Abstracts of Talks

Oleg Astafiev (Royal Holloway London)

Quantum wave mixing with an artificial atom in the open space

Full list of authors:
A. Yu. Dmitriev, T. Hönigl-Decrinis, R. Shaikhaidarov, N. Antonov, and O.V. Astafiev

Four-wave mixing is a well-known nonlinear effect of quantum optics. The effect is a result of the third order (Kerr) nonlinearity in a nonlinear medium and is revealed as two side peaks, when two close frequencies are passing through the medium. When the medium is scaled down to a single atom, several novel effects are observed due to fundamentality of the system. Particularly, the individual multi-photon scattering events can be separated in space and in time. We demonstrate a novel phenomenon of quantum optics – the quantum wave mixing on an artificial atom – a superconducting two-level system – strongly coupled to an open space. If two frequency microwave pulses are applied, a series of side peaks appear as a result of different order multi-photon scattering processes and quantum oscillations are decoupled into a series of side peaks exhibiting Bessel function oscillations according to the number of interacting photons.
Moreover, separating the pulses in time results in breaking the time symmetry and symmetry of the spectrum. Interestingly, the spectrum contains a single side peak due to one photon ‘stored’ in the atomic superposed state. Another series of phenomena are observed in a single three-level atom, when scattering of two frequencies on the atom creates a single mixed tone differently from classical mixing, when both sum and difference of two frequencies are allowed.

Alexandre Blais (Université de Sherbrook)

Itinerant Microwave Photon Detector

The realization of a high-efficiency microwave single photon detector is a long-standing problem in the field of microwave quantum optics. Here, we propose a quantum nondemolition, high-efficiency photon detector that can readily be implemented in present state-of-the-art circuit quantum electrodynamics. This scheme works in a continuous fashion, gaining information about the photon arrival time as well as about its presence. The key insight that allows us to circumvent the usual limitations imposed by measurement backaction is the use of long-lived dark states in a small ensemble of inhomogeneous artificial atoms to increase the interaction time between the photon and the measurement device. Using realistic system parameters, we show that large detection fidelities are possible.

Mihir Bhaskar (Harvard University)

Photon-mediated interactions between two quantum emitters in a diamond nanophotonic device

Photon-mediated interactions between quantum bits are essential for scalable quantum information pro- cessing and are enabled by efficient light-matter interfaces. In this talk, I will discuss recent experiments demonstrating strong light-matter interactions using color-centers coupled to diamond nanophotonic waveg- uides and cavities [1,2]. First, we demonstrate entanglement between two silicon-vacancy (SiV) centers coupled to a single waveguide by detecting indistinguishable waveguide photons [2]. Next, we couple SiV centers to nanophotonic cavities with high cooperativity ($C > 20$). We observe the formation of super- and sub-radiant two-SiV states arising from a coherent, cavity-mediated interaction between the two SiV centers. We use the long-lived electronic-spin degrees of freedom of the two SiVs at 100 mK [3] to create a controllable optically-mediated spin-dependent interaction. These results pave the way for the efficient implementation of quantum repeaters and studies of many-body physics using strongly-interacting SiV centers.

[1] M. K. Bhaskar et al. Phys. Rev. Lett. 118 (22), 223603 (2017).
[2] A. Sipahigil, et al. Science 354, 847 (2016).
[3] D. D. Sukachev, et al. Phys. Rev. Lett. 119 (22), 223602 (2017).

Giuseppe Calajò (TU Wien)

Atoms-light interactions in a photon conveyor belt

The coupling of atoms to a one dimensional periodic photonic waveguide gives rise to new exciting regimes where photons and atoms can interact at comparable velocities. In this work we consider the case where a propagating modulation of the waveguide moves with a speed comparable to the maximal photonic group velocity. Such modulation can act as an effective conveyor belt for the photons that are dragged along the structure. This effect can induce an externally controllable directional emission and can affect the resulting photon-mediated interaction between the atoms. We consider two different perturbation shapes, one periodically extended and the other localized, and we demonstrate how, in both cases, the tunability of the conveyor belt allows to build entanglement among the atoms. We finally show that an implementation involving a dynamical modulation of the waveguide's refractive index induced by a propagating surface acoustic wave could be experimentally accessible.

Derrick Chang (ICFO)

Simulating quantum light propagation through atomic ensembles using matrix product states

Atomic ensembles constitute a powerful and versatile platform to realize a quantum interface between matter and light. Recently, a number of such interfaces have emerged, most prominently ensembles with atoms excited to high-lying Rydberg states, which enable strong nonlinear interactions between propagating photons. A largely open problem, which is difficult to treat both analytically and numerically, is whether these systems can produce exotic quantum many-body states of light, and the development of new techniques to solve for the out-of-equilibrium quantum dynamics as photons propagate and interact with atoms is highly desirable. Here, we describe a novel numerical approach, wherein a problem involving quasi one-dimensional light propagation is mapped to the dynamics of an open 1D interacting "spin" system describing the atomic internal degrees of freedom, while all photon correlations are obtained from those of the spins by a quantum input-output relation. The spin dynamics in turn are numerically solved using the powerful matrix product state ansatz, which avoids the exponentially large Hilbert space nominally associated with the spins. As two specific examples, we apply this formalism to investigate vacuum induced transparency, a phenomena where the different photon number components of a pulse propagate with number-dependent group velocity and separate at the output, and Rydberg EIT in the high-photon limit, where it becomes possible to generate pulse trains of single photons starting from continuous input fields.

Joshua Combes (Rigetti Quantum Computing)

Designer photon-photon interactions

There is much debate over whether it is possible to build useful optical nonlinearities at the single photon level. The main contention is that the multimode nature of travelling photons precluded a high-fidelity interaction. This was pointed in two well-known results, due to Shapiro and Gea-Banacloche. In this talk, I will describe how to design an artificial medium that faithfully induces both cross Kerr and self Kerr nonlinearities at the few photon level.

Per Delsing (Chalmers University of Technology)

An artificial atom in front of a mirror:
A careful evaluation of decoherence rates

Full list of authors: Y. Lu, A. Bengtsson, J. Burnett, B. Suri, E. Wiegand, A. Ask B. Schneider, J. Bylander, G. Johansson, and P. Delsing

An artificial atom in the form of a superconducting transmon qubit is placed in front of a mirror and its scattering properties are investigated at microwave frequencies. In previous experiments it has been difficult to separate radiative and nonradiative decay of the “atom”.
In this set of experiments, we probe the decoherence rates in several different ways. We probe the reflection from the atom mirror system both as a function of frequency and power. We can also excite the “atom” and perform Rabi oscillations detected from the emitted microwaves of the system. Analysis of this radiation allows us to determine all rates and set an upper limit on the nonradiative rate. Moreover, we demonstrate that an incoming excitation pulse can be canceled by a directional coupler to better than 30dB, this is important if one wants to use this system as a single photon generator.

Shanhui Fan (Stanford University)

Analytic structures of multi-photon scattering matrix
in waveguide QED systems

In a waveguide QED system, one considers the interaction of multiple photons as induced by a local quantum system. Due to the local nature of the quantum system, the form of the scattering matrix is strongly constraint by the cluster-decomposition principle in quantum field theory. And moreover, the form of the scattering matrix depending the dimensionality of the ground state manifold of the local quantum system. In this talk, we discuss the general form of multi-photon scattering matrix in waveguide QED systems, and how such an understanding can be useful in quantum information processing.

Arkady Fedorov (University of Queensland)

A phototonic quantum diode using superconducting qubits

The interaction between freely propagating photons and atoms or atom-like systems is greatly enhanced in one dimension. A system of many atoms strongly coupled to a one-dimensional continuum of electromagnetic modes realizes the waveguide quantum electrodynamics (QED) regime which can be used for distribution of quantum correlations at distance and for manipulations of itinerant photons.

The basic ingredient of waveguide QED, a single two-level atom (a qubit) in a waveguide, behaves as a mirror whose transparency depends on the frequency and power of the incoming radiation. When two qubits are in a waveguide one can observe two distinct types of cooperative effects dependent on the distance between the qubits: formation of the super- and subradiant states and appearance of the coherent exchange interaction between qubits.

By exploiting these properties and the non-linear nature of the qubits one can achieve a population trapping in a non-local entangled state under continuous driving. The trapping conditions can depend on the photon propagation direction as the two-qubit can be made chiral with appropriate tuning of the frequencies of the qubits. This behaviour can be manifested in a non-reciprocal behaviour which allows the system operate as a microscopic light diode.

Ofer Firstenberg (Weizmann Institute of Science)

Quantum nonlinear optics with structural slow light

Longitudinal modulation of a finite medium can form an effective cavity that strengthens optical nonlinearities. We study the integration of these optically-induced cavities with a photonic quantum gate based on Rydberg blockade. We calculate the corresponding finesse and gate infidelity, establishing that the conventional limits imposed by the blockade optical depth are mitigated in long media. The induced cavities delay the signal pulse via `structural' slow light, as opposed to `material' slow light conventionally used with Rydberg blockade. While the latter maintains the amplitude of the incoming signal, the former increases it at the center of the structure.

Serge Florens (Néel Institute)

Particle production in ultra-strong coupling waveguide QED

Understanding large-scale interacting quantum matter requires dealing with the huge number of quanta that are produced by scattering even a few particles against a complex quantum object. Prominent examples are found from high energy cosmic ray showers to the optical or electrical driving of degenerate Fermi gases. We address this question in the context of many-body quantum optics, as motivated by the recent developments of waveguide quantum electrodynamics at ultrastrong coupling. Particle production is described quantitatively with a simple yet powerful concept rooted in the quantum superposition principle. This idea is illustrated by the study of multi-photon emission from a single two-level artificial atom coupled to a high impedance transmission line. We find surprisingly that the off-resonant inelastic emission lineshape is dominated by non-RWA broadband particle production, due to the large phase space associated with processes that do not conserve the number of excitations.

Pol Forn-Díaz (Barcelona Supercomputing Center)

Exploring the strongly driven spin-boson model in a superconducting quantum circuit

Quantum two-level systems interacting with their surroundings are ubiquitous in nature. The interaction suppresses quantum coherence and forces the system towards a steady state. Such dissipative processes are captured by the paradigmatic spin-boson model, describing a two-state particle, the "spin", interacting with an environment formed by harmonic oscillators. A fundamental question to date is to what extent intense coherent driving impacts a strongly dissipative system. A superconducting qubit strongly coupled to the electromagnetic environment from a waveguide realizes the Ohmic spin-boson model. This engineered qubit-waveguide setting is therefore a suitable platform to study many-body physics in parameter regimes usually inaccessible in experiments until now. In this talk, I will show that we can design qubit-waveguide interaction strengths to span a wide range of parameters of the spin-boson model, particularly in the non-perturbative regime. I will then discuss extensions to the spin-boson model with the influence of an externally applied strong drive on this highly dissipative system.

O. Astafiev, et al., Science 327, 840 (2010).
B. Peropadre, et al., Phys. Rev. Lett. 111, 243602 (2013).
P. Forn-Diaz, et al., Nature Physics 13, 39 (2017).
L. Magazzù, P. Forn-Díaz et al., Nature Communications 9, 1403 (2018).

Juan José García-Ripoll (IFF-CSIC Madrid)

Single and multiphoton scattering in the ultrastrong coupling regime

In this talk I will discuss our line of research on single and multiphoton scattering with ultrastrongly coupled qubits. I will review the numerical and analytical methods that we are developing, based on the polaron transformation, matrix product states and path integral formulations of scattering. I will then move on to discuss how to test those predictions experimentally, discussing the limitations of current studies of photon scattering with superconducting circuits, and introducing new methods for reconstructing and characterizing scattering with noise in generic waveguide setups.

[1] Ultrastrong coupling few-photon scattering theory, Tao Shi, Yue Chang, JJGR, arXiv:1701.04709, to appear in PRL

[2] Multiphoton Scattering Tomography with Coherent States, Tomás Ramos and JJGR, Phys. Rev. Lett. 119, 153601 (2017)
[3] Correlated Dephasing Noise in Single-photon Scattering, Tomás Ramos and JJGR, in preparation

Simone Gasparinetti (ETH Zürich)

Engineered light-matter interactions in Superconducting Coupled Resonator Microwave Waveguides

Arrays of coupled resonators can be used to realize one-dimensional waveguides with finite bandwidth and a structured density of states. Serving as a host material to small ensembles of atom-like emitters, they constitute a promising platform to explore atom-photon bound states [1,2] as well as tunable long-range interactions [3-6]. They also provide a way to "slow down" photonic wavepackets, enabling studies of non-Markovian interactions between distant emitters [7]. I will present our experimental realizations of coupled resonator microwave waveguides using superconducting circuits, and our preliminary results on coupling artificial atoms to them.

[1] G. Calajó, F. Ciccarello, D. Chang, and P. Rabl, PRA 93, 33833 (2016).
[2] T. Shi, Y.-H. Wu, A. González-Tudela, and J. I. Cirac, PRX 6, 21027 (2016).
[3] J. S. Douglas, H. Habibian, C.-L. Hung, A. V. Gorshkov, Kimble H. J., and D. E. Chang, Nat Phot. 9, 326 (2015).
[4] Y. Liu and A. A. Houck, Nat Phys 13, 48 (2017).
[5] N. M. Sundaresan, R. Lundgren, G. Zhu, A. V. Gorshkov, and A. A. Houck, arXiv:1801.10167.
[6] M. Mirhosseini, E. Kim, V. S. Ferreira, M. Kalaee, A. Sipahigil, A. J. Keller, and O. Painter, arXiv:1802.01708.
[7] T. Tufarelli, M. S. Kim, and F. Ciccarello, Phys. Rev. A 90, 12113 (2014).

Dario Gerace (University of Pavia)

Photon rectification in waveguide QED

I will give an overview on our past works on photon rectification in resonant and waveguide QED systems. In particular, I will show how both classical and quantum radiation fields can experience noise-resistant unidirectional propagation upon interaction with resonant systems that are nonlinear at the single-photon level. Specific examples include either a linear-nonlinear resonators junction [1], or a one-dimensional waveguide doped with a pair of two-level systems, i.e. a quantum Fabry-Perot interferometer [2,3]. I will finally discuss the relevance of these results in the context of realistic implementations of rectifying devices in state-of-the art nanophotonics, with emphasis on photonic crystal integrated circuits in semiconductor platforms.

[1] E. Mascarenhas et al., EPL 106, 54003 (2014)
[2] F. Fratini et al., Phys. Rev. Lett. 113, 243601 (2014)
[3] E. Mascarenhas et al., Phys. Rev. A 93, 043821 (2016)

Jean-Michel Gérard (CEA Inac)

Quantum dots in photonic wires : from spontaneous emission control to advanced quantum photonic devices

Over the last 20 years, major efforts have been devoted to the tailoring of the optical properties of semiconductor emitters using optical microcavities and photonic crystals. Since 2010, INAC has promoted photonic wires as an alternative solid-state platform for quantum photonics. I will review basic studies which demonstrate an excellent control over the spontaneous emission of InAsquantum dots (QDs) embedded in vertical single-mode GaAs photonic wires and first applications in the field of quantum photonic devices, such as ultrabright single mode single photon sources, or non-linear optical gates operating at the single/few photon level. We will furthermore show that a single QD in a photonic wire constitutes an original hybrid system, with remarkable optomechanical properties resulting from a very strong coupling mediated by strain.

This work has involved numerous coworkers, including J. Claudon, J Bleuse, M Munsch, P.Stepanov , N Gregersen and J.P. Poizat .

Carlos Gonzalez Ballestero (IQOQI, Innsbruck)

Few-photon quantum protocols and devices based on chiral waveguide-emitter couplings

The recent demonstration of asymmetric coupling between left/right propagating photons and quantum emitters in waveguide setups [1, 2] has resulted in a whole new research field within waveguide physics, namely chiral waveguide QED. Many theoretical and experimental works in this field aim at exploiting such directionality, either to design new quantum protocols and devices or to improve the existing ones. In the first part of our work [3], we revisit a well-known protocol for passive entanglement generation between two qubits coupled to a waveguide [4], showing how, by allowing the qubit-waveguide couplings to be chiral, the generated entanglement can be increased by 50%. Moreover, although the entangled state has a shorter lifetime than in the non-chiral scenario, it becomes very robust against small variations of the system parameters, thus easing the experimental implementation of the protocol. In the second part of our work [5], we propose a four-port device in which chiral waveguide-emitter couplings allow for the design of non-reciprocal few-photon devices based on quantum interference. We show the possibility of efficient single-photon routing and, for a two-photon input, we demonstrate how a transistor-like device can be achieved. We believe our results evidence the potential of chiral waveguide QED systems for quantum applications.

[1] Jan Petersen et al., Science 346, 67-71 (2014).
[2] Immo Söllner et al., Nature Nanotechnology 10, 775–778 (2015).
[3] C. Gonzalez-Ballestero et al., Physical Review B 92, 155304 (2015).
[4] A. González-Tudela et al., Physical Review Letters 106, 020501 (2011).
[5] C. Gonzalez-Ballestero et al., Physical Review A 94, 063817 (2016).

Alejandro González Tudela (Max-Planck-Institut für Quantenoptik)

Quantum optics in structured photonic environments

Recent experimental developments in nanophotonics [1], circuit QED [2] and atomicphysics [3] allow one to engineer systems where atoms (or other quantum emitters) couple to structured photonic environments. In this talk, I will discuss several phenomena emerging in these setups such as the emergence of photon bound states, which allow one to mediate tunable and long-range interactions [4], or the emergence of novel super/subradiance phenomena [5].

[1] Nature 508, 241–244 (2014), Nature Communications 5, 3808 (2014), Rev. Mod. Phys. 87, 347 (2015).
[2] Nature Physics 13 (1), 48-52 (2017).
[3] Phys. Rev Lett. 101 (26), 260404 (2010),Nature Physics 8, 267–276 (2012), arXiv:1712.07791
[4] Phys. Rev. X 6 (2), 021027 (2016), Nature Photonics 9 (5), 320-325 (2015), PNAS, 201603777 (2016).
[5] Phys. Rev. Lett. 119 (14), 143602 (2017), Phys. Rev. A 96 (4), 043811 (2017).

Alexey V. Gorshkov (University of Maryland)

Few-body and many-body physics with photons

First, we will discuss the use of Rydberg-mediated photon-photon interactions for the realization of single-photon sources, single-photon switches, single-photon subtractors, and few-photon bound states. Second, we will show how the concept of single-excitation bound states can be used to understand the propagation of photons through atomic ensembles. Finally, we will report on the demonstration of interacting qubit-photon bound states with superconducting circuits.

Vladimir Gritsev (University of Amsterdam)

Supersymmetry in Quantum Optics

Abstract: Light-matter interaction is naturally described by coupled bosonic and fermionic subsystems. This suggests that a certain Bose-Fermi duality is naturally present in the fundamental quantum mechanical description of photons interacting with atoms. We reveal submanifolds in parameter space of a basic light-matter interacting system where this duality is promoted to a supersymmetry (SUSY) which remains unbroken. We show that SUSY is robust with respect to decoherence and dissipation. In particular, a stationary density matrix at the supersymmetric lines in the parameter space has a degenerate subspace. A dimension of this subspace is given by the Witten index. As a consequence of this SUSY, dissipative dynamics at the supersymmetric lines is constrained by an additional conserved quantity which translates some part of information about an initial state into the stationary state subspace. We also demonstrate a robustness of this additional conserved quantity away from the supersymmetric lines. This suggest that optical systems at the SUSY points can be used for quantum information technology and can eventually open an avenue for quantum simulation of the SUSY field theories.

Göran Johansson (Chalmers University of Technology)

Steady-state negative Wigner functions from an atom in front of a mirror

Full list of authors: Fernando Quijandria, Ingrid Strandberg and Göran Johansson

In this talk, I'll discuss the reflected field from a continuously driven atom, positioned in front of a mirror in a 1D waveguide. We can analyse the outgoing field in terms of the Wigner function of propagating modes. For simplicity we consider box-normalised modes of different temporal extension. The most interesting parameter regime is close to the so-called incoherent point, where the drive strength is such that the coherent reflection is completely cancelled, due to perfect destructive interference between the reflection from the atom and the reflection from the mirror. Here, the modes are characterised by a clearly negative Wigner function, even though the driving is continuous. Field states with negative Wigner functions are considered a resource in quantum information processing and this system is potentially the simplest system where these can be generated continuously. The experimental realisation is straightforward using superconducting circuits, where the implementations in the optical regime would be more challenging.

Anton Frisk Kockum (Riken, Wako)

Decoherence-free interaction between giant atoms in waveguide QED

In quantum-optics experiments with both natural and artificial atoms, the atoms are usually small enough that they can be approximated as point-like compared to the wavelength of the electromagnetic radiation they interact with. However, superconducting qubits coupled to a meandering transmission line, or to surface acoustic waves [1,2,3], can realize "giant artificial atoms" that couple to a bosonic field at several points which are wavelengths apart [4,5]. Here, we study setups with multiple giant atoms coupled at multiple points to a one-dimensional (1D) waveguide [6]. We show that the giant atoms can be protected from decohering through the waveguide, but still have exchange interactions mediated by the waveguide. Unlike in decoherence-free subspaces, here the entire multi-atom Hilbert space is protected from decoherence. This is not possible with ”small" atoms. We further show how this decoherence-free interaction can be designed in setups with multiple atoms to implement, e.g., a 1D chain of atoms with nearest-neighbor couplings or a collection of atoms with all-to-all connectivity. This may have important applications in quantum simulation and quantum computing.

[1] M. V. Gustafsson et al., Science 346, 207 (2014).
[2] T. Aref et al., in Superconducting devices in quantum optics (Springer, 2016). arXiv:1506.01631.
[3] R. Manenti et al., Nat. Commun. 8, 975 (2017).
[4] A. F. Kockum et al., Phys. Rev. A 90, 013837 (2014).
[5] L. Guo et al., Phys. Rev. A 95, 053821 (2017).
[6] A. F. Kockum et al., Phys. Rev. Lett. 120, 140404 (2018).

Shingo Kono (University of Tokyo)

Quantum non-demolition detection of an itinerant microwave photon

Photon detectors are an elementary tool to measure electromagnetic waves at the quantum limit and are heavily demanded in the emerging quantum technologies such as communication, sensing, and computing. Of particular interest is a quantum non-demolition (QND) type detector, which projects an electromagnetic wave onto the photon-number basis. This is in stark contrast to conventional photon detectors which absorb a photon to trigger a ‘click’. The long-sought QND detection of a flying photon was recently demonstrated in the optical domain using a single atom in a cavity. However, the counterpart for microwaves has been elusive despite the recent progress in microwave quantum optics using superconducting circuits. Here, we implement a deterministic entangling gate between a superconducting qubit and an itinerant microwave photon reflected by a cavity containing the qubit. Using the entanglement and the high-fidelity qubit readout, we demonstrate a QND detection of a single photon with the quantum e云ciency of 0.84, the dark-count probability of 0.0147 and the photon survival probability of 0.87. Our scheme can be a building block for quantum networks connecting distant qubit modules as well as a microwave photon counting device for multiple-photon signals.

Leong Chuan Kwek (National University of Singapore)

Atomic ensemble coupled to band edge of photonic crystal waveguide

Long-range coherent dipole-dipole interactions can arise amongst an ensemble oftwo-level atoms coupled to a one-dimensional photonic crystal waveguide. We show that the long-range interactions can dramatically alter the linear and nonlinear optical behavior, as compared to a typical atomic ensemble. In particular, in the linear regime, we find that the transmission spectrum reveals multiple transmission dips, whose properties we show how to characterize. In the many-photon regime the system response can be highly non-linear, and under certain circumstances the ensemble can behave like a single two-level system, which is only capable of absorbing and emitting a single excitation at a time.

Peter Lodahl (Niel Bohr Institute)

Quantum-Information Processing with Quantum Dots in Nanophotonic Waveguides

Semiconductor quantum dots have improved their optical performance dramatically in recent years, and today a clear pathway is laid out for constructing a deterministic and coherent photon-emitter interface by embedding quantum dots in photonic nanostructures [1]. Such an interface can be employed as an on-demand single-photon source for quantum-information applications, but more generally enables single-photon nonlinearities and deterministic quantum gates [2]. We will review the recent experimental progress on quantum dots coupled to nanophotonic waveguides and cavities enabling unique ways of engineering light-matter interaction. A single-photon coupling efficiency exceeding 98.4% is reported [3] and the indistinguishability of the emitted photons is extracted [4] and the fundamental limits exploited [5]. Furthermore, various out-coupling strategies for efficiently transferring single photons to an optical fiber are implemented [6]. The unique engineering potential of the nanophotonic waveguides is demonstrated by implementing a chiral quantum interface [7,8]. Finally, the experimental demonstration of a photonic switched controlled by a single spin coupled to a waveguide is discussed.

[1] Lodahl et al., Rev. Mod. Phys. 87, 347 (2015).
[2] Lodahl, Quantum Science and Technology 3, 013001 (2018).
[3] Arcari et al., Phys. Rev. Lett. 113, 093603 (2014).
[4] Kirsanske et al., Phys. Rev. B 96, 165306 (2017).
[5] Tighineanu et al., submitted, ArXiv: 1702.04812 (2017).
[6] Daveau et al., Optica 4, 178 (2017).
[7] Solner et al., Nature Nano. 10, 775 (2015).
[8] Lodahl et al., Nature 541, 473 (2017).
[9] Javadi et al., Nature Nano (2018).

Sahand Mahmoodian (Leibniz Universität Hannover)

Strongly correlated photon transport with weakly coupled emitters in chiral waveguide QED

In this talk I will discuss recent work showing that strong photon-photon interactions can be generated in chains of chirally coupled emitters, even when the emitters are weakly coupled to the waveguide (ß << 1). The dynamics of this system are governed by an interplay between coherent driving, the nonlinear response of the emitters, and coupling to lossy modes outside of the waveguide. For optically dense ensembles of atoms, this interplay results in output photons with a strongly bunched second-order correlation function and a sub-exponential decay of the output power with the number of emitters N. The system can be described using a simple universal asymptotic solution governed by a single scaling parameter N(1-ß)ß. We anticipate that this proposal can be readily implemented in existed tapered fiber setups with trapped atoms.

[1] Mahmoodian, Čepulkovskis, Das, Lodahl, Hammerer, Sørensen, arXiv:1803.02428 (2018)

Saverio Pascazio (University of Bari)

Entanglement generation and bound states in one-dimensional QED

An excited atom in free space decays towards its ground state through spontaneous emission. Boundary conditions and artificial dimensional reduction drastically modify this picture, enhancing or inhibiting (sometimes hindering) decay.
We investigate the behaviour of two quantum emitters (two-level atoms) embedded in a linear waveguide, in a quasi-one-dimensional configuration. We focus on the single- and
two-excitation sector. We explore the relaxation towards bound states for resonant values of the interatomic distance, the generation of entanglement and the existence of plasmonic modes.

Hannes Pichler (Harvard University)

Universal photonic quantum computation via time-delayed feedback

We propose and analyze a deterministic protocol to generate two-dimensionally entangled photonic states using a single quantum emitter coupled to a 1D waveguide. I will show that delayed quantum feedback dramatically expands the class of achievable quantum states in such settings and in particular allows to generate 2D cluster states, i.e., universal resources for measurement based quantum computation. As a physical implementation, we consider a nanophotonic setting where delayed feedback is introduced by terminating the waveguide on one side with a mirror. We identify the class of many-body quantum states that can be produced using this approach, characterize them in terms of 2D tensor network states and give an explicit protocol to generate the 2D cluster state.

Mikhail Pletyukhov (RWTH Aachen University)

Geometry of driven dissipative phase transitions

The recent progress in the study of driven dissipative phase transitions (DPT) in open quantum systems puts forward the following question: How can a hysteteris inherent to a nonlinear semiclassical or mean-field dynamics be interpreted in the quantum Liouvillian approach to open systems? It is relevant, e.g., for understanding the optical bistability taking place in the Kerr nonlinearity model (which is also realizable in the waveguide QED).

In this talk I explain that for a Liouvillian description of hysteresis it is necessary to incorporate into the theory a measurement protocol which pre-defines a typical measurement time. A metastable state occurring after this time at every next experimental run appears to be dependent on the whole experimental procedure (that is, on a sequence of all preceding runs). This fact allows us to account within the Liouvillian approach (i.e. in terms of Liouvillian eigenstates) why different branches in parametric dependence of observables can at all occur in a system described by a linear set of equations (e.g., by the Lindblad master equation). Most surprisingly, metastable states in question allow for a description in terms of a path-dependent (in the parameter space) scaling factor, which is an open system analog of the geometric Berry phase in closed systems.

Peter Rabl (TU Wien)

Phonon quantum networks with SiV centers in diamond

In this talk I will discuss our recent proposal [1] for the realization of a novel phonon quantum network, where silicon-vacancy centers are coupled to the phonon modes of a quasi-1D diamond waveguide. In this setting, quantum states encoded in long-lived electronic spin states can be converted into propagating phonon wavepackets and be reabsorbed by a distant defect center in a fully controllable way. I will show that under realistic experimental conditions, this approach enables the implementation of high-fidelity, scalable quantum communication protocols within chip-scale spin-qubit networks. Apart from quantum information processing, this setup constitutes an interesting waveguide QED platform, where strong-coupling effects between solid-state defects and individual propagating phonons can be explored at the quantum level.

[1] M.-A. Lemonde, S. Meesala, A. Sipahigil, M. J. A. Schuetz, M. D. Lukin, M. Loncar, P. Rabl, arXiv:1801.01904.

Nicolas Roch (Néel Institute)

Exploring the many-body regime of light-matter interaction

Understanding the way light and matter interact remains a central topic in modern physics despite decades of intensive research. Since the end of the last century, the focus has been to isolate individual quantum systems (the "matter") and to couple them to single electromagnetic degrees of freedom (the "light"), giving birth to the celebrated field of cavity quantum electrodynamics. Owing to the naturally large light-matter interaction in superconducting quantum circuit, it is now realistic to think about experiments where the actual dynamics of environments containing many degrees of freedom becomes relevant. It suggests that many-body quantum optics is within reach. Apart from quantum optics, the control and tunability of circuits should allow us to bring new perspectives to phenomena usually observed in condensed matter physics or open quantum systems. Indeed, if the different theoretical predictions are to be validated, it is crucial to design experiments where the different degrees of freedom can be perfectly modeled. In this talk I will present a recent experiment [1]. The system under study consists in a single superconducting quantum bit ultra-strongly coupled to a large environment made of 4700 SQUIDs. This meta-material sustains many electro-magnetic modes. By performing microwave spectroscopy of this many-body system, we could understand in details how the qubit and its environment interact and hybridize. Thanks to a precise modeling of the system, these data can be explained by a theory without free parameters despite the fact that all the many-body ingredients are at play: non-perturbative coupling, many degrees of freedom and strong non-linearity. Finally I will also present our on-going efforts to observe many-body renormalisation in such systems and its links with dissipative quantum phase transitions

.[1] J. Puertas-Martinez et al., arXiv:1802.00633.

Dibyendu Roy (Raman Research Institute)

Dynamics of energy transfer in waveguide quantum electrodynamics systems

I shall discuss energy transfer dynamics in interacting multi-atom waveguide quantum electrodynamics systems. Using quantum Langevin equations method we derive an expression for the energy current in such systems driven by light. We explore scaling of energy current with system size at the different incident light power to determine nature of energy transport. We also detect the contribution of elastic and inelastic scattering in energy transport and how to control these contributions. Our study provides some microscopic understanding of nonlinear energy transfer via atoms and molecules in confined geometries.

Salvatore Savasta (University of Messina)

Nonlinear Optical Effects in the Ultrastrong Coupling Regime

The light-matter ultrastrong coupling (USC) regime, recently realized in a variety of solid state systems increases the efficiency of virtual processes that do not conserve the number of excitations. These processes can generate a coupling between two system states that otherwise do not have a direct coupling [1]. In this way nonlinear optical effects as multiphoton absorption and emission can become deterministic, and new intriguing nonlinear optical effects can be realized. Just as nonlinear-optics effects usually require rather high light intensity to be observed, the higher-order processes that we consider require a rather strong light-matter coupling to become noticeable. Specifically, the light-matter coupling must be strong enough to ensure that the effective coupling between system states, induced by the higher-order processes, becomes larger (or at least comparable) than the relevant decoherence rates in the system. In summary the coupling strength replace the role of high intense fields. This allows to obtain deterministic nonlinear optical effects with a minimum number of photons and with individual atoms [1]. In particular, I will discuss the occurrence of multiphoton quantum Rabi oscillations [2], the excitation of two or more spatially separated atoms with a single photon [3], and nonlinear optical effects with virtual atoms only [4]. As an example of the latter effects, I consider a physical process where one excited atom directly transfers its excitation to a pair of spatially separated atoms with probability approaching one. The interaction is mediated by the exchange of virtual rather than real photons. This nonlinear atomic process is coherent and reversible, so the pair of excited atoms can transfer the excitation back to the first one: the atomic analogous of sum-frequency generation of light. The possibility to observe these effects in USC waveguide WED systems is also discussed.

[1] A. F. Kockum, A. Miranowicz, V. Macrì, S. Savasta e F. Nori, «Deterministic

quantum nonlinear optics with single atoms and virtual photons,» Phys. Rev. A 95, 063849, 2017.
[2] L. Garziano, R. Stassi, V. Macrì, A. F. Kockum, S. Savasta e F. Nori, «Multiphoton quantum Rabi oscillations in ultrastrong cavity QED,» Phys. Rev. A, vol. 92, p. 063830, 2015.
[3] L. Garziano, V. Macrì, R. Stassi, O. Di Stefano, F. Nori e S. Savasta, «One photon can simultaneously excite two or more atoms,» Phys. Rev. Lett., vol. 117, p. 043601, 2016.
[4] R. Stassi, V. Macrì, A. F. Kockum, O. Di Stefano, A. Miranowicz, S. Savasta e F. Nori, «Quantum nonlinear optics without photons,» Phys. Rev. A, vol. 96, p. 023818, 2017.

Ephraim Shahmoon (Harvard University)

Guided-wave QED without waveguides: Quantum optics with atomic arrays in free space

Waveguide and cavity QED rely on the existence of structures that guide and confine light. These objects, such as fibers, cavities, or photonic microstructures, are typically made of bulk and dense materials. In my talk, I will describe a new platform for quantum optics which relies only on the collective response of ordered 2D atomic arrays in free space (e.g. trapped in an optical lattice). Such arrays can form perfect reflectors and can fully couple a collimated photon to an impurity atom, effectively realizing 1D quantum optics. They can also guide light in 2D via the collective surface modes of the array. Considering the motion of the array atoms, these systems exhibit very strong optomecharnical responses, which may lead to single-photon optomechanics and nonlinear optics.

Anders S. Sørensen (Niel Bohr Institute)

Exploiting and describing light matter interfaces in optical waveguides — Communications interfaces for superconducting qubits and how to des describe them

Superconducting qubits is one of the leading candidates for future quantum computers. Some of the promising applications of such quantum computers, however, require that they can be connected over long distances for quantum communications. Therefore there is a strong desire to generate quantum interfaces between superconducting qubits and optical photons. A major obstacle to such interfaces is, however, that superconducting qubits are very sensitive to light, since a single optical photon absorbed in the qubit can break a large number of Cooper pairs.
I will describe how to use emitters in optical waveguide to achieve an efficient coupling between single optical photons and superconducting

qubits. Such interfaces can operate at extremely low light levels, i.e. single photons, and thus minimize the possible absorption in the superconducting qubits. I will show how to achieve an efficient coupling using coupled molecules [1] and quantum dots [2] in waveguides. Furthermore I will show how to exploit the waveguide mediated interactions between multiple emitters to enhance the coupling between the optical photons and the superconducting qubits.

To describe these light matter quantum interfaces we have developed a novel scattering formalism [3,4]. In the regime where the quantum fields are sufficiently weak so that we can neglect saturation, this scattering formalism provides a solution to essentially any scattering problem involving an arbitrary number of emitters with any level structure. I will briefly sketch this formalism.

[1] S. Das, V.E. Elfving, S. Faez and A. S. Sørensen, Phys. Rev. Lett. 118, 140501 (2017).
[2] V. E. Elfving, S. Das, and A. S. Sørensen, in preparation.
[3] S. Das, V. E. Elfving, F. Reiter, and A. S. Sørensen, arXiv:1801.03025
[4] S. Das, V. E. Elfving, F. Reiter, and A. S. Sørensen, arXiv:1801.03037

Tao Shi (ITP Chinese Academy of Science)

Effective many-body Hamiltonians of atom-photon bound states

Quantum emitters (QEs) coupled to structured baths can localize multiple photons around it and form atom-photon bound states. In the Markovian or weak coupling regime, the interaction of QEs through these single-photon bound states is known to lead to effective many-body QE Hamiltonians with tunable but yet perturbative interactions. In this work, we study such models in the non-Markovian or strong coupling regime. The effective models for the non-Markovian regime with up to three excitations are characterized using analytical methods, uncovering the existence of exotic many-body states such as doublons or triplon states, absent in standard scenarios. Furthermore, we provide numerical results for systems with multiple excitations to demonstrate the emergence of polariton models with optically tunable interactions, where the many-body ground state exhibits superfluid to Mott insulator transition.

Tommaso Tufarelli (University of Nottingham)

Exploring corrections to the linearised Optomechanical Hamiltonian

I will start by qualitatively introducing the "Optomechanical Hamiltonian". This is a very common quantum model of radiation pressure, featuring a single-mode electromagnetic cavity with an oscillating boundary. With a few

exceptions, the literature so far has only explored the "linearised" version of this Hamiltonian, retaining only first-order effects in the light-matter coupling constant.
In the second part I will briefly describe our latest work [arXiv:1711.06688], in which we tried to capture radiation pressure effects that are beyond first order. We focused on the regime where the mechanical frequency is much lower than the cavity one, and compared two approaches that may be used to go beyond first order: (I) a widely used phenomenological Hamiltonian that conserves the photon number and (II) a two-mode truncation of a microscopic Hamiltonian model formulated by C.K. Law [Phys. Rev. A 51, 2537 (1995)].

Hakan Türeci (Princeton University)

Divergence-free Circuit Quantum Electrodynamics

Any quantum-confined electronic system coupled to the electromagnetic continuum is subject to radiative decay and renormalization of its energy levels. When inside a cavity, these quantities can be strongly modified with respect to their values in vacuum. In the planar circuit quantum electrodynamics architecture the radiative decay rate of a Josephson Junction qubit is strongly influenced by far off-resonant modes. A multimode calculation including all cavity modes however leads to divergences unless a cutoff is imposed. It has so far not been identified what the source of divergence is, or whether the divergence is a fundamental issue. I will show that unless gauge invariance is respected, any attempt at the calculation of circuit QED quantities is bound to diverge. I will then discuss an internally consistent theoretical and computational framework based on a Heisenberg-Langevin approach to the calculation of a finite spontaneous emission rate and the Lamb shift in an arbitrarily complex electromagnetic environment, that is free of cutoff.

Christopher M. Wilson (University of Waterloo)

Generation and Distribution of Nonclassical Microwave States

Nonclassical states of light will likely form an important part of next-generation communication networks. They can also be a resource for distributing entanglement between spatially separated units of a larger quantum processor. These important applications and others have driven great interest in developing sources of nonclassical light. Here we present three experiments that take important steps towards developing practical sources in the microwave regime. In the first, we demonstrate a single-photon source that allows the photon wave packet to be shaped to optimally match the requirements of a quantum receiver. This work uses a novel approach: we were able to shape the photons by modulating quantum vacuum fluctuations in both space and time. In the second experiment, we use a parametric superconducting cavity to produce tripartite entangled states of propagating microwave light. The technique developed can be easily extended to more modes. In addition, the entanglement structure of the states can be programmed in situ. We quantify entanglement in the states using a variety of Gaussian state measures. In the final experiment, we use higher-order nonlinearities to produce non-Gaussian tripartite states in the same system. These novel states show three-mode correlations and interference not possible with Gaussian states. To our knowledge, this is the first time such states have been produced and measured.

Vladimir I. Yudson (NRU HSE, ISAN RAS, RQC)

Wavequide QED of compactly located ensemble of two-level atoms with inhomogeneously broadened resonances

It is known that Dicke's model of compactly located ensemble of two-level atoms in three-dimensional space can be mapped on an effectively one-dimensional (waveguide) problem with chiral photons. This one-dimensional problem is exactly solvable by means of Bethe Ansatz [1]. For resonant atoms (in the absence of inhomogeneous broadening) the time evolution of an arbitrary initial state can be efficiently described with the use of a contour representation [2] that allows one to avoid complicated routine of the summation over Bethe string configurations. This approach can be extended also to the case of a nonchiral waveguide [3]. For identical atoms interacting with waveguide photons, the
atomic subsystem evolves along the ladder of Dicke states, the latter constitute only a small part of the whole Hilbert space. However, even a weak inhomogeneous broadening spreads the states of the atomic subsystem over the whole Hilbert space. Remarkably, the model remains integrable even in the presence of the inhomogeneous broadening [1], but the contour representation (analogous to that in [2]) for this case remains unknown. Despite of this, here we discuss some particular cases when the time evolution (atomic decay, photon scattering) of the inhomogeneously broadened system can be obtained analytically.

[1] V.I. Rupasov and V.I. Yudson, Rigorous theory of cooperative spontaneous radiation from a lumped system of two-level atoms: Bethe ansatz method. Zh. Eksp. Teor. Fiz. 87, 1617 (1984) [Sov. Phys. JETP 60, 927 (1984)].
[2] V.I. Yudson, Dynamics of integrable quantum systems. Zh. Eksp. Teor. Fiz. 88, 1757 (1985) [Sov. Phys. JETP 61, 1043 (1985)].
[3] V.I. Yudson and P. Reineker, Multiphoton scattering in a one-dimensional waveguide with resonant atoms; Phys.Rev. A 78, 052713 (2008).

David Zueco (ICMA, CSIC-Universidad de Zaragoza)

Single photons from vacuum

In this talk I discuss the emission from vacuum in a waveguide QED setup. If a non adiabatic change in the Hamiltonian occurs, an impurity coupled to a one dimensional waveguide emits radiation.
This resembles well known vaccum radiations as the ones occurring in the dynamical Casimir, Unhru or Hawking radiations. If the impurity is a nonlinear quantum system (e.g. a two level system) the radiation is not a guassian beam but it is a few photon emitter. Thus, we have ended up with a single photon emitter driven by vacuum fluctuations.

Val Zwiller (TU Delft)

Nano building blocks for quantum networks

Full list of authors: L. Schweickert , K. D. Jöns, T. Lettner, K. D. Zeuner , J. Zichi,
A.W. Elshaari, A. Fognini, I. Esmaeil Zadeh, V. Zwiller

With the aim of realizing complex quantum networks, we develop quantum devices based on nanostructures to generate quantum states of light with semiconductor quantum dots, single photon detectors based on superconducting nanowires and on-chip circuits based on waveguides to filter and route light.

The generation of single photons can readily be performed with single quantum dots. We demonstrate a very high single photon purity exceeding 99.99% generated at 795 nm with GaAs quantum dots [1], these quantum emitters also allow for interfacing with atomic ensembles. To enable long distance communication, we are also developing devices based on single InAs quantum dots able to emit at telecom frequencies [2].

Quantum entanglement is an important resource for quantum technologies, we will demonstrate generation of entanglement with quantum dots and discuss the limits to fidelity with the biexciton-exciton cascade [3].

To allow for complex architectures, on-chip integration is desirable. We will demonstrate filtering and routing of single photons with tunable ring resonators on a chip and discuss the scalability of this approach [4].

Generation and manipulation of quantum states of light would be useless without single photon detectors. We are therefore developing high-performance single photon detectors based on superconducting nanowires and will present state-of-the-art performance in terms of detection efficiency and time resolution [5].

[1] L. Schweickert et al., On-demand solid-state single-photon source with 99.99% purity, Appl. Phys. Lett. 112, 093106 (2018).
[2] K. D. Zeuner et al., A stable wavelength-tunable triggered source of single photons and cascaded photon pairs at the telecom C-band, Appl. Phys. Lett. Accepted (2018).
[3] A. Fognini et al., Path to perfect photon entanglement with a quantum dot, arxXiv:1710.10815(2017).
[4] A. W. Elshaari et al., On-chip single photon filtering and multiplexing in hybrid quantum photonic circuits, Nat. Commun. 8, 379 (2017).
[5] I. Esmaeil Zadeh et al., Single-photon detectors combining ultra-high efficiency, detection-rates, and timing resolution, APL Photonics 2, 111301 (2017).

Abstracts of Posters

Giuseppe Calajò (TU Wien)

Photon capture into a bound state in the continuum of a waveguide-qubit system

Full list of authors: G. Calajò, Y. L. L Fang, and H. U. Baranger, and F. Ciccarello

We show that it is possible to excite an exact bound state in the continuum (BIC) of a waveguide-qubit system by using a two photon pulse. The existence of such BIC states in the single photon sector is well-known but populating these states with an injected pulse is problematic. We study photon capture-- two photons are injected but only one comes out because the other is trapped in the BIC-- in two geometries, a single qubit in a semi-infinite waveguide or two qubits in an infinite waveguide. Photon capture proceeds by inelastic scattering due to the nonlinearity of the qubit and is suppressed for small qubit-qubit or qubit-mirror separation. Thereby, the system should in fact be in the non-Markovian regime due to non-negligible photon delay times. We investigate this effect in both a continuum model with linear dispersion and a coupled cavity array. In the case of two qubits, one outcome is heralded generation of very long-lived entanglement.

Dario Cilluffo (University of Palermo)

Photo-count detection of non classicality in non-local boson sampling devices

The goal of designing highly-specialized quantum devices with the technological tools available today is currently receiving large attention. In this respect, among the most investigated quantum devices is the boson sampler: It accomplishes the task of sampling from an output distribution of photons in a linear optical network, which is commonly known as 'boson sampling'.
It is believed that boson sampling problems cannot be efficiently solved using a classical computer.
In order to investigate the physical origin of such complexity, we considered integrated photonic circuits and investigated a variant of boson sampling: the non-local or "scattershot" boson sampling.
We observed that such complexity can be attributed to latent non-classical

features of the photonic input states. In particular, despite having a number of typically classical features, fully Dephased Squeezed Vaccum states (DSV) exhbit locally negative P-distribution (according to the Glauber-Sudarshan representation).
We designed and perfomed an experiment in order to indirectly measure such negativities via photo-count measurements only. Measurements were performed by photon-number resolving detectors made through avalanche pooth-diodes and cascaded in-fiber beam splitters.
The non-classical features detected by our experiment could potentially be exploited as a resource for novel quantum infornation processing tasks on quantum-optics-based multiple platforms

Stefano Cusumano (Scuola Normale Superiore, Pisa)

Interferometric Quantum Cascade Systems

In this work we consider quantum cascade networks in which quantum systems are connected through unidirectional channels that can mutually interact giving rise to interference effects. In particular we show how to compute master equations for cascade systems in an arbitrary interferometric configuration by means of a collisional model. We apply our general theory to two specific examples: the first consists in two systems arranged in a Mach-Zender-like configuration; the second is a three system network where it is possible to tune the effective chiral interactions between the nodes exploiting interference effects.

Leo Fang (Brookhaven National Laboratory)

Non-Markovian dynamics of a qubit due to photon scattering in a waveguide

Full list of authors: Y.-L. L Fang,, F. Ciccarello, and H. U. Baranger

We investigate the open dynamics of a qubit due to scattering of a single photon in an infinite or semi-infinite waveguide [1]. Through an exact solution of the time-dependent multi-photon scattering problem, we find the qubit's dynamical map. Tools of open quantum systems theory allow us then to show the general features of this map, find the corresponding non-Linbladian master equation, and assess in a rigorous way its non-Markovian nature. The qubit dynamics has distinctive features that, in particular, do not occur in emission processes. Two fundamental sources of non-Markovianity are present: the finite width of the photon wavepacket and the time delay for propagation between the qubit and the end of the semi-infinite waveguide.

[1] Y.-L. L. Fang, F. Ciccarello, H. U. Baranger, New J. Phys. 20, 043035 (2018)

Yong Lu (Chalmers University of Technology)

Towards an on-demand broadband single photon source in the microwave regime

Full list of authors: Y. Lu, A. Bengtsson, J. Burnett, B. Suri, E. Wiegand, A. Ask
B. Schneider, J. Bylander, G. Johansson, and P. Delsing

On-demand single microwave photon sources were demonstrated by several groups [1- 4]. Here, we discuss another experimental realization of a single photon generator using a different scheme proposed by Sathyamoorthy et al [5], where a transmon qubit is placed at the end of an open-ended transmission line. In this scheme, the qubit is excited using a short coherent π -pulse from one port of a directional coupler. The component of the pulse that is reflected by the mirror is then cancelled by destructively superposing it with another coherent pulse with opposite phase through another port of the directional coupler. Thereby a single photon is emitted by qubit relaxation on the transmission line and the reflected π- pulse is canceled. Theoretical calculations [2] show that photon generation efficiency close to 99% is possible with this method. This method also allows emission of photons over a broad frequency range.

[1] Bozyigit, D., *et al.*. Antibunching of microwave-frequency photons observed in correlation measurements using linear detectors. *Nature Physics* 7, 154 (2010).

[2] Houck, A. A., *et al.* Generating single microwave photons in a circuit. *Nature* 449, 328 (2007).

[3] Peng, Z. H., *et al.* Tuneable on-demand single-photon source in the microwave range. *Nature* Communications 7, 12588 (2016).

[4] M. Pechal et al. Microwave-Controlled Generation of Shaped Single Photons in Circuit Quantum Electrodynamics. PRX 4, 041010 (2014).

[5] Sathyamoorthy et al. Simple, robust, and on-demand generation of single and correlated photons. PRA 93, 063823 (2016).

Andrés Rosario Hamann (University of Queensland)

Entanglement stabilization of two superconducting qubits in a 1D waveguide

Full list of authors: A. Rosario Hamann, C. Muller, M. Jerger, J. Combes, M. Pletyukhov, T. M. Stace, and A. Fedorov

Here we propose a scheme to stabilize entanglement between two tunable superconducting qubits in a 1D waveguide. When dephasing and dissipation are ignored, we show that the steady state of the system approaches asymptotically the maximally entangled Bell state |Ψ+族= (|ge族 +|eg族/ 2 with fidelity F 闹1. Next, we analyze the effect of dissipation and

decoherence on the system and find that under realistic non-ideal conditions the steady state of the system approaches | Ψ +族with F > 0.8. Additionally, we present two different schemes to certify entanglement between the qubits, either by direct quantum state tomography or via the analysis of light correlations in the output field emitted by the qubits. We stress that our scheme for entanglement stabilization does not rely on the use of complicated time control schemes or feedback, and is resistant to moderate dephasing and dissipation, at the rates experimentally observed at our previous experiments with two qubits in a waveguide. Finally, we show our first experimental results, which provide indirect evidence that the two-qub

Alessio Settineri (University of Messina)

Interaction of Mechanical Oscillators Mediated by the Exchange of Virtual Photons

The electromagnetic quantum vacuum ?uctuations of the electromagnetic ?eld produce a force (Casimir e?ect) able to attract two close parallel mirrors. These vacuum ?uctuations are also able to induce motional forces exerted upon one mirror when the other one is moved. Here we consider an optomechanical system consisting of two vibrating mirrors coupled to a detuned optical resonator [1] . We ?nd a noticeable coupling rate between the two spatially-separated vibrating mirrors determined by the motional forces. Furthermore, by tuning the two mechanical oscillators into resonance, we demon- strate that mechanical quantum excitations can be coherently transferred among spatially-separated mechanical oscillators through a dissipation-less quantum bus, thanks to the exchange of virtual pho- ton pairs originating from the dynamical Casimir e?ect (DCE) (see, e.g., [2, 3]). The processes here proposed show that the electromagnetic quantum vacuum is able to transfer mechanical energy acting like an ordinary ?uid. It would be as if the vibration of a string (mechanical oscillator 1) could be transferred to the membrane of a microphone (mechanical oscillator 2) in the absence of air or of any medium ?lling the gap. This puzzling result opens up exciting possibilities of applying ideas from ?uid dynamics to the study of the electromagnetic quantum vacuum [4]. Furthermore, we show that this system can operate as a mechanical parametric down-converter even in the very low excitations regime. This e? ect can also be used as an indirect probe (not a?ected by the problem of thermal photons) of the DCE. In conclusion the obtained results show that the DCE in high frequency optomechanical sys- tems [3] can be a versatile and powerful new resource for the development of quantum optomechanical technologies.

[1] A. Ridolfo R. Stassi A. F. Kockum S. Savasta Salvatore O. Di Stefano, V. Macrì and F. Nori. Interaction of mechanical oscillators mediated by the exchange of virtual photon pairs. arXiv preprint arXiv:1712.00121, 2017.

[2] F. Nori P. D. Nation J. R. Johansson, M. P. Blencowe. Colloquium: Stimulating uncertainty: Amplifying the quantum vacuum with superconducting circuits. Rev. Mod. Phys., 84:1?24, Jan 2012.
[3] V. Macrì, A. Ridolfo, O. Di Stefano, A. F. Kockum, F. Nori, and S. Savasta. Nonperturbative Dynamical Casimir E?ect in Optomechanical Systems: Vacuum Casimir-Rabi Splittings. Phys. Rev. X, 8:011031, 2018.
[4] R. Golestanian M. Kardar. The ?friction? of vacuum, and other ?uctuation-induced forces. Rev. Mod. Phys., 71:1233?1245, Jul 1999.

Xin Zhang (Duke University)

Quantum Interference in Waveguide QED: Complex Photon Statistics and Heralded Entanglement

Full list of authors: Xin Zhang, Harold U. Baranger

We obtain photon statistics by using a quantum jump approach tailored to a system in which one or two qubits are coupled to a one-dimensional (1d) waveguide. Photons confined in the waveguide have strong interference effects, which play a vital role in quantum jumps and photon statistics. For a single qubit, for instance, bunching of transmitted photons is heralded by a jump that increases the qubit population. We show that the distribution and correlations of waiting times offer a clearer and more precise characterization of photon bunching and antibunching. The waiting times can be used to characterize complex correlations of photons which are hidden in g2(t), such as a mixture of bunching and antibunching.
Turning to the state of the qubits, we show that heralded generation of a maximally entangled state of two intrinsically open qubits can be realized in a 1d system with strong coherent driving and continuous monitoring. In contrast to the common belief that system-environment interaction leads to decoherence and so destroys quantum effects, continuous measurement and strong interference in our 1d system generates a pure state with perfect quantum correlation between the two open qubits. Another surprise is that this maximally entangled state survives the strong coherent state input, which is a classical state that overwhelms the whole system.