robert Fickler
IQOQI Wien
Title: Interface between path and OAM entanglement for high-dimensional photonic quantum information

Abstract:
Photonics has become a mature field of quantum information science, where integrated optical circuits offer a way to scale the complexity of the set-up as well as the dimensionality of the quantum state. On photonic chips, paths are the natural way to encode information. To distribute those high-dimensional quantum states over large distances, transverse spatial modes, like orbital angular momentum possessing Laguerre Gauss modes, are favourable as flying information carriers. Here we demonstrate a quantum interface between these two vibrant photonic fields. We create three-dimensional path entanglement between two photons in a nonlinear crystal and use a mode sorter as the quantum interface to transfer the entanglement to the orbital angular momentum degree of freedom. Thus our results show a flexible way to create high-dimensional spatial mode entanglement. Moreover, they pave the way to implement broad complex quantum networks where high-dimensionally entangled states could be distributed over distant photonic chips.

Konstantin Friebe, Dipl. Phys.
Institut für Experimentalphysik, Uversität Innsbruck
Title: Enhanced quantum interface using ion crystals

Abstract:
We prepare a maximally entangled state of two ions and couple both ions to the mode of an optical cavity. The phase of the entangled state determines the collective interaction of the ions with the cavity mode, that is, whether the emission of a single photon into the cavity is suppressed or enhanced. By adjusting this phase, we tune the ion-cavity system from sub- to superradiance. We then encode a single qubit in the two-ion superradiant state and show that this encoding enhances the transfer of quantum information onto a photon. These results constitute a proof of principle that cooperative effects can improve the performance of a quantum interface.

Dr. Alexander Glätzle
IQOQI Innsbruck
Title: Quantum Ice and dimer models with ultra-cold Rydberg atoms and ions

Abstract:
We will 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. Together with the pos- sibility of designing step-like potentials using ground state atoms weakly dressed by Rydberg states, we can implement Abelian gauge theories in a series of geometries, which could be demonstrated within state of the art experiments. [1] In a parallel project we implement quantum simulators for various quantum spin models and frus- trated magnets using a two-dimensional triagonal crystal of ions. Utilizing state dependent trapping frequencies of ions excited to a Rydberg state we can engineer localized modes, realizing exotic plaquette interactions imposing non-local energetic constraints. This allows to access a series of in- teresting models: 1) the Balents-Fisher-Girvin model where topological spin liquid phase has been predicted, 2) to observe Bose metal in a Honey-comb lattice with XY interactions and 3) to provide ion-lattice implementations for U (1) lattice gauge theories.
[1] A. W. Glaetzle, M. Dalmonte, R. Nath, I. Rousochatzakis, R. Moessner, P. Zoller, arxiv:1404.5326

Philip Holz, MSc
Institut für Experimentalphysik, Uversität Innsbruck
Title: 2D arrays of ion traps for quantum simulations

Abstract:
Ion traps are a promising tool for quantum simulations [1]. The possibility of producing superposition states as well as entanglement between qubits allows, in principle, to efficiently run simulations that are not tractable for classical computers. Currently, simulations are typically implemented using strings of ions. However,

certain problems such as the 2D Ising model [2] would be simulated more naturally in a 2D architecture, e.g. in an array of individual ion traps. Furthermore, such arrays are a possible way of implementing a scalable quantum computer [3]. We have proposed a 2D architecture consisting of individual surface traps in which interactions between nearest-neighbour ions can be deterministically switched on and off [4]. Recently we have shown trapping and shuttling of ions in a relatively large array [5]. I will report on our efforts to miniaturize the array in order to increase the coupling between adjacent qubits and realize coherent operations.

[1] R. Blatt, C.F. Roos, Nature Phys. 8, 277284 (2012)
[2] J.W. Britton et al., Nature 84, 489 (2012)
[3] J.I. Cirac and P. Zoller, Nature 404, 579 (2000)
[4] M. Kumph et al., New J. Phys. 13, 073043 (2011)
[5] M. Kumph et al., arXiv:1402.0791

Petar Jurcevic, MSc; Christine Maier, MSc
IQOQI Innsbruck
Title: Quasiparticle engineering and entanglement propagation i a quantum many-body system

Abstract:
The key to explaining and controlling a range of quantum phenomena is to study how information propagates around many-body systems. Quantum dynamics can be described by particle-like carriers of information that emerge in the collective behaviour of the underlying system, so called quasiparticles. These elementary excitations are predicted to distribute quantum information in a fashion determined by the underlying system's interactions.
Here we report on quasiparticle dynamics observed in a quantum many-body system of trapped atomic ions [1]. In detail we present the implementation of the Ising Hamiltonian as well as the measurement of its coupling matrix and the dispersion relation for the 1-excitation subspace. We show how entanglement is distributed by quasiparticles, as they trace out lightcone-like wavefronts. Furthermore, using the ability to tune the effective interaction range, we observe the predicted non-local transport of information and breakdown of the light-cone picture. Our results will enable experimental studies of a range of quantum phenomena, including transport, thermalisation, localisation, and entanglement growth, and represent a first step towards a new quantum-optic regime of engineered quasiparticles with tuneable non-linear interactions.
[1] P. Jurcevic et al., Nature, 511, 202-205 (2014).

Dr. Emil Kirilov
Institut für Experimentalphysik, Uversität Innsbruck
Title: Progress on the dual species KCs (Potassium-Cesium) experiment. Achieved goals and future directions.

Abstract: Tba

Kirill Lakhmanskiy, MSc
Institut für Experimentalphysik, Uversität Innsbruck
Title: Cryogenic silicon surface ion trap

Abstract: Tba

Dr. Marco Mattioli
Institut für Theoretische Physik, Innsbruck
Title: Quantum glass dynamics of Rydberg excitations in 1D optical lattices

Abstract:
We propose a setup to observe glassy dynamics of Rydberg excitations in an ensemble of cold atoms loaded into 1D optical lattices. We schematise each atom of the chain as a V-shaped three-level system, in which the ground state is coupled (i) resonantly to an excited short-living state with a large Rabi frequency Ω_e and (ii) far-off-resonantly to a metastable Rydberg state with a small Rabi frequency Ω_r. Strong interactions between Rydberg levels of neighbouring atoms may act as effective 'kinetic constraints' for the transition rates between different Rydberg configurations, facilitating some of them and inhibiting others. Our results, obtained from quantum Monte-Carlo trajectory simulations, show that the relaxation of the trajectory-averaged Rydberg population of a certain atom towards the steady state, strongly depends on the initial position of the atom itself respect to the one(s) that start in the Rydberg state. Finally we studied how an external disorder, induced e.g. by adding to the aforementioned setup spatially random detunings to the Rydberg states, can modify the dynamics of our Rydberg excitations.

Florian Meinert, Dipl. Phys.
Institut für Experimentalphysik, Uversität Innsbruck
Title: Quench dynamics in strongly correlated Bose-Hubbard chains

Abstract: Tba

Alexey Melnikov, MSc
IQOQI Innsbruck
Title: Projective simulation applied to the grid-world and the mountain-car problem

Abstract:
The model of projective simulation (PS) is a novel approach to artificial intelligence. The PS model is based on a random walk process and is a natural candidate for quantization. The performance of the PS agent was studied in a number of discrete toy-problems. In this work we analyse the PS model further in more complicated scenarios. We consider two well-studied benchmarking problems, the "grid-world" and the "mountain-car" problem, which challenge the model with large and continuous input space. The performance of the PS model is compared with those of existing models and we show that the PS agent exhibits competitive performance also in these tasks.

Dr. Christine Muschik
IQOQI Innsbruck
Title: Quantum Teleportation of Dynamics and Effective Interactions Between Remote Systems

Abstract:
Most protocols for Quantum Information Processing consist of a series of quantum gates, which are applied sequentially. In contrast, interactions, for example between matter and fields, as well as measurements such as homodyne detection of light, are typically continuous in time. We show how the ability to perform quantum operations continuously and deterministically can be leveraged for inducing non-local dynamics between two separate parties. We introduce a scheme for the engineering of an interaction between two remote systems and present a protocol which induces a dynamics in one of the parties, which is controlled by the other one. Both schemes apply to continuous variable systems, run continuously in time and are based on real-time feedback.

Fabian Pokorny, MSc
Institut für Experimentalphysik, Uversität Innsbruck
Title: Towards Two-Photon Rydberg Excitation of Trapped Strontium Ions

Abstract:
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. Here, we present our progress in realising such a system of trapped Rydberg ions. In particular, this includes a two-photon excitation scheme of Sr+ ions into the Rydberg state.

Klemens Schüppert, MSc
Institut für Experimentalphysik, Uversität Innsbruck
Title: Towards strong coupling in an ion-trap fiber-cavity apparatus

Abstract:
With atoms coupled to optical cavities it is possible to build up quantum interfaces between stationary and flying qubits. A quantum network based on these interfaces offers a compelling solution to the challenge of scalability in quantum computing. By using fiber-based cavities, we expect to reach the strong coupling regime of cavity quantum electrodynamics with single ions, which has not previously been accessed. To that end, we are further developing and testing the laser ablation of fiber facets, which are then coated to produce high-finesse fiber mirrors. Specifically, we plan to produce cavities of about 8 um mode waist and 500 um in length for use in our integrated ion-trap cavity setup. In parallel, we are currently optimizing trapping parameters for calcium ions in our miniaturized trap.

Dr. Cornelia Spee
Institut für Theoretische Physik, Innsbruck
Title: The maximally entangled set of 3- and 4-qubit states

Abstract:
Entanglement is non-increasing under Local Operations and Classical Communication (LOCC). Thus, studying deterministic LOCC transformations allows to obtain a (partial) order of the states with respect to their entanglement. In the bipartite case the maximally entangled state is well known. It is the state which allows to obtain all other states via LOCC but cannot be obtained from any other state via deterministic LOCC transformations (excluding local unitaries). As there exists no single state with this property in the multipartite case, we introduced in [1] the Maximally Entangled Set, which is the minimal set of n-partite states such that any other fully entangled n-partite state can be obtained via LOCC from a state in this set. We studied the MES for 3- and generic 4-qubit states and showed that the MES for 3-qubits is of measure zero, whereas for 4-qubits almost all states are in the MES. Moreover, we determined the LOCC convertible states in the MES for 3- and generic 4-qubit states, which are for both cases of measure zero. The investigation of these states, which are the relevant states concerning deterministic entanglement manipulation might well, lead to new applications. Currently, we are investigating the MES for non-generic 4-qubit states. One observes that for almost all SLOCC classes deterministic LOCC transformations are hardly ever possible. As we observed that the picture changes drastically going from the 3-qubit to the 4-qubit case, we extend our study to higher dimension, in particular studying the MES for 3 qutrits.
[1] J.I. de Vicente, C. Spee and B. Kraus, Phys. Rev. Lett. 111, 110502 (2013).

Bernhard Rauer, Dipl.-Ing.
AtomInstitut Wien
Title: Relaxation Dynamics of Isolated Quantum Many-Body Systems

Abstract:
Non-equilibrium dynamics in isolated quantum many-body systems is a highly active research topic with relevance for many different fields of physics. Despite important theoretical effort, no generic framework exists yet to understand when and how a quantum system relaxes to a steady state. In the last years we have developed techniques to characterize relaxed states and the dynamics leading to them. Our model system is a quantum degenerate 1d Bose gas which we take out of equilibrium by coherently splitting it into two parts. The subsequent evolution is measured through matter-wave interferometry, which provides a local probe for the relative phase field of the two parts. Studying the evolution of this relative phase field allows us to directly observe how the initial coherence between the two many-body systems is lost and how a steady state emerges. This steady state is identified as a prethermalized state and we explicitly show that it can be described by a generalized Gibbs ensemble.