Posters for the SFB meeting October 2014

Compressed Simulation and Computation of 1D Spin Chain

Boyajian Walter
Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

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.

Entanglement properties of hypergraph states

O. Gühne, F.E.S. Steinhoff, T. Moroder, M. Rossi, D. Bruß, B. Kraus, C. Macchiavello
Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria M. Cuquet,

Hypergraph states are multi-qubit states that form a subset of the locally maximally entangleable states and a generalization of the well-established notion of graph states. Mathematically, they can conveniently be described by a hypergraph that indicates a possible generation procedure of these states; alternatively, they can also be phrased in terms of a non-local stabilizer formalism. Here, we explore the entanglement properties and nonclassical features of hypergraph states. We identify the equivalent classes under local unitary transformations for up to four qubits, we present general conditions under which the local unitary equivalence of hypergraph states can simply be decided by considering a finite set of transformations with a clear graph-theoretical interpretation, and we demonstrate that various noncontextuality inequalities and Bell inequalities can be derived for hypergraph states.

Operational characterization of few-body entanglement

Katharina Schwaiger, Martí Cuquet, David Sauerwein
Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

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.

Measuring higher-order interference with a three-path waveguide interferometer

Kaufmann Thomas
Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

Several different experiments were performed to test Born's rule – one of the fundamental axioms of quantum mechanics – and to set an upper bound on possible higher order interference terms. Those tests were usually performed with optical free space multi-path interferometers. This work shows an attempt towards the realization of a three-path Michelson waveguide interferometer written into a fused silica chip. The aim of the on-chip integration is to minimize experimental uncertainties – in particular phase instabilities – of such a test.

Measurements of higher order interference terms with a five-path interferometer and single photons

Kauten Thomas
Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

In this work we will present results of five-path interferometer experiments with the goal of putting a bound on the potential magnitude of higher order interference terms. This experiment was first proposed for three paths by Sorkin, and was experimentally implemented for the first time in 2010 by Sinha et al. Our experiment expands this to five paths, which allows us to measure also third and fourth order interference terms.

Ideal single photons from a cavity-free trapped ion

Araneda Gabriel
Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

Tba

Preparation and spectral characterization of emitter-doped crystals on nanofibers

Hardy Schauffert
Atominstitut, Vienna University of Technology, Stadionallee 2, 1020 Vienna, Austria

Tapered optical fibers with a nanofiber waist have proven to be a highly sensitive tool for surface spectroscopy. A route towards extending the range of applications to the single-molecule level is to deposit dye-doped organic crystals of sub-micron size, in our case terrylene-doped p-Terphenyl, onto the nanofiber and to interface them with evanescent field of the fiber-guided light. Here we would like to show methods of sample preparation and deposition on the fiber surface. We detect the molecules within the crystal by fluorescence excitation spectroscopy via the nanofiber.

The host crystal induces inhomogeneous broadening which makes it possible to detect single molecules when the homogeneous broadening is reduced under cryogenic conditions. We show these temperature dependence on the poster. Also we were able to observe the statistical fine structure arising from the Poissonian fluctuations of the number of addressed molecules per spectral interval.

Dissipative cooling of one-dimensional Bose-Einstein quasicondensate

Pjotrs Grišins
Atominstitut, Vienna University of Technology, Stadionallee 2, 1020 Vienna, Austria

tba

General dynamical description of quasi-adiabatically encircling exceptional points

Milburn Thomas
Atominstitut, Vienna University of Technology, Stadionallee 2, 1020 Vienna, Austria

The appearance of so-called exceptional points in the complex spectrum of non-Hermitian systems is often associated with dynamical phenomena that contradict our physical intuition. Perhaps most strikingly, adiabatically encircling an exceptional point was predicted to effect a state-exchange. In this work we analyse the generic model of two linearly coupled dissipative harmonic oscillators. Our principal results are two-fold. Firstly, the non-adiabatic coupling is a singular perturbation thus prohibiting the use of standard perturbation theory. By applying singular perturbation theory we find that the system has a characteristic solution consisting of periods of adiabatic tracking interspersed with abrupt non-adiabatic transitions. Our framework provides a unified qualitative and quantitative description of the diverse dynamical phenomena associated with quasi-adiabatically encircling exceptional points. Secondly, this characteristic solution is robust to physical noise.

Protected subspace Ramsey metrology

L. Ostermann, D. Plankensteiner, H. Ritsch, C. Genes
Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

The present poster introduces the concept of asymmetric Ramsey spectroscopy, where collective dipole-dipole interaction is exploited to increase the sensitivity of a Ramsey experiment instead of being an unwanted source of noise. Employing two extra (local) operations on the individual atoms, one before and one after the period of free evolution, allows for the collective state to exhibit a minimal total dipole, thus protecting it from environmental decoherence and decay. The poster will focus on recent results in extended 2D- and 3D-systems and provide examples as to how such a technique could be implemented using today's experimental methods.

Designing Superconducting Qubits for Quantum Simulation using HFSS

Phani Rahja Mupalla, Oscar Gargiulo, Seyed Iman Mirzai, Gerhard Kirchmair
Institut für Quantenoptik und Quanteninformation,
Österreichische Akademie der Wissenschaften, Technikerstr. 21a, 6020 Innsbruck, Austria
Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

This poster presents our numerical simulations of 3D superconducting qubits inside a waveguide cavity. Our simulations show, that the qubits interact directly with each other like two electric dipoles. We confirm the distance and angel dependence expected from two interacting dipoles. The cavity mediates and additional long range coupling, which is much smaller than the direct interaction between the two qubits. We plan to use these qubits for a quantum simulation of frustrated spin systems in a ladder configuration.

Josephson Junction Array Resonators

Oscar Gargiulo, Phani Rahja Mupalla, Seyed Iman Mirzai, Gerhard Kirchmair
Institut für Quantenoptik und Quanteninformation,
Österreichische Akademie der Wissenschaften, Technikerstr. 21a, 6020 Innsbruck, Austria
Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

The presented poster shows the first measurements in our lab on superconducting circuits. We were able to measure Josephson Junction Array Resonators with GHz resonance frequencies and Quality Factors of a few 10.000. We observed and investigated the strong interaction between the different modes of the array. This interaction can be used for cooling and readout of one mode of the array resonator with another one. In the long run we plan to push the resonance frequencies of these arrays down to a few 10 MHz to couple them to other AMO systems.

Towards a Fermi-Fermi mixture of dysprosium and potassium

Slava Tzanova, Cornelis Ravensbergen, Rudolf Grimm
Institut für Quantenoptik und Quanteninformation,
Österreichische Akademie der Wissenschaften, Technikerstr. 21a, 6020 Innsbruck, Austria
Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 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.

Cryogenic silicon surface ion trap

M. Niedermayr, K. Lakhmanskiy, M. Kumph, S. Partel, J. Edlinger, M. Brownnutt, R. Blatt

Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

Tba

Quasiparticle engineering and entanglement propagation in a quantum many-body system

P. Jurcevic, B. P. Lanyon, P. Hauke , C. Maier, C. Hempel, P. Zoller, R. Blatt and C. F. Roos
Institut für Quantenoptik und Quanteninformation,
Österreichische Akademie der Wissenschaften, Technikerstr. 21a, 6020 Innsbruck, Austria
Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria
Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

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.

Quantum computations on a topologically encoded qubit

Esteban Martinez
Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

The construction of a quantum computer remains a fundamental scientific and technological challenge because of the influence of unavoidable noise. Quantum states and operations can be protected from errors through the use of protocols for quantum computing with faulty components. We present a quantum error-correcting code in which one qubit is encoded in entangled states distributed over seven trapped-ion qubits. The code can detect one bit flip error, one phase flip error, or a combined error of both, regardless on which of the qubits they occur. We applied sequences of gate operations on the encoded qubit to explore its computational capabilities. This seven-qubit code represents a fully functional instance of a topologically encoded qubit, or color code, and opens a route toward fault-tolerant quantum computing.

Towards Two-Photon Rydberg Excitation of Trapped Strontium Ions

Fabian Pokorny
Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 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. 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.

The maximally entangled set of multipartite quantum states

Cornelia Spee
Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

Entanglement is a resource when state manipulation is restricted to Local Operations assisted by Classical Communication (LOCC). It is therefore of importance to decide which LOCC transformations are possible and which states are maximally useful under this restriction.
While the bipartite maximally entangled state is well known (it is the only state that cannot be reached from any other and, at the same time, it can be transformed to any other by LOCC), no such state exists in the multipartite case. In order to cope with this fact, we introduced in [1] the notion of the Maximally Entangled Set (MES) of n-partite states. This is the set of states which are maximally useful under the restriction to LOCC, i. e. it is the minimal set of n-partite states s. t. any other truly n-partite entangled state can be obtained deterministically from a state in MES via LOCC.

In [1] we determined the MES for 3-qubit and generic 4-qubit states. While the MES is of measure zero for 3-qubit states, almost all 4-qubit states are in the MES. Moreover, we determined for the 4-qubit generic case the measure-zero subset of the MES of LOCC convertible states. This is the most relevant class of states for entanglement manipulation.

Currently we investigate the MES for non-generic 4-qubit states. One observes that for almost all SlOCC classes deterministic LOCC transformations are almost never possible among fully entangled 4-partite states. Moreover, for all instances we looked at, any state that is not in the MES can be reached via a simple protocol, where one party measures and the other parties apply depending on the outcome a local unitary.

[1] J.I. de Vicente, C. Spee and B. Kraus, Phys. Rev. Lett. 111

Chiral photon emission beyond paraxial approximation

Stefan Walser
Atominstitut, Vienna University of Technology, Stadionallee 2, 1020 Vienna, Austria

Electromagnetic radiation is typically considered as a fully transverse polarized wave, where the electric field is perpendicular to the propagation direction. However this is only valid in the paraxial approximation. Beyond this approximation in highly confined light fields non-transversal polarization components appear. Together with the transversal components this leads to local circular polarization where the sense of rotation (spin) depends on the propagation direction. Thus the internal spin of photons gets coupled to their orbital angular momentum. Using this spin-orbit interaction of light we break the mirror symmetry of the scattering of light. Positioning a gold nano particle on the surface of a nano-photonic waveguide we thereby realize a chiral waveguide coupler in which the handedness of the incident light determines the propagation direction in the waveguide [1]. We also show that freely propagating optical beams in high numerical-aperture optical systems are accompanied by spin-orbit interaction of light [2]. Making use of the expected directional emission we plan to demonstrate optical microscopy beyond the diffraction limit.