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BOOK OF ABSTRACTS
CONTRIBUTED POSTERS

CoQuS ComplexQuantumSystems · universität wien · TU WIEN · FWF Der Wissenschaftsfonds. · VCQ Vienna Center for Quantum Science and Technology · IQOQI Vienna · IST AUSTRIA Institute of Science and Technology

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1. Generation of optical Fock and W states with single-atom-based bright quantum scissors

Ziv Aqua, M. S. Kim, Barak Dayan

We introduce a multi-step protocol for optical quantum state engineering that performs as "bright quantum scissors" (BQS), namely truncates an arbitrary input quantum state to have at least a certain number of photons. The protocol exploits single-photon pulses and is based on the effect of single-photon Raman interaction, which is implemented with a single three-level system (e.g. a single atom) Purcell-enhanced by a single-sided cavity. A single step of the protocol realises the inverse of the bosonic annihilation operator. Multiple iterations of the protocol can be used to deterministically generate a chain of single-photons in a W state.
Alternatively, upon appropriate heralding, the protocol can be used to generate Fock-state optical pulses. This protocol could serve as a useful and versatile building block for the generation of advanced optical quantum states that are vital for quantum communication, distributed quantum information processing, and all-optical quantum computing.

2. Bell violations with entangled and non-entangled optical fields

Victor Avalos, J. Gonzales, P. Sanchez, F. de Zela

We report Bell violations with classical light prepared in both entangled and non-entangled polarization-path, binary states. Our results show that violations of constraints such as the Bell–Clauser–Horn–Shimony–Holt inequality do not necessarily falsify local realism. Correlations in the realm of classical statistical optics, which are not of the Bell type, may lead to Bell violations.

3. Evolution of a scalar field in curved spacetime: a general method

Ana Lucia Baez Camargo, Luis C. Barbado, Ivette Fuentes

We develop a method for computing the evolution of a Klein-Gordon field in a globally hyperbolic spacetime. Instead of solving the Klein-Gordon equation, we define and formally compute Bogoliubov transformations of the field between spacelike hypersurfaces at different times, without having to physically interpret the field modes between all these surfaces. The method is generally applicable to both classical and quantum fields. It is particularly useful in the study of confined quantum fields under small perturbations of the background geometry and/or the boundary conditions, such as, dynamical Casimir effect in curved spacetime, analogue gravity schemes and different experimental proposals using Bose-Einstein condensates. We use this method to address two problems; a confined quantum field under a gravitational wave and particle creation in a cosmological expansion.

4. Entangled radiation from superconducting circuits

Shabir Barzanjeh, Johannes Fink

Mechanical quantum systems facilitate the development of a new generation of hybrid quantum technology comprising electrical, optical, atomic and acoustic degrees of freedom. Entanglement is the essential resource that defines this new paradigm of quantum-enabled devices. Here I confirm the long-standing prediction that a parametrically driven mechanical oscillator can entangle electromagnetic fields. We observe stationary emission of path-entangled microwave radiation from a micro-machined silicon nanostring oscillator, squeezing the joint field operators of two thermal modes by 3.40(37)~dB below the vacuum level. Interestingly, even at room temperature, where entangled microwave states are overwhelmed by thermal and amplifier noises, we measure finite quantum correlations; a first indication that superconducting circuits could be used for quantum enhanced detection at ambient conditions. Nevertheless, we experimentally demonstrate an on-chip magnetic-free circulator based on reservoir-engineered electromechanical interactions. This mechanical based circulator is compact, its silicon-on-insulator platform is compatible with both superconducting qubits and silicon photonics, and its noise performance is close to the quantum limit. This special circulator can also be used to control the flow of thermal noises and heat in quantum devices.

5. Page-Wootters conditional probability interpretation and the quantum measurement problem

Veronika Baumann, Flavio Del Santo

In the case of Wigner's-friend gedankenexperiments, the conditional probability interpretation (CPI) of Page and Wootters allows to formally ask: (i) What is the probability of W measuring w at time t2, given that F has measured f at time t1? (ii) What is the probability that F measures f at time t1, given that W will measure w at time t2? There exist more than one way to consistently assign two-time conditional probabilities in the CPI framework, all of which reduce to standard quantum mechanics for non-Wigner's-friend scenarios. However, they lead to different probability assignments in Wigner's-friend experiments that resemble either "collapse" or full unitary evolution, thus resolving the paradox of the ambiguous probability assignments. Moreover, the formalism seems to impose a limit to the possible joint probabilities that can be meaningfully assigned, in accordance with previous no-go theorems.

6. How complex is a quantum process?

Felix Binder, Simon Milz, Felix Pollock, Jayne Thompson, Mile Gu, Kavan Modi

The complexity of a stochastic process is proportional to the minimal amount of memory required for its faithful simulation. We here present new results on extending this notion of complexity from classical stochastic processes to stationary quantum stochastic processes. This is done by expressing quantum processes as quantum combs, carefully defining process stationarity, and then identifying process memory via its representation as a tensor network state.

7. Quantum solitons propagation in chiral waveguide QED

Giuseppe Calajo, Sahand Mahmoodian, Darrick Chang, Klemens Hammerer, Anders S. Sørensen

We show that waveguide QED can be used as a platform for observing rich soliton physics in the few-photon and many-photon limit. In particular we examine pulse propagation through a system of N emitters chirally coupled to a waveguide. An incident coherent or Fock pulse breaks into a series of pulses that are ordered by their photon correlations. The ordered state is composed of a series of bound states that propagate with a photon-number-dependent group velocity. In the large photon-number limit, we show that a combination of n-body bound states can be used to reconstruct the mean-field soliton solutions of self-induced transparency. In addition our many-body treatment allows us to go beyond mean-field theory and consider pulse propagation in a medium with both a large number of photons and emitters.

8. Interfering fluorescence to observe single atom oscillations

Giovanni Cerchiari, Gabriel Araneda, Lukáš Podhora, Yves Colombe

Analysis and control of trapped ion motion have key importance in the investigation of fundamental processes and for the implementation of quantum technologies. We developed a position-sensitive method able to discriminate a single quantum of the ion's oscillation. The ion position is revealed by the optical self-interference of the fluorescence light emitted by trapped ions. Thus, the technique can be extended to complex light scatters that, unlike atoms, possess no electronic forbidden transition like trapped nanoparticles. We tested our technique on a single Ba+ ion and two-ion crystals confined in a linear Paul trap. With the two-ion chain, we found promising results to achieve sympathetic cooling and oscillation analysis of mixed ion species.

9. Cavity cooling by coherent scattering of a levitated nanosphere in high vacuum

Uros Delic, Manuel Reisenbauer, Kahan Dare, David Grass, Nikolai Kiesel, Vladan Vuletic, Markus Aspelmeyer

Optically levitated nanoparticles in ultra-high vacuum promise access to quantum behavior of massive objects at room temperature. Coupling the nanoparticle center-of-mass motion to an optical cavity provides a route to control its motion at the quantum level and gives rise to a new type of light-matter interface. Here we demonstrate a new method of cavity cooling a silica nanosphere based on coherent scattering. An optical tweezer allows for precise positioning of the nanosphere inside an empty optical cavity. In contrast to standard optomechanics, cooling of its motion is performed by cavity-enhanced coherent scattering of the red-detuned optical tweezer. We demonstrate genuine three-dimensional cavity cooling, which also allows for stable levitation in high vacuum. Our observed cooling performance and absence of laser phase noise heating indicates that this new method enables ground state cooling of levitated nanoparticles in our current experiment.

10. Single-copy non-locality detection

Aleksandra Dimic, Ivan Supic, Borivoje Dakic

Non-locality is one of the most important properties of quantum mechanics, where two or more spatially separated observers sharing entangled quantum bits can create correlations that cannot be explained by any local realistic theory. The aim of this paper is to apply methods developed in our recent paper "Single copy entanglement detection" for non-locality verification. In order to do this, we study non-local properties of cluster states and translate the procedure for entanglement verification in linear cluster states into procedure for non-locality verification. In addition, we compare our protocol with the protocols for self-testing.

11. State generation with quantum feedback in parametric down-conversion

Melanie Engelkemeier, Ish Dhand, Evan Meyer-Scott, Jan Sperling, Sonja Barkofen, Benjamin Brecht, Martin Plenio, Christine Silberhorn

Quantum Metrology, as well as fundamental quantum physics rely on the generation of higher-order Fock states. Despite of this necessity, the efficient generation of high photon numbers with high rates is still problematic. Our scheme makes use of quantum feedback in parametric down conversion to gain from self-stimulation in the generation of Fock states. One generated photon is fed back into the process, which increases the generation probability for subsequent photon pairs. Within our scheme, Fock states are generated due to a coherent addition of photons to the feedback mode. The stimulation effect is demonstrated by correlation measurements, which shows that the generation of a subsequent photon pair is enhanced by (30.8 ± 0.6) %. This result agrees well with theoretical calculations. We report on the current state of the project and highlight the implications of our results on the generation of higher-order Fock states.

12. The use of additive manufacturing for portable quantum technologies

William Evans, Reece Saint, Rob Shah, Xiaoke Li, Julia Fekete, Thomas Barrett, Fedja Oručević, Peter Krüger

The compatibility of additively manufactured (AM) components with ultra-high vacuum (UHV) environments provides novel solutions to a number of challenges for portable quantum technology systems from miniaturisation and weight reduction to heat management. These approaches also allow for integration into existing laboratory based ultra-cold atomic systems and the production of Bose-Einstein condensates. Here we present a number of devices and highlight key results from experimental characterisation of AM components in use as electrical conductors, vacuum wall components and thermal management systems. In particular the efficacy of AM current carrying devices is shown experimentally in an atom trap and the suitability for vacuum wall components is demonstrated by the maintenance of an UHV environment in an AM vacuum chamber. Analysis of the material properties and heat flow simulations provide further evidence of the array of solutions where AM can provide innovative approaches to issues limiting the development of quantum technology devices.

13. Photonic architecture for reinforcement learning

Fulvio Flamini, Arne Hamann, Sofiene Jerbi, Lea M. Trenkwalder, Hendrik Poulsen Nautrup, Hans J. Briegel

We present the blueprint for a photonic implementation of an active agent that supports well-established reinforcement learning algorithms, such as SARSA, Q-learning, and projective simulation. The simple geometry of the optical circuit, based on single-photon evolutions on binary decision trees, enables mechanisms of abstraction and generalization, two key features for artificial intelligence. We numerically investigate its performance under imperfect experimental conditions, showing that realistic levels of noise can be tolerated or even be beneficial for the learning process. The proposed architecture is robust, scalable, and a first integration in portable systems appears to be within the reach of near-term technology.

14. Quantum Fourier transform of a single photon

Xiaoqin Gao

In quantum information processing, the quantum Fourier transform plays an important role. At the same time, the orbital angular momentum of single photons represents a convenient carrier of the quantum information. A single photon can represent a qudit in arbitrarily high dimension and many quantum gates have been found to operate on such qudits. An implementation of the high-dimensional quantum Fourier transform for such a system has been nevertheless missing. Here we present the implementation of the high-dimensional quantum Fourier transform for arbitrarily high dimension. The proposed experimental setup can be implemented in a laboratory using accessible optical components, which is important in practical applications.

15. Ultracold Caesium on an Atomchip: An Atom Interferometer with Tunable Interactions

Benedikt Gerstenecker, Maximilian Lerchbaumer, Clemens Maderböck, Alexander Wiener, Florian Honz, Stephanie Manz, Thorsten Schumm

The matter-wave properties of atoms and the macroscopic behavior of Bose-Einstein condensates make interference experiments with ultracold atoms a useful tool for both fundamental research and metrology applications. We have recently managed to magnetically trap Caesium atoms on an atomchip, below whose surface we will condense them in an optical dipole trap by interaction-tuning via magnetically induced Feshbach resonances. The BEC will then be split by deforming the single- into a double-well and the energy difference between the two resulting clouds determined by measuring the phase difference accumulated over time. The tunability of the scattering length of the Caesium atoms combined with the convenient access to the trap characteristics of the optical potential will give us full control over the crucial parameters, allowing for the simulation of different regimes of two-mode systems as well as for competing with the sensitivity of large interferometric sensors despite a much more compact setup.

16. Violation of Bell's inequality for trajectories

Dragoljub Gocanin, Aleksandra Dimic, Flavio del Santo, Borivoje Dakic

In classical theory, the trajectory of a particle is completely pre-determined by the set of initial conditions and dynamical equations (Hamiltonian). Based on this, we formulate a no-go theorem for dynamics of classical particles, i.e. a \textit{Bell's inequality for trajectories} and discuss the possible violation in quantum scenario. We tackle the idea that non-local quantum correlations may be realized at the level of trajectories of a pair of initially entangled particles. Formally, a trajectory is not an outcome of a quantum measurement, in the sense that there is no observable associated to the trajectory, and thus there is no "direct" experimental test of the Bell's inequality for trajectories. However, by means of a simple model, we demonstrate that quantum mechanics allows for "point-by-point" violation of the Bell's inequality for trajectories, throughout an entire interval of time. Since the violation pertains during a finite continuous interval of time and not just at a particular moment of time, it tells us something about the correlations between a continuum of pairs of points $(x(t),y(t))$ that constitute pieces of trajectories that particles travel during that time interval. We interpret the violation of such an inequality to imply that trajectories cannot exist predetermined. We also provide a fairly general method for producing the violation that could have a potential experimental verification.

17. Single-shot electron spin readout with a dispersively probed single-lead quantum dot charge sensor

Mark Hogg, M.G. House, P. Pakkiam, A.V. Timofeev, S.K. Gorman, M.Y. Simmons

Dispersive sensors for readout of semiconductor spin qubits have been growing in popularity due to the compact integration of readout capability with structures already required for gating the device. Here we show that a dispersively probed, single-lead quantum dot (SLQD) charge sensor can be used for high-fidelity single-shot readout of spin qubits in a device consisting of four quantum dots, fabricated in silicon using atomic precision STM lithography. We demonstrate projective spin readout with fidelities of up to 97%. We show that the capacitive coupling between all four quantum dots and the charge sensor is strong enough to achieve full on/off signal contrast during readout, implying that the same charge sensor could be used to measure multiple qubits out to a distance of ~150 nm with no reduction in sensitivity. The good sensitivity and long-range sensing we demonstrate make the SLQD a promising choice of sensor for scaling up future atomic-precision spin qubit devices.

18. Ultrastrong coupling circuit QED in the radio-frequency regime

Tuomas Jaako, Juan Jose Garcia-Ripoll, Peter Rabl

We study a circuit QED setup where multiple superconducting qubits are ultrastrongly coupled to a single radio-frequency resonator. In this extreme parameter regime of cavity QED the dynamics of the electromagnetic mode is very slow compared to all other relevant timescales and can be described as an effective particle moving in an adiabatic energy landscape defined by the qubits. The focus of this work is placed on settings with two or multiple qubits, where different types of symmetry-breaking transitions in the ground- and excited-state potentials can occur. Specifically, we show how the change in the level structure and the wave packet dynamics associated with these transition points can be probed via conventional excitation spectra and Ramsey measurements performed at GHz frequencies. More generally, this analysis demonstrates that state-of-the-art circuit QED systems can be used to access a whole range of particle-like quantum mechanical phenomena beyond the usual paradigm of coupled qubits and oscillators.

19. All-fibre postselection-loophole-free generation of a one-photon time-bin qubit characterised by energy-time tomography

Maxime Jacquet, Lee A Rozema, Philip Walther

Franson's Bell test suffers from the postselection loophole (PSL): although the photon-number correlation is sinusoidal, it does not violate a CHSH inequality. We revisit a proposal to generate energy-time entanglement without the PSL, and adapt it to create a one-photon time-bin qubit. A heralded photon from a type-II SPDC source is sent into an unbalanced Michelson-Faraday interferometer, to create a superposed state of two temporal modes. After propagation through a 50km fibre-link, the state is characterised by state tomography in the Energy-Time basis. Our methods can be used in quantum computing experiments, where single mode operation is of paramount importance.

20. Engineering solitons in Raman tunnel-coupled one dimensional Bose gases

Sicong Ji, Valentin Kasper, Jamir Marino, Jörg Schmiedmayer, Eugene Demler

We predict a commensurate-incommensurate phase transition in a pair of Raman tunnel-coupled one dimensional Bose gases. Whereas the commensurate phase shows a homogeneous density and homogeneous relative phase, the incommensurate phase is characterized by periodic density modulations and a nite density of solitons in the relative phase of the two Bose gases. Our results are derived using a variational approach to determine the ground state of the model. We demonstrate that under experimentally viable conditions the phases of the microscopic system can be effectively described by the Pokrovsky-Talapov model, a variant of the sine-Gordon eld theory describing an equilibrium transition into a phase with a nite density of solitons. We relate the mismatch parameter of the Pokrovsky-Talapov model with the wave vector difference of the Raman beams, and observe a quantized injection and storage of solitons in the system. We also discuss regimes where the system is described by physics beyond the effective Pokrovsky-Talapov eld theory.

21. Spin Ensembles in Quantum Solids

Andrew Kanagin

Spin technologies are a prime candidate to usher in the next quantum revolution. They offer an ideal system which can be used to study and implement quantum physics. Isolated they are an ideal quantum memory; interacting with each other they are the basis for many body physics. While placed in the correct environment they can be employed as ultra-sensitive sensors. We propose building a new solid state spin system based on impurity spins isolated in spin-0 (quantum) solids. These spin-0 solids offer a uniquely soft environment, creating less stress and pressure induced inhomogeneous broadening on the chosen impurities. Relatively large densities of impurities can be achieved which can enable one to build quantum memories for superconducting quantum information circuits. Our initial choice of impurities will be rubidium, which has a hyperfine splitting capable of being addressed by superconducting coplanar waveguides, while the spin-0 solid will be made out molecular hydrogen (H2). Para-hydrogen, one of the two species of molecular hydrogen has been shown in recent years to be an extremely good candidate for isolating spins at large impurity densities.

22. Efficient non-Markovian quantum dynamics using time-evolving matrix product operators

Peter Kirton, A. Strathearn, D. Kilda, B Lovett, J. Keeling

In order to model realistic quantum devices it is necessary to simulate quantum systems strongly coupled to their environment. To date, most understanding of open quantum systems is restricted either to weak system–bath couplings or to special cases where specific numerical techniques become effective. Here we present a general and yet exact numerical approach that efficiently describes the time evolution of a quantum system coupled to a non-Markovian harmonic environment. Our method relies on expressing the system state and its propagator as a matrix product state and operator, respectively, and using a singular value decomposition to compress the description of the state as time evolves. We demonstrate the power and flexibility of our approach by numerically identifying the localisation transition of the Ohmic spin-boson model, and considering a model with widely separated environmental timescales arising for a pair of spins embedded in a common environment.

23. Quantum state engineering within superposition of causal orders

Seid Koudia, Abdelhakim Gharbi

Non-Gaussian states are considered as a useful resource for many tasks in quantum information processing, from quantum metrology and quantum sensing to quantum communication and quantum key distribution. Another useful tool that is growing attention is the newly constructed quantum switch. Its applications in many tasks in quantum information have been proved to be outperforming many existing schemes in quantum communication and quantum thermometry. In this contribution, we are addressing this later to be very useful to engineer non-Gaussian states from Gaussian operations whose order is controlled by a control qubit. The non-convexity of the set of Gaussian states and the set of Gaussian operations guarantees the emergence of non-Gaussianity after postselection on the control qubit. Conditions on the used gaussian operations are discussed in order to tune and maximize the probability of obtaining non-Gaussian states. The usefulness of the proposed hybrid protocol is compared with other schemes available in the literature.

24. Device-independent information processing with spatiotemporal degrees of freedom

Marius Krumm, Andrew J. P. Garner, Markus P. Mueller

Nonlocality, as demonstrated by the violation of Bell inequalities, enables device-independent cryptographic tasks that do not require users to trust their apparatus. In this poster, we consider devices whose inputs are spatiotemporal degrees of freedom, e.g. orientations or time durations. Without assuming the validity of quantum theory, we prove that the devices' statistical response must respect their input's symmetries, with profound foundational and technological implications. We exactly characterize the bipartite binary quantum correlations in terms of local symmetries, indicating a fundamental relation between spacetime and quantum theory. For Bell experiments characterized by two input angles, we show that the correlations are accounted for by a local hidden variable model if they contain enough noise, but conversely must be nonlocal if they are pure enough. This allows us to construct a Bell witness that certifies nonlocality with fewer measurements than possible without such spatiotemporal symmetries, suggesting a new class of semi-device-independent protocols for quantum technologies.

25. Generating random quantum channels

Ryszard Kukulski, Ion Nechita, Łukasz Pawela, Zbigniew Puchała, Karol Życzkowski

In this work we study the techniques of generating random quantum channels. We present three possible approaches to the problem of sampling random channels. We show that each of these approaches leads to the Lebesgue measure and that these approaches are mathematically quivalent. However, this methods differ in their physical interpretation, mathematical background and computational complexity. On the other hand, we analyzed the invariant state and showing that due to the measure concentration phenomenon it converges asymptotically to the maximally mixed state. Furthermore, we related investigation of random quantum channel to their classical counterpart of random stochastic matrices and demonstrated common properties of the spectra of operators used in both set-ups.

26. Self-referenced Hologram of a Single Photon Beam

Sanjukta Kundu, Wiktor Szadowiak, Jerzy Szuniewicz, Radek Łapkiewicz

Complete characterization of spatial structure of single photons is essential for free space quantum communication and for the efficient extraction of information from light in quantum imaging. We introduce and experimentally demonstrate an interferometric technique which enables complete characterization of a 2D spatial structure of a single photon without using a known reference photon. Our technique relies on the fact that a single photon can interfere with itself. Our setup comprises of a heralded single photon source with an unknown spatial phase and a modified Mach-Zehnder interferometer with a spatial filter in one of its arms. We experimentally confirm the feasibility of our technique for heralded single photons, by reconstructing their spatial phase profile. The technique can be applied to characterize arbitrary pure spatial states of single photons, and due to its simplicity, might find multiple applications in the fields of quantum imaging and communication.

27. Modular generation of high-dimensional entanglement

Jaroslav Kysela, Manuel Erhard, Mario Krenn, Armin Hochrainer, Anton Zeilinger

High-dimensional entanglement plays a crucial role in implementation of many quantum-information protocols. For photonic systems, the orbital angular momentum (OAM) of light can be used to represent a quantum system with three and more dimensions. So far, preparation of an arbitrary high-dimensionally entangled state in OAM has been rather difficult. In our poster, we present a novel way of generation of photons entangled in high dimensions. Our experimental realization relies on the concept of entanglement by path identity. The entanglement does not emerge as a direct result of a physical phenomenon such as spontaneous parametric down-conversion, but rather as a result of indistinguishability of multiple photon-generation processes. Bipartite three-dimensionally entangled states are created in OAM degree of freedom in our setup. The setup allows for straightforward adjustment of local phases as well as magnitudes of individual terms in a coherent superposition. Experimental results are demonstrated for several chosen states.

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28. (Strong) quantum Darwinism and witnessing non-objectivity

Thao Le, Alexandra Olaya-Castro

Objectivity of everyday, classical objects is typically taken for granted, in the sense of having well-defined states independent of observation. Quantum Darwinism [1], along with the associated frameworks of spectrum broadcast structure [2] and strong quantum Darwinism [3], describe the process in which quantum systems become objective. These three [1,2,3] focus on different aspects of objectivity. Regardless, the complete description of any of (strong) quantum Darwinism or spectrum broadcast structure requires full state tomography over the system and accessible environments. Thus, we also describe a subspace dependent witness of non-objectivity that could simplify future experiments on quantum Darwinism.

[1] W. H. Zurek, Nat. Phys. 5, 181 (2009).
[2] R. Horodecki, J. K. Korbicz, and P. Horodecki, Phys. Rev. A 91, 032122 (2015).
[3] T. P. Le and A. Olaya-Castro, Phys. Rev. Lett. 122, 010403 (2019).

29. Prospects for a Cesium Interferometer with Tunable Interactions

Maximilian Lerchbaumer, Benedikt Gerstenecker, Alexander Wiener, Stephanie Manz, Thorsten Schumm

The special scattering properties of caesium atoms, notably the tunability of their scattering length via magnetically induced Feshbach resonances, make them a promising candidate for improving the phase sensitivity in BEC matter-wave interferometry, but also require the use of a trapping scheme not reliant on magnetic fields.

30. Benchmarking and comparison of the Rigetti and IBM Q quantum architectures

Paulina Lewandowska, Łukasz Pawela, Przemysław Sadowski

We have an access quantum computers implementing the gate model of quantum computation. These are the best developed machines, which can be thought of as fully quantum computers, by which we understand that the qubits can be in an entangled state. There are currently two main providers of such architectures. The first one is IBM. In order to access the machine and make programming it simpler for the community, a Python library, qiskit is provided by IBM. The second one is Rigetti. As was the case for IBM, Rigetti also provides a Python library, pyquil, which enables easy access to the machine. In this work, we present and comparison thats architectures. The main goal is to introduce a new benchmark, based on the problem of discrimination of quantum measurements, for NISQ devices.

31. Intersubband Polaritons in Triple Barrier Resonant Tunneling Diodes

Benedikt Limbacher, Martin A. Kainz, Sebastian Schönhuber, Moritz Wenclawiak, Christian Dentl, Andreas Schwaighofer, Bernhard Lendl, Hermann Detz, Aaron M. Andrews, Gottfried Strasser, Juraj Darmo, Karl Unterrainer

We demonstrate the existence of Intersubband Polaritons in Tripble Barrier Resonant Tunneling Diodes, which are devices designed for electrical transport. We invesitgate the influence of Intersubband Polaritons on the electric transport regime and vice-verse. We show that the coupling-strength can be modulated by applying an electric field and hence also an electric current.

32. Circular motion of a quantum impurity in a bosonic bath

Mikhail Maslov, Enderalp Yakaboylu, Mikhail Lemeshko

We consider a rotating quantum impurity (such as a linear ultracold molecule) whose translational motion is confined to a ring in a plane, in the presence of a bosonic environment. A recently performed analytical study of the so-called rotating polaron problem [1] has shown, that the coupling between linear and angular momenta affects quasiparticle states. To extend the studies to a case, when transverse momentum of impurity is not conserved, here, we choose the circular motion of the molecule inside the bosonic gas. We apply the variational method to solve Hamiltonian as well as to calculate the gauge field emerging due to the presence of a bath, similar to [2], that changes the angular momentum of impurity. One may show that in the case of an impurity moving along the circular trajectory in a bosonic bath, its angular momentum is a fractional number. Also, the presence of bath has an impact on effective mass and rotational constant of the impurity.

[1] E. Yakaboylu, B. Midya, A. Deuchert, N. Leopold, M.Lemeshko, Phys. Rev. B. 98 (2018)
[2] E. Yakaboylu, A. Deuchert, M. Lemeshko, Phys. Rev. Lett. 119 (2017)

33. Quantum thermodynamics and the repeatable use of resources

Markus Müller

Thermodynamics at the nanoscale differs significantly from the textbook formulation: the possibility of state transitions is not determined by free energy alone, but by an infinite family of free-energy-like quantities. Here we show, however, that the standard free energy regains exact operational meaning for single particles in quasiclassical states if we allow correlations to build up in the process. We also give a purely quantum information-theoretic version of this theorem in terms of a catalytic entropy conjecture, suggesting a surprising one-shot interpretation of von Neumann entropy, and prove a general no- broadcasting theorem for quantum coherence, yielding further insights into the repeatable use of quantum resources and reference frames.

34. Quantum Phase Transitions in Phase Space

Zakaria Mzaouali, Steve Campbell, Morad El Baz

We apply the Wigner function formalism from quantum optics, through Wootters' discrete Wigner function, to detect quantum phase transitions in critical spin-1/2 systems. We develop a general formula relating the discrete Wigner function and the thermodynamical quantities of spin models, which allows us to introduce a novel way to represent, detect, and distinguish first-, second- and infinite-order quantum phase transitions in phase space. We establish that the discrete Wigner function provides a simple, experimentally promising tool in the study of many-body systems and we show its relation with measures of quantum correlations.

35. QUAPITAL - QUAntum Photonic Intercity TrAnsmission Lattice

Sebastian Neumann, Thomas Scheidl, Rupert Ursin, Anton Zeilinger

Quantum Key Distribution (QKD) holds the promise of unconditionally secure communication. However, high losses in fibers have so far made a “trusted node” scheme necessary if two communication partners were separated by more than 150 kilometers. We present a ground-bound approach which does not require read-outs of the quantum state by anybody but the communication partners themselves, using already existing glass fiber infrastructure. Thus, we will be able to establish the first trusted-node-free country-border-crossing quantum network in Europe. It will connect capital cities and governments, providing unconditionally secure communication.

36. Concepts of work in autonomous quantum heat engines

Wolfgang Niedenzu, Marcus Huber, Erez Boukobza

One of the fundamental questions in quantum thermodynamics concerns the decomposition of energetic changes into heat and work. Contrary to classical engines, the entropy change of the piston cannot be neglected in the quantum domain. As a consequence, different concepts of work arise, depending on the desired task and the implied capabilities of the agent using the work generated by the engine. This provides a unified perspective on quantum work and we illustrate that each work quantifier---from ergotropy to non-equilibrium free energy---has well defined operational interpretations. We analyse these work quantifiers for a heat-pumped three-level maser and derive the respective engine efficiencies. In the classical limit of strong maser intensities the engine efficiency converges towards the Scovil--Schulz-DuBois maser efficiency, irrespective of the work quantifier.

37. A passive photon–atom qubit swap operation

Tal Ohana, Orel Bechler, Adrien Borne, Serge Rosenblum, Gabriel Guendelman, Ori Ezrah Mor, Moran Netser, Ziv Aqua, Niv Drucker, Ran Finkelstein, Yulia Lovsky, Rachel Bruch, Doron Gurovich, Ehud Shafir, Barak Dayan

Deterministic quantum interactions between single photons and single quantum emitters are a vital building block towards the distribution of quantum information between remote systems. Deterministic photon–atom state transfer has previously been demonstrated with protocols that include active feedback or synchronized control pulses. We demonstrate a passive swap operation between the states of a single photon and a single atom. The underlying mechanism is single-photon Raman interaction- an interference-based scheme that leads to deterministic interaction between two photonic modes and the two ground states of a Λ-system. Using a nanofibre-coupled microsphere resonator coupled to single Rb atoms, we swap a photonic qubit into the atom and back, demonstrating fidelities exceeding the classical threshold of 2/3 in both directions. In this simultaneous write and read process, the returning photon, which carries the readout of the atomic qubit, also heralds the successful arrival of the write photon. Requiring no control fields, this single-step gate takes place automatically at the timescale of the atom's cavity-enhanced spontaneous emission. Applicable to any waveguide-coupled Λ-system, this mechanism, which can also be harnessed to construct universal gates, provides a versatile building block for the modular scaling up of quantum information systems.

38. Development of an interferometric multi-pass microscope

Jan Pac, Clara Conrad-Billroth, Thomas Juffmann

Proteins are essential components of living organisms and perform a variety of tasks within cells, ranging from DNA replication to molecular transport. Thus, molecular biology and biomedical research are highly interested in the study of protein structure and dynamics. For dynamic studies, the sensitivity of interferometric imaging techniques has recently been pushed to sensitivity levels that allow the label-free detection of single proteins. Most notably, interferometric scattering microscopy (iSCAT) was used to precisely determine the mass of single proteins. The sensitivity of iSCAT is limited by shot noise and can be improved using cavity enhancement techniques like multi-pass microscopy. Multi-pass microscopy is a quantum optimal way to amplify signal in full field microscopy by re-imaging light multiple times onto the sample. Combining interferometric imaging with multi-pass microscopy should allow us to further increase the sensitivity, enabling dynamic studies of even smaller proteins with numerous possible applications in biomedical research.

39. Strongly Correlated Photon Transport in a Waveguide with Weakly Coupled Emitters

Adarsh Prasad, Jakob Hinney, Klemens Hammerer, Sahand Mahmoodian, Samuel Rind, Philipp Schneeweiss, Anders Sørensen, Jürgen Volz, Arno Rauschenbeutel

We experimentally show correlated photon transport through an optical waveguide that contains an ensemble of weakly coupled quantum emitters. We observe that the photon statistics of the transmitted light can be continuously changed from anti-bunched light to bunched light by solely changing the number of emitters. This effect arises due to an interplay of the nonlinear optical response of the emitters, linear optical losses, and interference between the transmitted and the forward-scattered two-photon states. We use laser-cooled atoms confined in a nanofiber-based optical dipole trap and analyze the transmission through the fiber with single-photon counters. The recorded second-order time-correlation function is in agreement with its theoretical prediction and reaches values as low as g2(0) ~ 0.5.

40. Towards laser refrigeration of NV centres on the nanoscale

Markus Rademacher, J. Gosling, A.T.M Anishur Rahman, P.F. Barker

Nitrogen vacancy (NV) centres in nano-diamonds are of considerable interest for exploring macroscopic quantum mechanics via a type of Ramsey interferometry utilising the single electron spin of the embedded NV [1]. While this idea is attractive, as it does not require strong centre-of-mass cooling, a central issue in its experimental realization is internal heating of the diamond due to the absorbed 532nm light that is used for spin polarisation. This problem intensifies when one tries to levitate the nano-diamond using optical fields, since the thermal interaction with the environment is reduced to the black body radiation of the nanoparticle. A promising route to combat the deleterious effects of heating is the use of a laser-refrigeration via a nanocrystat [2] attached to the NV centre. So far, levitated rare-earth metal doped crystals on the nanoscale have shown to exhibit comparable cooling rates to bulk solid-state material refrigeration [3] where heat transfer from the crystal to the environment occurs by fluorescence without physical contact. A major current obstacle in exploiting the fluorescence based refrigeration of levitated nanometre sized Yb3+:YLF crystals is getting the vacuum sufficiently low to reduce the interaction with the background gas. The poster will discuss feedback cooling implementations based on the redpitaya platform so that the particles can be refrigerated in high vacuum.

[1] M. Scala, M. S. Kim, G. W. Morley, P. F. Barker, and S. Bose, Phys. Rev. Lett. 111, 180403 (2013)
[2] A. T. M. A. Rahman and P. F. Barker, Nature Photonics 11, 634 (2017)
[3] D. V. Seletskiy, R. Epstein, and M. Sheik-Bahae, Reports on Progress in Physics 79, 096401 (2016)

41. Periodically Pulsed Quantum Light from a Superconducting Qubit Ensemble

Elena Redchenko, M. Zens, F. Hassani, M. Peruzzo, H.S. Dhar, D. O. Krimer, S. Rotter, J.M. Fink

Nonclassical light sources are extremely important in the fields of quantum information, quantum communication, and photonic quantum technologies. We study a driven inhomogeneous ensemble of superconducting qubits coupled to a microwave resonator. The constructive rephasing of spins in the frequency comb is predicted to result in a periodic pulse train of quantum light (g2(t,0)<1) which corresponds to the collective transfer of excitations from the qubit ensemble to the resonator [1]. Such periodic nonclassical pulses can be interesting fora temporal synchronization in quantum memory protocols. We will present results of our ongoing experiments on periodic quantum light generation in the system of five transmon qubits capacitively coupled to a coplanar waveguide resonator.

[1] Himadri Shekhar Dhar, Matthias Zens, Dmitry O. Krimer, and Stefan Rotter. Variational renormalization group for dissipative spin-cavity systems: Periodic pulses of nonclassical photons from mesoscopic spin ensembles. Phys. Rev. Lett., 121:133601, Sep 2018.

42. Quantum Information beyond Qubits

Martin Ringbauer

Quantum systems naturally occupy high-dimensional Hilbert spaces that have to be artificially constrained for building qubits. In this poster I explore some of the hidden potential that lies in the unused corners of Hilbert space beyond the two-level approximation. A natural testbed for these explorations is a trapped-ion quantum processor.

43. Quantum Advantage for Probabilistic One-Time Programs

Marie-Christine Röhsner, Joshua A. Kettlewell, Tiago B. Batalhão, Joseph F. Fitzsimons, Philip Walther

One-time programs, computer programs which self-destruct after being run only once, are a powerful building block in cryptography and would allow for new forms of secure software distribution. However, ideal one-time programs have been proved to be unachievable using either classical or quantum resources. Here we relax the definition of one-time programs to allow some probability of error in the output and show that quantum mechanics offers security advantages over purely classical resources. We introduce a scheme for encoding probabilistic one-time programs as quantum states with prescribed measurement settings, explore their security, and experimentally demonstrate various one-time programs using measurements on single-photon states. These include classical logic gates, a program to solve Yao’s millionaires problem, and a one-time delegation of a digital signature. By combining quantum and classical technology, we demonstrate that quantum techniques can enhance computing capabilities even before full-scale quantum computers are available.

44. Quantum Thermal Machines with Cold Atoms

Joao Sabino, M. Tajik, F. Cataldini, T. Schweigler, B. Rauer, J. Schmiedmayer

The field of quantum thermodynamics has evolved significantly over the past years, trying to make clear the role of quantum features in the properties of thermodynamic systems. However, the development of experiments implementing and testing the ideas of quantum thermodynamics, e.g. quantum thermal machines, is still in an early stage. In this work, we propose an experimental implementation of a quantum thermodynamic cycle using 1D clouds of ultra-cold atoms trapped with an atomchip. Using this experimental framework, together with a Digital Micro-mirror Device, we are able to design traps and potentials which allow us to implement and study the primitive operations needed for a quantum version of a thermal machine.

45. Microwave induced single electron transitions between Majorana zero modes in hybrid superconducting-semiconducting islands

Deividas Sabonis

Superconductor-semiconductor structures can be driven into a topological regime by application of an external magnetic field, in which Majorana zero modes emerge. Our contribution extends previous work on Majorana modes in superconducting structures by developing nanowire-based double-island devices where both the Josephson coupling as well as Majorana coupling between islands can be manipulated using gate electrodes, whereas the charge of islands can be measured with high-bandwidth proximal charge sensors. We experimentally study microwave induced transitions between two superconducting islands when the magnetic field along the nanowire axis is applied. At higher magnetic fields we observe a change in gate space periodicity of the microwave induced transitions. Results are compatible with single electron transitions between zero modes on both sides of the junction. From microwave spectroscopy extracted energy scales for Josephson and single electron coupling are fundamentally important quantities for future developments of topologicaly protected qubits.

46. Phase diagrams of strongly correlated cavity-QED systems from exact diagonalization

Michael Schuler

We study a cavity-QED setup where a set of strongly interacting two-level dipoles is non-perturbatively coupled to single-mode electrical field. We apply the Exact Diagonalization method in the Krylov space to exactly compute ground state properties of samples of a few ten dipoles in various configurations and unveil their zero-temperature phase diagrams. Depending on the relative strength of the direct dipole-dipole interactions, the dipole-field interactions, and the spatial configurations of the dipoles we discover an amount of different phases, among them superradiant and different subradiant phases.

47. Using optical nanofibers for quantum optics

Sarah Skoff, Hardy Schauffert, Johanna Hütner, Arno Rauschenbeutel

In recent years, solid-state quantum emitters have gained increased interest as building blocks for quantum networks, quantum metrology and nanosensors. For all these applications, strong light-matter interactions are essential.

A versatile tool to achieve such interactions is an optical nanofiber, which is the tapered part of a commercial optical fiber that has a subwavelength diameter waist. This allows an appreciable amount of light to propagate outside the fiber in the form of an evanescent wave. We use such optical nanofibers to optically address individual molecules in solids and we will present this fully fiber-integrated system in more detail.

Due to the transverse confinement of the light field provided by the optical nanofiber, the interaction with quantum emitters is already significant. However, this nanofiber-based approach can be combined with a fiber-based cavity to enhance the light-matter interaction even further. As many solid-state quantum emitters require cryogenic temperatures, we will show the implementation of an optical resonator for these temperatures and demonstrate that it is sufficient to reach the strong coupling regime.

48. Non-Abelian Majorana fermions in topological s-wave Fermi superfluids

Lauri Toikka

By solving the Bogoliubov-de Gennes equations analytically, we derive the fermionic zero-modes satisfying the Majorana property that exist in vortices of a two-dimensional s-wave Fermi superfluid with spin-orbit cou- pling and Zeeman spin-splitting. The Majorana zero-mode becomes normalisable and exponentially localised to the vicinity of the vortex core when the superfluid is topologically non-trivial. We calculate the energy split- ting due to Majorana hybridisation and identify that the s-wave Majorana vortices obey non-Abelian statistics.

49. Remote Time Manipulation

David Trillo, Benjamin Dive, Miguel Navascues

It has been recently shown that the evolution time of a quantum system can be altered in a heralded way even when we have no knowledge or control over it. This is called time warping. In this contribution, we provide several families of protocols which warp the time of a system. We also show that they are optimal in the sense that it is impossible to drive a system further into its future or past. This improves on previous work in which only resetting protocols were considered, or in which control of the system was required.

50. Rotational feeback cooling of levitated nanorods

Pietro Vahramian, Stephan Troyer, James Millen, Stefan Kuhn, Markus Arndt

In nano-optomechanics with free and levitated nanoparticles, non-spherical objects have attracted increasing interest because of their additional degrees of freedom, which provide a new handle for their manipulation and the observation of new phenomena. While center of mass cooling is expected to open new avenues for matter-wave interferometry and tests of the quantum superposition principle, rotational cooling shall lead to quantum superpositions in rotation and quantum revivals, with applications in extremely sensitive torque sensing. An essential ingredient towards these goals is cavity cooling, which theory predicts to achieve even a 5D ground state cooling, along 3 center of mass directions and two rotational axes [5]. Optical control of the rotational motion has recently been demonstrated with silicon nanorods, but so far, the trapping of the rods was limited to pressures above 1 mbar, where the buffer gas damps instabilities of the trapped rod. This is a severe limit for cavity cooling, particle manipulation and metrology. To overcome this limit, we here discuss our advances in feedback cooling of the translational degrees of freedom and rotational feedback cooling of the two librational motions, via parametric modulation of the trapping intensity and how this influences the capability to trap the rods in different pressure regimes.

51. Coupling a single trapped atom to a whispering-gallery-mode microresonator

Elisa Will, Luke Masters, Michael Scheucher, Jürgen Volz, Arno Rauschenbeutel

Whispering-gallery-mode (WGM) resonators provide ultra-high optical quality factors in combination with small optical mode volumes. This enables one to strongly couple single atoms to the evanescent field of such resonators. In addition, these resonators provide chiral, i.e. propagation-direction-dependent, light-matter interaction [1] which enables novel functionalities for classical and quantum devices [2]. However, trapping atoms in the evanescent field of such resonators has so far been an elusive goal, severely hampering the applicability of WGM resonators for future applications.

In our experiment we show that we can trap single atoms in the resonator mode at a distance of ~200nm from the surface of the WGM microresonator using a standing-wave optical dipole trap which is created by retroreflecting a focused beam on the resonator surface [3]. In addition, we present a method to remove the light shift of the trapped atom's transition, which allows us to measure the transmission spectrum of the atom-resonator system.

[1] C. Junge et al. PRL 110, 213604 (2013)
[2] M. Scheucher et al. Science 354, 1577 (2016)
[3] J. D. Thompson et al. Science 340, 1202 (2013)

52. Engineering Strongly Correlated States in Bose-Einstein Condensate using Optimal Control Theory

Tiantian Zhang, Filippo Borselli, Mira Maiwöger, Philipp Haslinger, Marie Bonneau, Jörg Schmiedmayer

Strongly correlated, such as entangled states and squeezed states, are key elements in quantum technologies and are broadly applied. One of the many important applications are in quantum sensing beyond the standard quantum limit. In this work, we demonstrate how one can use one-dimensional quasi Bose-Einstein condensates (BECs) to engineer such strongly correlated states. In order to achieve the desired states, implementation of optimal control theory is crucial, since it enables one to reach the target states with high fidelity. Within the scope of this work, we are applying the optimal control algorithm Chopped Random Basis (CRAB) method for producing pairs of entangled atoms from motionally excited BECs and the Gradient Ascent Pulse Engineering (GRAPE) algorithms have been used to develop experimental sequences for maximizing the spin squeezed states.

53. General generation of pure two-qubit states and entanglement diagnosis by single-qubit tomography

Fabio Auccapuclla, J. Gonzales, P. Gonzales, B. Miller, M. V. Andrés and F. De Zela

We report experimental tests of a protocol designed to generate and tomographycally characterize pure two-qubit states. Our protocol allows us to perform both two-qubit characterization and entanglement measurement by single-qubit polarization tomography. We carried out our tests using classical light with qubits encoded as binary-path and polarization.

54. Optimally correlationg unitaries in multipartite systems

Faraj Bakhshinezhad, Fabien Clivaz, Giuseppe Vitagliano, Paul Erker, Ali Rezakhani, Marcus Huber, Nicolai Friis

Correlations lie at the heart of almost all scientific predictions. It is therefore of interest to ask whether there exist general limitations to the amount of correlations that can be created at a finite amount of invested energy. Within quantum thermodynamics such limitations can be derived from first principles. In particular, it can be shown that establishing correlations between initially uncorrelated systems in a thermal background has an energetic cost. This cost, which depends on the system dimension and the details of the energy-level structure, can be bounded from below but whether these bounds are achievable is an open question. Here, we put forward a framework for studying the process of optimally correlating identical (thermal) quantum systems. The framework is based on decompositions into subspaces that each support only states with diagonal (classical) marginals. Using methods from stochastic majorisation theory, we show that the creation of correlations at minimal energy cost is possible for all pairs of three- and four-dimensional quantum systems. For higher dimensions we provide sufficient conditions for the existence of such optimally correlating operations, which we conjecture to exist in all dimensions.