IQIT Workshop - Integrated Quantum Information Technology

September 23 - 27, 2013

Monday 23.9

Registration 16:00 – 20:00 *outside the Ball Room of Corfu Holiday Palace Hotel*

Tuesday 24.9

8:45-9:15 iQIT Overview

9:15-10:15 Mika Sillanpaa (Aalto U): Hybrid circuit cavity quantum electrodynamics with a micromechanical resonator

10:15-10:35 coffee break + discussion

10:35-11:35 Yuimaru Kubo (CEA Saclay): Hybrid Quantum Circuit with a Superconducting Qubit and an Electron Spin Ensemble

11:35-11:50 coffee break + discussion

11:50-12:50 Alexandre Blais (U Sherbrooke): Squeezing by damping modulation in circuit quantum electrodynamics

Lunch

16:00-17:00 Dvir Kafri (JQI, Maryland): Quantum Interfaces Between LC Circuits and Single Ions

17:00-17:20 coffee break + discussion

17:20-18:20 Evgeni Ilichev (IPHT, Jena): Quantum metamaterials - first experimental results; Georg Oelsner (IPHT, Jena):

18:20-18:40 coffee break + discussion

18:20-19:20 Miroslav Grajcar (Bratislava U): Parametric amplification and photon detection using of an array of superconducting flux qubits;
Sergey Philippov (Bratislava U): Feasible coupling of two superconducting resonators by a single trapped atom

Wednesday 25.9

9:00-10:00 Jason Petta (Princeton U): Quantum Interconnects for Spin Qubits

10:00-10:20 coffee break + discussion

10:20-11:20 David Vitali (U Camerino): Quantum cavity optomechanics with nanomembranes

11:20-11:40 coffee break + discussion

11:40-12:40 Guillermo Romero (U Basque Country): Entanglement generation via dynamical Casimir-like effect

Lunch

16:00-17:00 Oleg Astafiev (Royal Holloway U London): Lasing on a three-level artificial quantum system with controlled intra-atomic transitions

17:00-17:20 coffee break + discussion

17:20-18:20 Stefano Zippilli (U Salerno): Arrays of quantum systems in an entangled reservoir: steady-state entanglement replication in driven quantum many-body systems

18:20-19:00 iQIT internal session

20:00 Conference dinner

Thursady 26.9

9:00-10:00 Humberto Campanella (A*STAR, Singapore): Bulk Acoustic Wave (BAW) Resonators for Quantum Systems

10:00-10:20 coffee break + discussion

10:20-11:20 Christof Wunderlich (Siegen U): Elements of an Ion Trap on the Route towards an Integrated Quantum Information Processing Device

11:20-11:40 coffee break + discussion

11:40-12:40 Klaus Moelmer (Aarhus U)

Lunch

16:00-17:00 Natalia Korolkova (U St. Andrews): Quantumness of Gaussian discord;
Svetoslav Ivanov (U St. Andrews): Quantum Fourier transform without two-qubit gates;
Lachezar Simeonov (U Sofia): Accelerated conditional quantum phase gate with trapped ions in thermal motion

17:00-17:20 coffee break + discussion

17:20-18:20 Winfried Hensinger (Sussex U): Towards large scale quantum information processing with trapped ions

Friday 27.9

Departures, possibly guided tour in the morning

Abstracts (invited talks)

Oleg Astafiev

Royal Holloway University of London

Title: Lasing on a three-level artificial quantum system with controlled intra-atomic transitions

Abstract: We demonstrate classical three-level lasing with optical pumping on a superconducting quantum system. The system is based on the flux qubit geometry with tunable gap (energy splitting between two lowest levels). It is embedded into a superconducting coplanar resonator (with the fundamental frequency of several gigahertz) and tuned by external magnetic field so that frequency between two excited states coincides with one of high frequency modes of the resonator. This results in strong enhancement of relaxation between the second and the first excited states, which is necessary condition for creating population inversion when it is pumped from the ground to the second excited state. When the transition frequency between two lowest states is in resonance with the low mode of the resonator, strong lasing emission is observed. The lasing action is proved by amplification of the low frequency microwave and by a strong effect of narrowing of the emission spectra.

Alexandre Blais

Universite de Sherbrooke

Title: Squeezing by damping modulation in circuit quantum electrodynamics

Abstract: Dissipation-driven quantum state engineering uses the environment to steer the state of quantum systems and preserve quantum coherence in the steady state. We show that modulating the damping rate of a microwave resonator generates a new squeezing mechanism that creates a vacuum squeezed state of arbitrary squeezing strength, thereby allowing perfect squeezing. Given the recent experimental realizations in circuit QED of a microwave resonator with a tunable damping rate [Yin et al., Phys. Rev. Lett. 110, 107001 (2013)], superconducting circuits are an ideal playground to implement this technique. By dispersively coupling a qubit to the microwave resonator, it is possible to obtain qubit-state dependent squeezing.]

Humberto Campanella

RFMEMS Group Leader, Institute of Microelectronics IME, Agency for Science Technology and Research A*STAR, Singapore

Title: Bulk Acoustic Wave (BAW) Resonators for Quantum Systems

Abstract: Bulk acoustic wave (BAW) resonators are receiving considerable attention to integrate quantum information systems, due to their properties and high performance at microwave frequencies (at GHz bands). The talk will thus provide technical insight on the micro electromechanical system (MEMS) integration technologies involved in the fabrication of BAW resonators and their integration challenges in quantum systems. We will discuss some of the recent, embryonal examples in BAW resonator-to-quantum system integration, and the difficulties and opportunities to integrate BAW and other MEMS technologies in future quantum information systems.

Miroslav Grajcar

Comenius University, Bratislava

Title: Parametric amplification and photon detection using of an array of superconducting flux qubits

Abstract: Kinetic inductance in superconducting resonators gives rise to nonlinear effects such as bifurcation of the resonance curve or intermodulation gain. We report measurement of parametric amplification using nonlinearity of a pair of mutually coupled superconducting flux qubits embedded in a current antinode of a superconducting coplanar waveguide resonator. Qubits are strongly coupled to the resonator's photon field by shared Josephson junctions. These elements create a unit cell which can be straightforwardly extended to quasi one-dimensional quantum metamaterial with large Kerr nonlinearity tunable by applied dc magnetic field. Performance of the parametric amplifier at different working points is examined. Maximal measured gain is 20 dB regardless of applied dc magnetic field. The unit cell can also work as a switching detector, if larger Josephson junctions are used in the design. The hysteretic behavior with switching events was measured at 10 mK.

Winfried Hensinger

University of Sussex, UK

Title: Towards large scale quantum information processing with trapped ions

Abstract: To this point, entanglement operations on ion qubits have predominantly been performed using lasers. When scaling to larger qubit numbers however this becomes problematic due to the challenging engineering that might be required. The use of microwaves combined with a static magnetic field gradient overcomes this problems. Using multiple in-vacuum permanent rare earth magnets we have realized a large static magnetic field gradient at the position of a trapped ion (24 T/m). Using this setup we demonstrated the individually addressing of closely spaced ions by tuning the microwave frequency. We have also demonstrated motional sidebands transitions using the coupling between the ion s internal states and its motion induced by the magnetic field gradient. Both these achievements are the main ingredients required to realize microwave entanglement gates. Microwave entanglement gates operate on magnetic-field sensitive states which leave them vulnerable to decoherence due to fluctuating magnetic fields. By dressing the ions with microwaves we can protect against this source of noise and we show that our qubit coherence is preserved for two orders of magnitude longer compared with the bare states. Manipulation of microwave dressed state qubits have been described by Timoney et al.. We have developed a new powerful method of dressed state manipulation which gives us the ability to perform the arbitrary Bloch sphere rotations which are required for quantum computing while only requiring half as many rf fields for gate operations as Timoney s method . We have also developed several microfabricated traps for quantum information processing. I report the successful operation of the first two-dimensional ion trap lattice integrated on a microchip. Due to the device s long ion lifetimes and high secular frequencies this offers an exciting architecture with many applications including quantum simulation, field sensing and cluster state quantum computing. The device was fabricated using a process we developed to allow extremely large voltages to be applied to microfabricated devices. I will also report our progress towards the operation of a centrally segmented microfabricated ring trap featuring 90 electrodes capable of storing &#61627,1000 ions. This electrode arrangement provides periodic boundary conditions and therefore homogeneous ion-ion spacings which opens up the possibility to study quantum systems such as the homogenous Kibble-Zureck mechanism. Ion trapping in a cryogenic environment has a multitude of application. We have successfully constructed a cryogenic ion trap experiment and I will discuss details of the experiment. Finally I will discuss the development of high Q resonators integrated in an ion chip towards the implementation of quantum hybrid systems.

Evgeni Ilichev

IPHT, Jena

Ttile: Quantum metamaterials first experimental results

Abstract: Manipulating the propagation of electromagnetic waves through subwavelength sized artificial structures is the core function of metamaterials. Recently, it has been suggested to use arrays of superconducting qubits in order to implement a quantum metamaterial. While natural materials consist of identical atoms, superconducting qubits are never exactly the same. The properties of each qubit depend strongly on the fabrication parameters. In a linear qubit chain, which relies on the nearest-neighbour interaction, single off-resonant qubits act as defects and may destroy coherent modes. This drawback can be circumvented by using a common cavity for coupling the qubits one by one to a collective quantum mode, disregarding their relative position. Today we report on the realization of such an experiment with 20 superconducting flux qubits embedded into a single microwave resonator. The phase of the signal transmitted through the resonator reveals the resonant coupling of up to 8 qubits.

Svetoslav Ivanov

University of St. Andrews, UK

Title: Quantum Fourier transform without two-qubit gates

Abstract: We will present a new method for the implementation of the quantum Fourier transform with trapped ions in a magnetic field gradient. The method builds upon the visionary idea of Mintert, F. and Wunderlich, C. [Phys. Rev. Lett. 87, 257904 (2001)] for implementing quantum logic gates with microwave and radiowave radiation. Instead of using circuits of universal gates as prescribed by the standard computational approach, we simply apply a series of phased Pi pulses at specific moments of time. This improves the scalability as the number of interaction steps is greatly reduced. Different trap designs will be considered.

Dvir Kafri

Joint Quantum Institute, Maryland

Title: Quantum Interfaces Between Circuits and Atoms

Abstract: By careful modulation of its characteristic parameters, we show how to coherently couple the electric field of an LC circuit to the motional mode of a single ion. This can be used to couple the ion internal state to the circuit, with the same speed as ion-ion motional gates. All the well-known quantum information protocols linking ion internal and motional states can be converted to protocols between circuit photons and ion internal states. Our results enable quantum interfaces between solid state qubits, atomic qubits, and light, and lay the groundwork for a direct quantum connection between electrical and atomic metrology standards.

Natalia Korolkova

University of St. Andrews, UK

Title: Quantumness of Gaussian discord

Abstract: Quantum correlations in separable mixed quantum states as quantified, for example, by quantum discord, are currently attracting increasing attention and may change our understanding of what the ultimate Quantum Information Processing (QIP) resources are. We focus here on infinitely-imensional systems and study experimentally and theoretically Gaussian quantum discord in bi-partite and multi-partite Gaussian states confirming the usefulness of such general quantum correlations as a physical resource for QIP.

Yuimaru Kubo

Quantronics Group, SPEC, CEA-Saclay

Title: Hybrid Quantum Circuit with a Superconducting Qubit and an Electron Spin Ensemble

Abstract: We report the experimental realization of a hybrid quantum circuit combining a superconducting qubit and an ensemble of electronic spins. The qubit, of the transmon type, is coherently coupled to the spin ensemble consisting of nitrogen-vacancy (NV) centers in a diamond crystal via a frequency-tunable superconducting resonator acting as a quantum bus[1,2]. Using this circuit, we prepare arbitrary superpositions of the qubit states that we store into collective excitations of the spin ensemble and retrieve back into the qubit later on [3]. These results constitute a first proof of concept of spin-ensemble based quantum memory for superconducting qubits. We also report a new method for detecting the magnetic resonance of electronic spins at low temperature with a qubit using the hybrid quantum circuit [4]. References [1] Y. Kubo et al., Phys. Rev. Lett., 105, 140502 (2010). [2] Y. Kubo et al., Phys. Rev. A, 85, 012333 (2012). [3] Y. Kubo et al., Phys. Rev. Lett., 107, 220501 (2011). [4] Y. Kubo et al., Phys. Rev. B, 86, 064514 (2012).

Klaus Moelmer

Aarhus University

Title: TBA

Georg Oelsner

IPHT, Jena

Title: Underdamped Josephson junction as a switching current detector

Abstract: Quantum information technologie based on artificial superconducting quantum systems uses comparatively small energies, usually corresponding to the GHz range. Therefore a challenging task in this field is to find detectors suitable of identifing this small signals. Special interest attracts the development of single photon detectors for this frequency domain. The detection of photons should be irreversible and provide good effeciency. We propose the use of an underdamped Josephson junction as high sensitive switching current detector. Therefore, we demonstrate the narrow switching distribution of such a system from the zero to the finite voltage state at millikelvin temperatures. We argue that such junctions can operate close to the quantum limit: a given initial (zero voltage) state can be driven by an incoming signal to the finite voltage state. The width of the switching distribution at a nominal temperature of about T = 10 mK was 4,5 nA, which corresponds to an effective noise temperature of the device below 60 mK.

Jason Petta

Princeton University, USA

Title: Quantum Interconnects for Spin Qubits

Abstract: A single electron spin in an external magnetic field forms a two-level system that can be used to create a spin qubit. Single spins are controlled using electron spin resonance and nearest neighbor spin couplings are achieved using the exchange interaction. A major challenge is to develop methods for coherently coupling spin qubits that are separated by large distances. I will describe our recent efforts to couple a spin qubit to a superconducting quantum bus in the circuit quantum electrodynamics architecture. Our results show that spin dynamics can be controlled using electric fields and the spin-orbit interaction. We find that the microwave field of the superconducting resonator is sensitive to single

spin dynamics. Our results suggest that a spin-cavity coupling rate of ∼1 MHz may be feasible, allowing spatially separated spin qubits to be coupled by a microwave field.

Sergey Philippov

Bratislava University

Title: Feasible coupling of two superconducting resonators by a single trapped atom

Guillermo Romero

Basque Country Univeristy

Title: Entanglement generation via dynamical Casimir-like effect

Abstract: We study the quantization of two LC oscillators coupled through a superconducting quantum interference device (SQUID). When a driving field is injected through the SQUID loop, the boundary conditions of the two LC oscillators changes accordingly and so it does the effective length of the cavities. If the driving frequency is of the same order of the cavity resonant frequency, photon generation occurs. This phenomenon corresponds to a dynamical Casimir-like effect where the photon generation is due to a parametric amplification process. The net effect on the resonators is the creation of single-mode and two-mode squeezing. When considering two two-level systems interacting with a single cavity mode, respectively, the above mechanism allows for generating two-qubit entanglement. The above proposal can be scaled up for the sake of tunable quantum networks and for multipartite entanglement generation.

Mika Sillanpaa

Aalto University

Title: Hybrid circuit cavity quantum electrodynamics with a micromechanical resonator

Abstract: One can add intriguing features to the setup by including a superconducting qubit, a quantum two-level system. Such a hybrid approach will allow for combining the benefits of each subsystem, such as the long lifetime of phonons, together with the machinery learned with superconducting qubits. Our superconducting transmon qubit interacts with a 70 MHz phonon mode in a micromechanical resonator. We operate the qubit in the circuit cavity quantum electrodynamics (circuit QED) architecture, where the qubit is coupled also to a microwave cavity. Hence, the combined setup represents an artificial atom coupled to two different cavities. We measure the phonon Stark shift, as well as the splitting of the qubit spectral line into motional sidebands, which feature transitions between the dressed electromechanical states. In the time domain, we observe coherent conversion of qubit excitation to phonons as sideband Rabi oscillations. This is a model system having potential for a quantum interface, which may allow for storage of quantum information in long-lived phonon states. We also discuss recent work on applying the qubit-mechanical resonator coupling for studying radiation-pressure physics known from optomechanics.

Lachezar Simeonov

Sofia University

Title: Accelerated conditional quantum phase gate with trapped ions in thermal motion

Abstract: We introduce a two-qubit control-phase gate, which operates with trapped ions in a linear Paul trap. Each ion is addressed individually with two sequential bichromatic laser fields, the two frequency components of which are tuned on exact resonance with the first blue and red vibrational sidebands of

the qubit transition frequency. For suitably chosen pulse areas and relative laser phases the dependence on the phonon number vanishes and the net effect is a control-phase gate between the electronic qubit states. In contrast to earlier gates, in which the pulses addressing the two ions are separated in time, we use partially overlapping pulses, which make this gate faster, e.g., by about 13% for rectangular and 30% for sinusoidal pulses.

David Vitali

School of Science and Technology, Physics Division, University of Camerino, Camerino (MC), Italy

Title: Quantum cavity optomechanics with nanomembranes

Abstract: A semitransparent thin membrane within a Fabry-Perot cavity is a promising tool for investigating quantum effects in cavity optomechanics. We show recent experimental results demonstrating tunable optomechanical induced transparency at room temperature, and also theoretical results showing how such a system could be used for interfacing microwave and optical radiation.

Christof Wunderlich

University of Siegen

Title: Elements of an Ion Trap on the Route towards an Integrated Quantum Information Processing Device

Abstract: We present the design, fabrication, and characterization of a segmented surface ion trap with integrated current carrying structures. The latter produce a spatially varying magnetic field necessary for magnetic gradient induced coupling (MAGIC) between ionic spins. Trapping of strings of Yb+ ions is demonstrated and the performance of the trap is characterized. In addition, we apply and characterize a magnetic gradient and demonstrate individual addressing in a string of three ions using RF radiation in this surface trap. The next generation surface trap will include microwave resonating structures to efficiently couple microwave radiation to ionic spins.

Tailoring of coupling constants between ionic spins is particularly versatile in ion traps with segmented electrodes. It is shown how static potentials applied to individual electrodes of a micro-structured trap together with suitable RF pulses allow for creating various spin-spin coupling Hamiltonians that give rise to long distance entanglement (LDE). LDE maybe used as a quantum bus and/or a means to detect coupling between ion spins and superconducting qubits.

Stefano Zippilli

Salerno University

Title: Arrays of quantum systems in an entangled reservoir: steady-state entanglement replication in driven quantum many-body systems

Abstract: We study the dynamics of two non-directly interacting arrays of quantum system which are locally driven, on one of their ends, by a two-mode squeezed reservoir. We show that in the steady state the entanglement of the driving field is reproduced in an arbitrarily large series of inter-array entangled pairs over all distances. Each pair is made of an element of the first array and one of the second, and their entanglement is ideally equal to that of the driving field.

Local nonclassical driving thus realizes a scale-free entanglement replication and long-distance entanglement distribution mechanism that has immediate bearing on the implementation of quantum communication networks.

The entanglement is characterized and studied as a function of the system parameters, showing that it is robust against various source of noise and imperfections, including different sources of dissipation, thermal character of the external driving field, asymmetries of the arrays and finite bandwidth of the driving reservoir.

Abstracts (contributed)

Constantin V. Usenko

Kyiv Shevchenko University

Title: Complexity of measurement of a qubit pair

Abstract: Statistical nature of quantum laws makes need in a large number of measurements in the process of solving the problem of reconstruction of state of a quantum system. Analysis of the process of accumulation of the results of measurements shows that the success of this process substantially depends on the possibility of coordination of actions of two participants of the process - preparator who prepares the series of the states being measured and registrator who chooses in each event of measurement one of incompatible observables. In the problems on information transfer or transformation, coordination of the source and the receiver makes it possible to get unambiguous reconstruction of states by one measurement (non-demolition measurements). In the problems of research character or adjustment of equipment with coordination of the sequence of the prepared states and the sequence of the measured (incompatible) observables, even at use of entangled states, it is possible to decrease the needed number of the measurement events to the theoretical minimum. For a pair of qubits the minimal needed number is the measurement of 5 pairs of incompatible observables, for N gubits -- 2^N+1 observables. The problems of information protection against interception differ by absence of coordination of actions of preparator and registrator, this substantially complicates the registrator's problem. It is shown that by an appropriate selection of coding sequences it is possible to achieve insolubility of the problem of reconstruction of the coding state set and as a result insolubility of the problem of intercept. A new value, the complexity of measurement of a state, is used, this characterizes the number of the measurement events needed for solution of the reconstruction problem. By means of this value it is shown that the dependence of the upper limit of the needed number of measurements on the permissible error is a square law one, so a twofold decrease of permissible error corresponds to a fourfold increase of needed number of measurements. By the example of a pair of quibits formed by a two-level atom and a quantum mode coupled with the atom it is shown that measurement of 5 incompatible pairs of local observables is enough for reconstruction of an arbitrary state, and availability of prior information on the states that are used makes it possible to limit the measurement with 3 incompatible pairs of local observables.