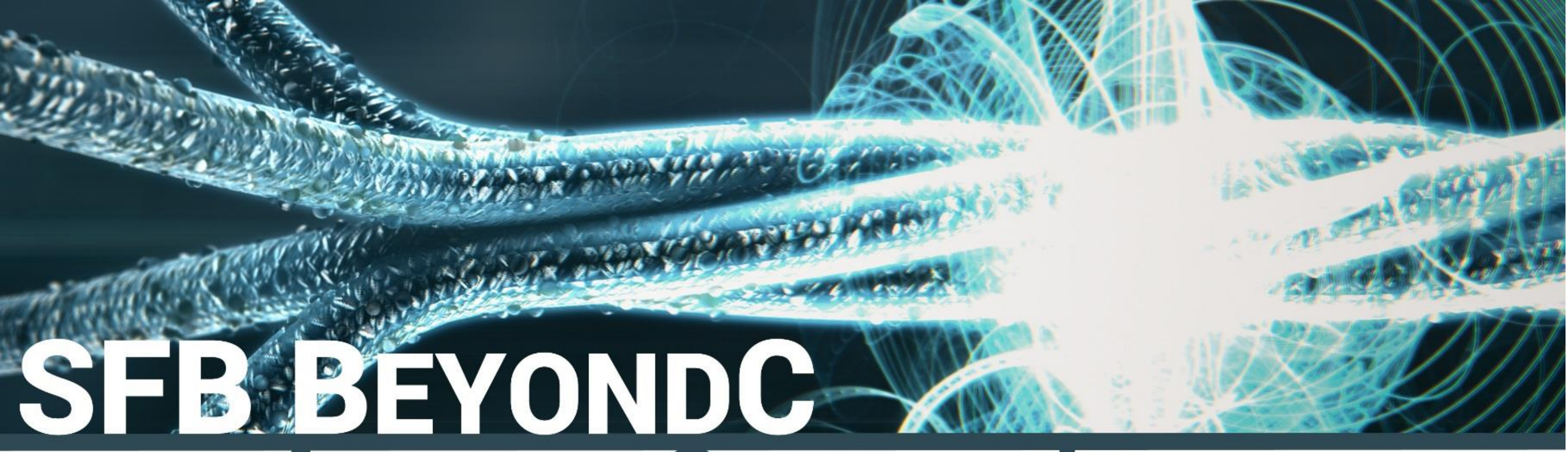

AUSTRIAN QUANTUM INFORMATION CONFERENCE 2019

Thursday, OCTOBER 31st

Ceremonial Hall, University of Vienna

BOOK OF ABSTRACTS

INVITED SPEAKERS

& POSTER CONTRIBUTIONS

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INVITED SPEAKERS

Ignacio CIRAC
Max Planck Institute

Symmetries and State Transformation with Tensor Networks

Tensor networks offer efficient ways of describing and dealing with certain multipartite quantum states. The one-dimensional version, so-called matrix product state (MPS) appear very naturally in the context of systems in thermal equilibrium, and also describe many of the features that appear in quantum optical systems. Despite their high description power, they are relatively simple to analyze and characterize. In this talk, after describing the basic mathematical facts of translationally invariant MPS, we analyze their entanglement and symmetry properties. We give a criterion to determine when two states can be transformed into each other by SLOCC transformations, a central question in entanglement theory. We use that criterion to determine SLOCC classes, and explicitly carry out this classification for the simplest, non-trivial MPS. We also characterize all symmetries of MPS, both global and local (inhomogeneous). We illustrate our results with examples of states that are relevant in different physical contexts.

Barak DAYAN
Weizmann Institute of Science

Photon-Atom Gates for Hybrid Quantum Information Processing

Deterministic quantum gates between single photons and single quantum emitters are a valuable building block for the distribution of quantum information between remote systems, as well as for the construction of photonic quantum states. I will review the tools cavity-QED provides for the construction of such gates, and present our recent demonstration of a native photon-atom qubit SWAP gate [1]. The underlying mechanism is single-photon Raman interaction (SPRINT) - an interference-based effect in which a photonic qubit deterministically controls the state of a material qubit and vice versa [2-4]. This open-system scheme, which had also been demonstrated in microwave with superconducting qubits [5-6], is applicable to any waveguide-coupled Lambda system, including ions [7] and quantum dots [8], and can serve as a basis for a variety of other photon-"atom" interactions - from universal gates, through single photon subtraction and addition, to the preparations of a wide range of photonic quantum states [9].

[1] Nature Physics 14, 996 (2018)
[2] Science 345, 903 (2014)
[3] Nature Photonics 10, 19 (2016)
[4] Phys. Rev. A 95, 033814 (2017)
[5] Phys. Rev. Lett. 113, 063604 (2014)
[6] Nature Communications 7, 12303 (2016)
[7] arXiv:1902.03469v2 [quant-ph] (2019)
[8] Rev. Mod. Phys. 87, 347 (2017)
[9] Photonics Research 7, A45 (2019)

Ashley MONTANARO
University of Bristol

Quantum Algorithms for Constraint Satisfaction and Optimisation Problems

Quantum algorithms can deliver asymptotic speedups over their classical counterparts. However, as quantum computers become a reality, it becomes increasingly important to determine the real-world runtimes and other complexity parameters of these algorithms, taking into account all realistic overheads. In this talk I will discuss how general-purpose quantum algorithms for solving constraint satisfaction problems can be applied to two families of prototypical NP-complete problems: boolean satisfiability and graph colouring. Even when considering only problem instances that can be solved within one day, we find that there are potentially large quantum speedups available in the long term. In the most optimistic parameter regime we consider, this could be a factor of over 10^5 relative to a classical desktop computer for random instances; in the least optimistic regime, the speedup is reduced to a factor of over 10^3. However, the number of physical qubits used is extremely large, and improved fault-tolerance methods will likely be needed to make these results practical. I will also describe a quantum algorithm that achieves a quadratic speedup over the general classical method known as branch-and-bound for solving combinatorial optimisation problems.

Tracy NORTHUP
University of Innsbruck

Beyond Classical Capabilities with Trapped-Ion Networks

How can networks based on trapped ions enable us to go beyond classical capabilities for quantum communication and computation? I will discuss our plans for an elementary demonstration of distributed computing within BeyondC, linking together two cavity-coupled ion strings, in separate vacuum chambers, via optical fiber. Using remote entanglement as a resource, we intend to carry out and characterize tasks on this distributed ion-trap processor. Looking towards future long-distance networks of multiple qubits, we will also test recently proposed approaches for mitigating photon loss in channels linking optical cavities. I will present ongoing experimental work to link remote trapped-ion systems in Innsbruck, including characterization of a new fiber-based cavity platform.

William OLIVER
MIT Lincoln Laboratory

Quantum Engineering of Superconducting Qubits

Superconducting qubits are coherent artificial atoms assembled from electrical circuit elements and microwave optical components [1]. Their lithographic scalability, compatibility with microwave control, and operability at nanosecond time scales all converge to make the superconducting qubit a highly attractive candidate for the constituent logical elements of a quantum information processor [2,3]. In this talk, we review the promise, progress, and challenges of engineering systems of superconducting qubits [4]. We will also briefly discuss the Center for Quantum Engineering at MIT, its industrial consortium, and their role in training tomorrow's quantum workforce.

[1] P. Krantz, M. Kjaergaard, F. Yan, T.P. Orlando, S. Gustavsson, W.D. Oliver, "A Quantum Engineer's Guide to Superconducting Qubits," Appl. Phys. Reviews 6, 021318 (2019) | arXiv:1904.06560
[2] M. Kjaergaard, M.E. Schwartz, J. Braumueller, P. Krantz, J.I-J. Wang, S. Gustavsson, W.D. Oliver, "Superconducting qubits: Current state of play," arXiv:1905.13641
[3] D. Rosenberg, D.K. Kim, R. Das, D. Yost, S. Gustavsson, D. Hover, P. Krantz, A. Melville, L. Racz, G.O. Samach, S.J. Weber, F. Yan, J. Yoder, A.J. Kerman, W.D. Oliver, "3D integrated superconducting qubits," npj Quantum Information 3, 42 (2017) | arXiv:1706.04116
[4] W.D. Oliver and P.B. Welander, "Materials in Superconducting Qubits," MRS Bulletin 38, 816-825 (2013)

Fabio SCIARRINO
Sapienza University of Rome

Machine Learning for Processing and Certification of Photonic Quantum Information

Photonic technologies provide a promising platform to address at a fundamental level the connection between quantum information and machine learning. As first step in this direction, we will address the design and implementation of protocols that apply classical machine learning methods to problems of quantum information theory: learning of quantum states and quantum metrology. We will then exploit machine learning as a tool to validate quantum devices such as Boson Samplers. Indeed, the difficulty of validating large-scale quantum devices poses a major challenge for any research program that aims to show quantum advantages over classical hardware. To address this problem, we propose a novel data-driven approach wherein models are trained to identify common pathologies using supervised and unsupervised machine learning. Our results provide evidence on the efficacy and feasibility of this approach, paving the way for its adoption in large-scale implementations.

POSTER CONTRIBUTIONS

OCTAGON 1

1 | Quantum Computing with Graphene Plasmons

Irati Alonso Calafell, J. D. Cox, M. Radonjić, J. R. M. Saavedra, F. J. García de Abajo, L. A. Rozema, P. Walther

Among the various approaches to quantum computing, all-optical architectures are especially promising due to the robustness and mobility of single photons. However, the creation of the two-photon quantum logic gates required for universal quantum computing remains a challenge. Here we propose a universal two-qubit quantum logic gate, where qubits are encoded in surface plasmons in graphene nanostructures, that exploits graphene's strong third-order nonlinearity and long plasmon lifetimes to enable single-photon-level interactions. In particular, we utilize strong two-plasmon absorption in graphene nanoribbons, which can greatly exceed single-plasmon absorption to create a “square-root-of-swap” that is protected by the quantum Zeno effect against evolution into undesired failure modes. Our gate does not require any cryogenic or vacuum technology, has a footprint of a few hundred nanometers, and reaches fidelities and success rates well above the fault-tolerance threshold, suggesting that graphene plasmonics offers a route towards scalable quantum technologies.

2 | Generation of optical Fock and W states with single-atom-based bright quantum scissors

Ziv Aqua, M. S. Kim, B. 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 realizes 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.

3 | Compact and bidirectional conversion of microwave and optical signals at Millikelvin temperatures

Georg Arnold, M. Wulf, E. Redchenko, S. Barzanjeh, A. Rueda, W. Hughes, J. M. Fink

Superconducting circuits are promising candidates for future quantum processors. However, when it comes to long distance communication, small energy microwave signals show significant drawbacks compared to optical photons, since optical fibers offer ultra-low loss transmission and unmatched resilience to thermal noise and environmental interference. High efficiency conversion between microwaves and optical wavelengths would therefore represent a key feature to establish a long distance quantum network of superconducting processors. We will present our work on an integrated on-chip converter showing bidirectional conversion between microwave and optical photons with efficiencies around 1%. Our approach on a silicon-on-insulator platform is fully compatible with superconducting qubits

4 | Automated Design of Superconducting Circuits

Philipp Aumann, W. Lechner

Superconducting circuits are an important platform for the realization of qubits or qubit networks. During the past, many different circuits have been designed and tested which differentiate in their quantum mechanical properties. We created a toolbox to automate the process of finding suitable circuits in the transmon regime. Circuits are stored as graphs from which a corresponding symbolic Hamiltonian is constructed by the algorithm. Eventually, this Hamiltonian is quantized and numerically expressed which opens the way for the investigation of its quantum mechanical properties. In this way, it is possible to search for circuits automatically that realize certain Hamiltonian terms, while taking the length of the circuit and the anharmonicity of the corresponding subsystems into account.

5 | Characterising the performance of QAOA to solve NP problems on NISQ devices

Utkarsh Azad, L. Priyadarshi

Even though fault-tolerant quantum computers appear to be more than a decade away, slow but steady progress in quantum technology has lead to the development of Noisy Intermediate-Scale Quantum (NISQ) devices. Since, the limited connectivity, short coherence time, and poor qubit quality along with minimal error-correction place major restrictions on their computational capabilities, there’s a growing interest in finding tasks appropriate for these near term quantum machine. With this intention, a class of hybrid quantum-classical algorithms have been proposed which integrate quantum processors with the classical ones to solve a given problem. One such algorithm Quantum Approximate Optimization Algorithm (QAOA), encodes the objective function of a problem of interest in a target spin Hamiltonian to perform the optimization. Since various combinatorial optimization problems can be mapped to the Ising problem, we describe here the formulation of Graph Partitioning problem and Hamiltonian Cycle problem as instances of the Ising problem and then attempt to solve them QAOA on a density matrix simulator developed by us. Furthermore, in order to simulate the hardware of NISQ devices more realistically, our simulator incorporates various error models related to initialisation, logic gates, memory and measurement. Using these models, we benchmarked the effect of thermalization, decoherence, amplitude decay, depolarization, imprecise rotation gates on the performance of QAOA algorithm.

6 | Verification of Quantum Optimizers

Flavio Baccari, C. Gogolin, P. Wittek, A. Acín

Classical Ising models are among the most paradigmatic and widely studied models in statistical physics. Moreover, they can also be used to encode optimization problems that have relevant applicaitons in fields as diverse as risk assessment in finance, logistics and machine learning. An ubiquitous question for such optimization problems is to determine the ground-state energy and configuration of these models. The generality and exponentially growing configuration spaces of such models, however, precludes the existence of any efficient general purpose algorithm to obtain the ground state. It is hence no surprise that a wealth of approximate but more scalable classical and quantum techniques for the energy minimization in such models has been developed. However, all these methods have one thing in common: they only yield upper bounds on the ground state energy. It is thus a problem of great importance to develop schemes that provide lower bounds to the ground state energy, against which the results of such widely used upper-bound techniques can be compared. In this poster, I will address this issue and introduce a novel technique, the so-called chordal-branch-and-bound (CBB), to obtain a converging series of lower and upper bounds to the ground state energy with a computational effort that is polynomial in the size of the system per step. I will also show how it can be used to verify the solution of quantum annealing devices such as the D-Wave 2000Q machine.

7 | Evolution of a scalar field in curved spacetime: a general method

Ana Lucia Baez Camargo, L. C. Barbado, I. 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.

8 | Entangled Radiation from Superconducting Circuits

Shabir Barzanjeh, J. 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 electromechanic 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.

9 | Quantum acousto-optic control of light-matter interactions in nanophotonic networks

Giuseppe Calajo, M. J. A. Shuetz, H. Pichler, M. D. Lukin, P. Schneeweiss, J. Volz, P. Rabl

We analyze the coupling of atoms or atom-like emitters to nanophotonic waveguides in the presence of propagating acoustic waves. Specifically, we show that strong index modulations induced by such waves can drastically modify the effective photonic density of states and thereby influence the strength, the directionality, as well as the overall characteristics of photon emission and absorption processes. These effects enable a complete dynamical control of light-matter interactions in waveguide structures, which even in a two dimensional system can be used to efficiently exchange individual photons along selected directions and with a very high fidelity. Such a quantum acousto-optical control provides a versatile tool for various quantum networking applications ranging from the distribution of entanglement via directional emitter-emitter interactions to the routing of individual photonic quantum states via acoustic conveyor belts.

10 | Accessing ion crystal motion with light interference

Giovanni Cerchiari, G. Araneda, L. Podhora, Y. Colombe

For implementing quantum technologies, the analysis and control of motion of trapped ions is fundamental. We detect a single Ba+ ion oscillations by using the self-interference of the fluorescence light. The technique is sensitive to the ion position and only relies on the light scattered by the atoms. Thus, the method can be applied to complex light scatters that have no electronic forbidden transition, such as trapped nanoparticles. We tested our technique also with a two-ion chain and resolved all the oscillation modes of the confined crystal.

11 | Quantum processes and absolute time

Durgadas Datta

Modern physics on various tensions due to misinterpretation of time in classical and quantum arena with a wrong Copenhagen interpretation and partially correct relativity theory in more dynamic space-time with pilot waves theory for milky way galaxy separating from the mother universe by a dark pull causing Hubble tension etc.

12 | Inaccessible entanglement in SPT phases

Caroline deGroot, D. T. Stephen, A. Molnar, N. Schuch

We study symmetry-restricted local operations and classical communication (sym-LOCC) and define the accessible entanglement under super-selection rules (SSR). We determine a new tool for the characterisation of symmetry protected topological (SPT) phases, namely the inaccessible entanglement, which relates quite naturally to the edge mode degeneracy, and existing tools such as SPT-entanglement and string order parameters. However, inaccessible entanglement is a measure with a clear operational meaning framed within the context of resource theory of entanglement. This inaccessible entanglement is interpreted as being stored in the presence of SPT order, since the SPT phase reduces the amount of entanglement which acts as a resource under the allowed LOCC; it is therefore named the SPT-stored entanglement E_S. We derive a tight bound on E_S, showing that $\log(\frac{|G|}{|k|}) \leq E_S \leq \log(|G|)$, and investigate the properties of states which saturate the upper and lower bounds, particularly focusing on certain examples of maximally non-commutative phases such as the Haldane phase, which have the highest edge-mode degeneracy, and embeddings of such phases, as well as exploring the relation to the computational power of such systems.

13 | Stroboscopic Rydberg dressing for near term quantum optimization

Clemens Dlaska, W. Lechner, P. Zoller, R. van Bijnen

State of the art experiments with cold neutral atoms are capable of arranging in the order of one hundred particles in arbitrary geometries. Off-resonant laser excitation to strongly interacting Rydberg states (Rydberg dressing) allows to realize a broad class of non-trivial many-body spin Hamiltonians for quantum simulation and quantum optimization. Here we are interested in applying the dressing laser light in pulses resulting in a stroboscopic version of Rydberg dressing, allowing us to realize arbitrary interaction graphs. We numerically optimize the shape of the laser pulses with respect to the desired interaction while at the same time minimizing decoherence effects such as, for example, due to atomic motion. Our stroboscopic Rydberg-dressing scheme can be used to implement quantum approximate optimization algorithms for solving quantum optimization tasks on near term devices.

14 | Cross-Platform Verification of Intermediate Scale Quantum Devices

Andreas Elben, B. Vermersch, R. van Bijnen, C. Kokail, T. Brydges, C. Maier, M. Joshi, R. Blatt, C. F. Roos, P. Zoller

Recently, protocols based on statistical correlations between random measurements were developed in context of engineered quantum many-body systems, to access Renyi entropies, out-of-time-ordered correlators and topological invariants [1-4]. On this poster, we focus on the Cross-Platform Verification of quantum computers and simulators by means of fidelity measurement. We show how to measure the overlap between (reduced) density matrices, and the (mixed-state) fidelity of two quantum states prepared on separate experimental platforms. The protocol requires only local measurements (in randomized product bases) and classical communication. As a proof-of-principle, we present the measurement of experiment-theory fidelities for entangled 10-qubit quantum states in a trapped ion quantum simulator.

[1] A. Elben, B. Vermersch, M. Dalmonte, J. I. Cirac, and P. Zoller Phys. Rev. Lett. 120, 050406 (2018)
[2] T. Brydges,, A. Elben, P. Jurcevic, B. Vermersch, C. Maier, B.P. Lanyon, P. Zoller, R. Blatt, C. F. Roos, Science 364, 260 (2019)
[3] B. Vermersch, A. Elben, L. M. Sieberer, N. Y. Yao, and P. Zoller, Phys. Rev. X 9, 021061 (2019)
[4] A. Elben, J. Yu, G. Zhu, M. Hafezi, F. Pollmann, P. Zoller, B. Vermersch, arXiv:1906.05011

15 | Entanglement of stabilizer states

Matthias Englbrecht, D. Sauerwein, R. Brieger, B. Kraus

LOCC transformations provide a meaningful order in the set of entangled states. In order to understand the capabilities of stabilizer states under LOCC and thus to find new applications for them, it is essential to characterize their local symmetries. Since every stabilizer state is Local Clifford equivalent to a graph state [1] it is sufficient to characterize the symmetries for this set of states. We show that in addition to graph states with a continuous symmetry group and graph states with just the stabilizer, there are states with a finite local symmetry group larger than the stabilizer. Furthermore we demonstrate that this additional symmetry allows for more finite round LOCC transformations from a single resource state than just the stabilizer symmetries.

[1] Van den Nest, Maarten, Jeroen Dehaene, and Bart De Moor. "Graphical description of the action of local Clifford transformations on graph states." Physical Review A 69.2 (2004): 022316.

16 | Controlling photon generation in ion-cavity systems for quantum networks

Dario Fioretto, M. Galli, Y. Pu, M. Teller, K. Schüppert, V. Messerer, Y. Zou, R. Blatt, T. Northup

The problem of scalability is currently one of the most important challenges in the field of quantum computing. A possible solution is to interconnect multiple computers and consider each computer as a node of a quantum network. Our implementation of such a quantum network node is an ion trap interfaced with a cavity. Here, the cavity has the role of efficiently collecting photons produced by ions in the network. Quantum information is encoded in those photons and thus transferred between the nodes. Our work focuses specifically on sending and receiving photons at the nodes. Those photons are generated via a three-level lambda-type scheme known as a cavity-mediated Raman transition, in which a laser drive is applied to one branch of the lambda transition, and the cavity enhances the efficiency of photon emission and collection on the other branch. The topic of our poster is twofold: first, we show how manipulating the temporal intensity profile of the laser drive allows us to control the temporal wavepacket of the photon leaving the node; secondly, we show how this concept can be used to improve the matching of different kind of cavity systems.

17 | Photonic architecture for reinforcement learning

Fulvio Flamini, A. Hamann, S. Jerbi, L. M. Trenkwalder, H. Poulsen Nautrup, H. 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.

18 | Spatial Resolution in Quantum Imaging with Undetected Photons

Jorge Fuenzalida, A. Hochrainer, G. B. Lemos, M. Lahiri, A. Zeilinger.

I am presenting the experimental results of the spatial resolution in the quantum imaging with undetected photons [Nature 512, 409 (2014)]. We studied the effects of the momentum correlation of a photon pair on the resolution. Because this is a two photon scheme, we also determine which one of the photon governs the resolution.

19 | Towards strong coupling of a trapped ion to a fiber cavity

Maria Galli, M. Teller, K. Schüppert, F.R. Ong, P. Jobez, D. A. Fioretto, K. Friebe,, V. Messerer, R. Blatt, T. E. Northup

Trapped ions coupled to optical cavities can be used to build up quantum interfaces between stationary and flying qubits in a quantum network. Fiber-based optical cavities have been coupled to single ions, and it is expected that these cavities will allow access to the strong coupling regime. Operating in this regime would enable quantum communication protocols to be carried out over long distances with enhanced fidelity and efficiency. We have constructed an ion-cavity system consisting of a linear ion trap and a fiber cavity with finesse of 70,000 at a length of 550μm, designed to reach the strong coupling regime. However, charges on the fiber mirror's surfaces were observed to alter the trap potential and to push ions out of the center of the trap. We subsequently developed a method in which we use a single ion as a sensor for the surface charge density, enabling the reconstruction of the number of charges on the fibers. Furthermore, we have designed and constructed a novel ion-cavity system which incorporates compensation of the surface charges, based in part on the charge reconstruction. I will discuss the method for reconstructing the surface charge density and will present details on our ion-cavity system.

20 | Towards the characterisation of LOCC in a multi-state setting

David Gunn, A. Neven, M. Hebenstreit, L. Czarnetzki, B. Kraus

Entanglement theory is a resource theory in which local operations assisted by classical communication (LOCC) are the free operations. Therefore, characterising transformations under LOCC is vital to an understanding of multipartite entanglement. However, for homogeneous systems larger than three qubits, almost all states are isolated under LOCC. That is, almost all states can neither be reached from, nor reach, any other state via LOCC. Moreover, there are an infinite number of Stochastic LOCC (SLOCC) classes. States in one SLOCC class cannot be transformed, even probabilistically, via LOCC into states in any other SLOCC class. One approach to resolving these issues is characterising LOCC in the multi-state (non-asymptotic) setting. Counter-intuitively, we observed that in the multi-state regime one can easily change SLOCC class using only Local Unitaries (LUs). We, therefore, study LU transformations in the multi-state setting, with the ultimate aim of understanding better multipartite LOCC transformations in the multi-state setting.

21 | Rapid counter-diabatic and inhomogeneous sweeps in the LHZ model

Andreas Hartmann, W. Lechner

We present a coherent counter-diabatic quantum protocol to prepare ground states in the lattice gauge mapping of all-to-all Ising models (LHZ) with considerably enhanced final ground state fidelity compared to a quantum annealing protocol. We make use of a variational method to find approximate counter-diabatic Hamiltonians that has recently been introduced by Sels and Polkovnikov [Proc. Natl. Acad. Sci. 114, 3909 (2017)]. The resulting additional terms in our protocol are time-dependent local on-site y-magnetic fields. A single free parameter is introduced which is optimized via classical updates. The protocol consists only of local and nearest-neighbor terms which makes it attractive for implementations in near term experiments. We further present an inhomogeneous driving protocol in LHZ with modified transverse fields with improved ground state fidelity and enlarged minimal energy gaps. The inhomogeneously driven transverse field introduces an additional time-dependent parameter that improves the efficiency of the method. For the 2D lattice gauge model LHZ we analytically derive the free energy term and numerically verify it.

22 | All pure fermionic non-Gaussian states are magic states for matchgate computations

Martin Hebenstreit, R. Jozsa, B. Kraus, S. Strelchuk, M. Yoganathan

In this work we study the boundary between classical and quantum computational power. Magic states were introduced in the context of Clifford circuits as a resource that elevates classically simulatable computations to quantum universal capability, while maintaining the same gate set. Here we study magic states in the context of matchgate (MG) circuits, where the notion becomes more subtle, as MGs are subject to locality constraints and also the SWAP gate is not available. We give a characterization of pure magic states. Moreover, we show that despite fundamental differences between the Clifford gates and the matchgates, surprisingly similar behaviour regarding complexity of simulation arises.

23 | 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.

24 | Quantum-enhanced information speed

Sebastian Horvat, B. Dakić

The speed of the transmission of a physical signal from a sender to a receiver is limited by the speed of light, regardless of the physical system being classical or quantum. In this sense, quantum mechanics can not provide any enhancement of the speed of information. On the other hand, given that the information that needs to be sent/collected is not localized at the sender's location, but dispersed throughout space, spatial coherence might provide an enhancement of the information speed. In this work, we show that this is indeed the case, by providing a clear quantum mechanical advantage in the speed of acquirement and transmission of information globally encoded in space.

25 | Scalable quantum computation - keeping a qubit alive

Pavel Hrmo, M. van Mourik, L. Gerster, T. Monz, P. Schindler, R. Blatt

Trapped atomic ion systems have demonstrated the prerequisite quantum control to implement universal gate sets for performing arbitrary quantum algorithms. The main challenge remains in scaling up the number of qubits such that quantum error correction on a logical qubit can be implemented. To push towards a scalable design, we work with strings of ions in a cryo- genically cooled planar surface trap with multiple trapping zones. Our setup supports the trapping of two ion species, 40Ca+ and 88Sr+, where the Sr ion can either be used for sympathetic re-cooling of the motional modes of the ion string or additional coherent control. The Ca+ ion acts as an optical qubit with coherence times of up to 31 ms. The low heating rate of the axial motion at 1.1 MHz of 12.7(13) phonons/s allows us to perform maxi- mally entangling Ca+- Ca+ gates with fidelities of 98.0(3)% and 90(3)% for 2 and 4 ions respectively. A 0.8 NA lens yields two ion state discrimination error of 10-3 in 100 us.

26 | A hybrid, time and polarisation source of entangled photons for linear optical quantum computation

Maxime Jacquet, F. Laudenbach, L. Rozema, P. 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 hybrid, polarisation and time-bin entangled state. The heralded, signal photon is sent into an unbalanced Michelson-Faraday interferometer to create a superposed state of two temporal modes, and its' polarisation information is erased. Its' state may be manipulated by means of projective measurements on the polarisation state of the idler. The resulting state is measured by quantum state tomography in the Energy-Time basis. Our methods can be used in quantum computing experiments, where single mode operation is of paramount importance.

27 | A framework for deep energy-based reinforcement learning with quantum speed-up

Sofiene Jerbi, H. Poulsen Nautrup, L. M. Trenkwalder, H. J. Briegel, V. Dunjko

In the past decade, deep learning methods have seen tremendous success in various supervised and unsupervised learning tasks such as classification and generative modeling. More recently, deep neural networks have emerged in the domain of reinforcement learning as a tool to solve decision-making problems of unprecedented size. Despite the successful combinations of ideas from quantum computing with machine learning methods, there have been relatively few attempts to design quantum algorithms to enhance deep reinforcement learning. This is partly due to the absence of a proper generalization of deep neural networks to the quantum domain to begin with. In contrast, projective simulation is a reinforcement learning model inspired by the stochastic evolution of physical systems that enables a quantum speed-up in decision making. In this paper, we develop a unifying framework which connects deep learning and projective simulation, opening the route to quantum improvements in deep reinforcement learning. Our approach is based on so-called generative energy-based models to design reinforcement learning methods with a computational advantage in solving complex and large-scale decision-making problems.

28 | Spins in Quantum Solids

Andrew Kanagin, A. Angerer, J. Schmiedmayer

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.

29 | Side-band Inequivalence: The Unexpected Symmetry Breaking

Sina Khorasani

Frequency shifts of red- and blue-scattered (stokes/anti-stokes) side-bands in quantum optomechanics are shown to be counter-intuitively inequal, resulting in an unexpected symmetry breaking. This difference is referred to as Side-band Inequivalence (SI) [1,2], which normally leans towards red, and being a nonlinear effect it depends on optical power or intracavity photon number. Also, there exists a maximum attainable SI at an optimal operation point. The mathematical method employed here is a combination of a new operator algebra referred to as the method of higher-order operators [1-4] equipped with harmonic balance, which allows a clear understanding of the associated nonlinear process. This reveals the existence of three distinct operation regimes in terms of pump power, two of which have immeasurably small SI. Compelling evidence from various experiments sharing similar interaction Hamiltonians, including quantum optomechanics, ion/Paul traps, electrooptic modulation, Brillouin scattering, and Raman scattering are presented, which unambiguously confirm existence of a previously unnoticed SI. Condition for presence of SI is simultaneous presence of nonlinear dynamical backaction as well as nonlinear modulation terms.

[1] S. Khorasani, Scientific Reports 9, 9075 (2019)
[2] S. Khorasani, Scientific Reports 8, 11566 (2018)
[3] S. Khorasani, Scientific Reports 8, 16676 (2018)
[4] S. Khorasani, Scientific Reports 9, 1830 (2019)

Octagon 2

30 | Quantum networks with single trapped ions in ultraviolet fiber cavities

Pascal Kobel, H.M. Meyer, T. Ballance, K. Kluge, M. Breyer, J. Schmitz, V.S. Nair, R. Berner, M. Köhl

We investigate the integration of fiber cavities into ion traps for use in quantum networks. Up to now, fiber cavities have been combined with trapped ions only in the infra-red spectral range. Since ions typically have their strongest dipole transition in the ultraviolet (UV), the extension of fiber cavities to work in the UV is important for high bandwidth networks. We present coupling of a single Ytterbium ion to a 150 μm long fiber cavity, which is resonant with the electric dipole transition at 370 nm. We achieve a coherent coupling rate of a single ion to the cavity of about g/2p = 60 MHz, which exceeds previous realizations by more than one order of magnitude. Using the Purcell effect, we demonstrate single photon generation by continuous and pulsed ion excitation. Coherent manipulation of the hyperfine qubit, using microwaves and optical Raman pulses, enables us to investigate entanglement between the photon polarization and the spin state of the ion.

31 | Quantum NonGaussianity from an indefinite causal order of Gaussian operations

Seid Koudia, A. 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.

32 | Fast Quantum Oblivious Transfer for Secure Multiparty Computation

Mariano Lemus, P. Schiansky, M.-C. Röhsner, M. Goulão, P. Yadav, S. Zeppetzauer, A. Souto, N. Paunković, P. Mateus, P. Walther

Motivated by the usefulness of secure multiparty computation as a privacy-protecting data analysis tool, and identifying its oblivious transfer cost as its main implementation challenge, we propose a practical realisation of quantum oblivious transfer. The protocol uses cryptographic hash functions to implement commitments, as well as to increase secure (oblivious) key rates, as compared to techniques based on standard error correction during classical post processing. The security of the resulting oblivious transfer is analysed within the framework of universal composability. Preliminary results of performance from an experimental setup based on photon polarisation encoding are provided.

33 | Variational Quantum Simulation with Trapped Ions

Christine Maier, C. Kokail, R. van Bijnen, T. Brydges, M. K. Joshi, P. Jurcevic, C. A. Muschik, P. Silvi, R. Blatt, C. F. Roos, P. Zoller

A quantum simulator employs a highly controllable, well accessible system which itself obeys quantum mechanical laws, to mimic complex quantum systems that become intractable for classical computers in the limit of large particle numbers. For example, quantum simulators allow us to investigate quantum many-body problems of condensed matter and high-energy physics, molecular potential curves, and transport phenomena in noisy environment. Trapped ions are very suitable candidates for realizing quantum simulators because they provide us with excellent control over all quantum degrees of freedom: we can repeatedly and reliably prepare a quantum state, control its dynamical evolution, create entanglement and carry out quantum measurements with high efficiency. In my poster, I present an experimental application of "Variational Quantum Simulation", which allowed us to investigate complex lattice models with up to 20 particles. We employ a state-of-the-art analog quantum simulator based on trapped Calcium ions, capable of performing multi-qubit entanglement and high-fidelity single-qubit operations. We experimentally determine the ground state and the energy gap to the first excited state and study the phase transition of the Lattice Schwinger model. Furthermore, by measuring variances of the Hamiltonian, we provide algorithmic error bars for the measured ground state energy, thus addressing the long-standing challenge of verifying quantum simulations.

34 | Verifying quantum information designs with Conservation Laws and Change diagrams

Carlos Martinez

We research methods to verify quantum operations. We explore models similar to Fredkin and Toffoli Conservative logic but adding other ad-hoc conservation laws for specific goals. When the objective is to validate a chain of operations, we account a side effect on every operation. The result of combining all effects should be coherent with the quantum calculations; if not, we have a hint on possible errors. Applied this parallel verification on 1 qbit quantum designs. It let us corroborate whether matrix calculus is coherent with the approach of accounting non-local side effects along the quantum system. In short, this is a parallel calculation method for consistency and error checking. We represent visually a quantum system as a chain of operations in Feynman-like diagrams. We model a Mach Zehnder interferometer MZI by chaining diagrams of beam splitters and phase shifts. A single diagram can model equally either a superposition state or the entanglement between two states. A color convention is proposed to the community software tools for states and operators, this work shows how 3 primary colors with their reverse maps to the main axis of a Bloch sphere. Future research aims at exploring GHZ entanglement with similar conservation model and change diagrams used to model the MZI setup. We believe on comparing behaviors from different perspectives to examine non classical implications, Using the model as tool to inspect questions and research.

35 | Environment induced Rabi Oscillations in the Boson-Boson Model

Yuri Minoguchi, P. Kirton, P. Rabl

We analyze the strong-coupling dynamics of a driven harmonic oscillator whose energy is mod- ulated by a continuum of other bosonic modes. This type of system-bath interaction appears, for example, in optomechanical or equivalent circuit QED setups, where the frequency of a confined photonic mode depends linearly on a fluctuating boundary. Compared to the canonical spin-boson model, where coupling to bath modes only leads to decoherence, the role of the environment in such systems is more complex, since it also provides the only source of nonlinearity. We show that even for an unstructured bath, these environment-induced nonlinearities can dominate over decoherence pro- cesses resulting in Rabi oscillations and the formation of highly non-classical states. These findings provide important insights into the non-Markovian dynamics of higher-dimensional open quantum systems and for realizing few-photon optical nonlinearities through strong interactions with a bath.

36 | Selective Quantum State Tomography

Joshua Morris, B. Dakić

We introduce the concept of selective state tomography, a tomographic scheme that enables a user to estimate individual elements of an arbitrary quantum state, without requiring determination of the complete density operator. We achieve this using a number of measurements that depend only on the desired precision and probability of success rather than the dimension of the system. In addition to this, any element can be estimated from the same set of measurements with a constant error. We show that when generalised to complete tomography, our scheme saturates the known optimal bounds when restricted to independent measurements.

37 | Entanglement robustness against particle loss of multiqubit pure states

Antoine Neven, J. Martin, T. Bastin

When some of the parties of a multipartite entangled pure state are lost, the question arises whether the residual mixed state is also entangled, in which case the initial entangled pure state is said to be robust against particle loss. In this poster, we investigate this entanglement robustness for N-qubit pure states. We identify exhaustively all entangled states that are fragile, i.e., not robust, with respect to the loss of any single qubit of the system. We also study the entanglement robustness properties of symmetric (permutation invariant) states and put these properties in the perspective of the classification of states with respect to Stochastic Local Operations Assisted with Classic Communication (SLOCC classification).

38 | A passive photon–atom qubit swap operation

Tal Ohana, O. Bechler, A. Borne, S. Rosenblum, G. Guendelman, O. E. Mor, M. Netser, Z. Aqua, N. Drucker, R. Finkelstein, Y. Lovsky, R. Bruch, D. Gurovich, E. Shafir, B. 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.

39 | Observing pairs of zero-bias end states in three-terminal superconductor-semiconductor devices

Denise Puglia, G.-L. Anselmetti, G. Menard, F. Malinowski, E. Martinez, J. S. Lee, S. Choi, M. Pendharkar, G. C. Gardner, S. Gronin, R. Kallaher, M. J. Manfra, C. J. Palmstrøm, C. M. Marcus, L. Casparis, A. Higginbotham

Majorana zero-energy modes located at the ends of topological superconductors are an appealing platform for topological quantum computing. Zero-bias peaks (ZBPs) are ubiquitously observed in tunneling spectroscopy of hybrid superconductor-semiconductor nanowires, consistent with expectations for Majorana modes. However, the emergence of those zero-energy modes in pairs at the ends of 1D topological superconductors is a central - and so far untested - prediction. Enabled by recent materials breakthroughs in selective area growth (SAG), we demonstrate a platform for testing this prediction by probing the conductance matrix of a three-terminal InAs wire proximitized by Al. We introduce the measurement technique and study correlations of sub-gap states at zero field, finding evidence of localized states at the wire ends and delocalized bulk states.

40 | 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. 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 are interesting for a 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.

41 | Autonomous learning agents make sense of a complex environment by proposing latent variables

Katja Ried, B. Eva, T. Müller, H. J. Briegel

Learning agents are becoming powerful tools that help us understand and control complex systems, both classical and quantum. One major challenge in their development is the exponentially large number of possible inputs they may encounter. Humans overcome this challenge by decomposing their perceptions, identifying features, variables and concepts. We present a minimal example of an artificial learning agent that, upon interacting with a structured environment, autonomously develops an internal representation that uses latent (unobserved) variables to organize its knowledge. We further show how this representation allows the agent to apply previous knowledge to situations it has not encountered before.

42 | Quantum Information Processing 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, J. A. Kettlewell, T. B. Batalhão, J. F. Fitzsimons, P. 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. In our work 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 | Generation of strongly correlated photons using atoms weakly coupled to an optical mode

Philipp Schneeweiss, A. Prasad, J. Hinney, K. Hammerer, S. Mahmoodian, S. Rind, A. S. Sørensen, J. Volz, A. Rauschenbeutel

The realization of complex quantum many-body physics of photons is an outstanding challenge of modern quantum optics as it arises from interactions in out-of-equilibrium systems. Typical schemes for generating correlated states of light require a highly nonlinear medium strongly coupled to an optical mode. Such approaches are often strongly impaired by unavoidable dissipative processes which reduce the nonlinearity and cause photon loss. Here, we experimentally demonstrate the opposite approach where a highly dissipative, weakly coupled medium can be harnessed to generate and study strongly correlated states of light [1]. Specifically, we measure the second-order correlation function of light transmitted through an ensemble of atoms that weakly couple to the optical mode of an optical nanofiber. Dissipation removes uncorrelated photons while preferentially transmitting highly correlated photons created through nonlinear interactions. As a result, the transmitted light constitutes a highly correlated many-body state of light which reveals itself in the second order correlation function that exhibits antibunched or bunched photon statistics depending on the optical depth of the atomic ensemble.

[1] S. Mahmoodian et al., Phys. Rev. Lett. 121, 143601 (2018)

45 | Phase diagrams of strongly correlated cavity-QED systems from exact diagonalization

Michael Schuler, D. De Bernardis, P. Rabl

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.

46 | Gravity, entanglement, and CPT violation in particle mixing

Kyrylo Simonov, S. M. Giampaolo, A. Capolupo

We study the probability oscillations of mixed particles in the presence of self gravitational interaction. We show that the presence of the parity leads to the violation of the time-reversal symmetry while the CP symmetry is preserved hence inducing a CPT symmetry violation. This violation is directly associated with the rising of the entanglement among the elements of the system that can be seen as a pure many-body effect scaling with the number of the elements in the system. This effect could have played a relevant role in the first stages of the Universe or in the core of very dense systems. Experiments, based on Rydberg atoms confined in microtraps can simulate the mixing and the mutual interaction and could allow testing the mechanism here presented.

47 | An optical nanofiber-based interface for solid-state quantum emitters

Sarah Skoff, H. Schauffert, J. Hütner, T. Hoinkes, A. 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 and we will show the implementation of a resonator that makes it possible to reach the strong coupling regime.

48 | Distinguishing photons and anti-photons for highly-localised mirror Hamiltonians

Jake Southall, A. Beige, R. Purdy

Photons with well-defined energy are highly non-localised and occupy all available space in one dimension. On the other hand, optical elements, like mirrors, are highly-localised objects. To model the electromagnetic field in the presence of optical elements, we therefore introduce annihilation operators for highly-localised field excitations. These are different from single-particle annihilation operators and arise naturally if we quantise the negative as well as the positive solutions of Maxwell's equations. Moreover, they enable us to obtain highly-localised interaction Hamiltonians for two- sided semi-transparent mirrors with applications in quantum optics.

49 | Remote Time Manipulation

David Trillo, B. Dive, M. 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 | Quantum heuristics for near-term devices

Jordi Tura, I. Cirac

Here we present a method to build a quantum circuit to heuristically minimize the energy of a quantum Hamiltonian under a set of restrictions, such as having a limited number of gates of a given type. The algorithm is based on an adaptive algorithmic cooling procedure, aided by some classical optimization. Algorithms for the so-called NISQ (noisy, intermediate-scale quantum) devices have become an intensive field of research, and in our work we focus on the following directions: first, we benchmark the performance of the algorithm in for a number of qubits $N > 50$, thus going beyond the limits of classical simulation; second, we take into consideration and study the effect of different noise models; and third, we take into account the statistical noise arising from estimating expectation values of operators, thus giving realistic estimates for the number of measurements and actual runtime of the algorithm. Furthermore, the principles our procedure is based upon can be easily exported to specific experimental platforms, where only a restricted subset of operations is typically available, and coherence time is limited.

51 | Observation of multimode strong coupling of cold atoms to a 30-m long optical resonator

Jürgen Volz, A. Johnson, M. Blaha, A. E. Ulanov, A. Rauschenbeutel, P. Schneeweiss

Coupling neutral atoms to photons propagating in nanoscale waveguides is a promising approach for realizing light-matter quantum interfaces. In combination with resonator enhancement of the guided light, such systems provide powerful tools for a broad range of quantum applications. In particular, they allow one to reach and study new paradigms of light-matter interaction such as the multimode strong coupling regime of resonator quantum electrodynamics (QED), where the atom-resonator interaction strength exceeds the free spectral range of the resonator. We report on the observation of multimode strong coupling of a small ensemble of atoms interacting with the field of a 30-m long fiber resonator containing a nanofiber section. In our experiment, the collective light-matter coupling strength exceeds the free spectral range and the atoms couple to many consecutive longitudinal resonator modes. The measured transmission spectra of the coupled atom-resonator system provide evidence of this new regime, realized with a few hundred atoms with an intrinsic single-atom cooperativity of 0.26. Our results are the starting point for studying the dynamics of light-matter interaction in this new setting and making use of it for future applications.

52 | Wavelength-scale errors in optical localization due to spin–orbit coupling of light

Stefan Walser, G. Araneda, Y. Colombe, D. B. Higginbottom, J. Volz, R. Blatt , A. Rauschenbeutel

The precise determination of the position of sub-wavelength scale emitters using far-field optical imaging techniques is of utmost importance for a wide range of applications in medicine, biology, astronomy and physics. We theoretically and experimentally show that, for a standard optical imaging system like an optical microscope, the image of an elliptically polarized point-like emitter does in general not coincide with the emitter's real position. Instead, even for perfect, aberrationfree imaging with high numerical aperture, the image can in general be shifted. Imaging a single gold nanoparticle in a standard immersion microscopy setup, we experimentally demonstrate this effect and observe shifts up to one optical wavelength. Such shifts can lead to a systematic error in the optical localization of emitters which exceeds the typical precision of super-localization microscopes by far. Moreover, for the case of small numerical aperture, the shift can in principle reach arbitrarily large values. Beyond its relevance for optical imaging, the demonstrated phenomenon may also occur for sources of other types of waves as for instance in radar and sonar imaging.

53 | An entanglement-based wavelength-multiplexed quantum communication network

Soeren Wengerowsky, S. K. Joshi, F. Steinlechner, H. Hübel, R. Ursin

We present a proof-of-principle experiment consisting of four users in a novel network architecture which enables scalable quantum communication based on polarization-entangled photon pairs at telecommunications wavelength. Our scheme uses frequency multiplexing to share 6 two-photon entangled states between each pair of clients in a mesh-like network topology using only one fiber per client.

54 | Linear optical quantum computing with feedforward using ultrafast optical switches

Guilherme Zanin, M. Jacquet, I. A. Calafell, R. Peterson, L. Rozema, P. Walther

Linear optical quantum computing (LOQC) is the best candidate for quantum computation with photons as information carriers. LOQC requires single-photon operation, and notably with a single spatial mode. Here, we present a LOQC scheme based on feed-forward control with a bi-photon state. The state of the idler (heralding photon) is used to set the path of the signal (heralded photon) by feed-forward control of ultrafast optical switches (UFOS) that operate with a duty cycle of 1 MHz. To perform LOQC, the signal photon is sent to the setup where we apply unitary operations on polarisation such that its state at the output is controlled without postselection. We obtain a versatile setup with exquisite control of the state of the heralded photon at the output. This LOQC system is stable and good for tasks with a single spatial mode such as operations with time-bin encoding or the study of quantum foundations (e.g. causality).

55 | Compact SOI vacuum gap transmon qubits

Martin Zemlicka, M. Peruzzo, F. Hassani, S. Barzanjeh, J. Fink

Our goal is to develop a compact transmon qubit that eliminates the use of dielectrics as much as possible and that minimizes the electric field participation ratio of the metal dielectric interfaces. Several attempts to realize vacuum gap capacitors were already implemented usually relying on an out-of-plane geometry that involved a challenging cleaning step to release the structure. We utilize suspended SOI (silicon on insulator) membranes to form a micro-machined in-plane vacuum finger capacitor. We fabricate small and low-loss vacuum finger capacitors by dry etching 400 nm wide trenches into a 220 nm thick high resistivity silicon membrane, followed by shadow evaporation which fully covers both the top and sidewalls of the circuit element. After thorough cleaning, in a last step the membrane is released in hydrofluoric acid vapor, which fully removes the buffered oxide layer beneath the qubit capacitor. This process is compatible with standard Josephson junction fabrication and allows transmon sizes of only 25x100 um2. Currently we are characterizing the properties of lumped element resonators formed by such a capacitor and a meander inductor. We are also fabricating first qubit devices and will report our progress on the fabrication and characterization of small in-plane vacuum transmons.

56 | Nonclassical light in the quantum dynamics of mesoscopic spin-cavity systems

Matthias Zens, H. Dhar, D. Krimer, S. Rotter

Mesoscopic spin ensembles strongly coupled to a cavity offer the exciting prospect of observing complex nonclassical phenomena with features intermediate between that of single spins and of macroscopic spin ensembles. To unravel the full quantum dynamics and photon statistics of the mesoscopic spin-cavity systems, we present a time-adaptive variational renormalization group method that accurately captures the underlying Lindbladian dynamics. We demonstrate how the collective interactions in an ensemble of as many as 100 spins, arranged in a spectral frequency comb, can be harnessed to obtain a periodic pulse train of sub-Poissonian, nonclassical light.