PhD program in Quantum Technologies 2022 Summer School

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Book of Abstracts

Contents

Session 1 / 134

Probing Atomic Quantum States

Francesco Cataliotti[1]

[1] *CNR - INO*

Corresponding Author(s): francescosaverio.cataliotti@ino.cnr.it

Probing Atomic Quantum States

Session 1 / 132

Frequency metrology and laser stabilization: tools for Quantum technologies

Mario Siciliani de Cumis[1]

[1] *Agenzia Spaziale Italiana*

Corresponding Author(s): mario.sicilianidecumis@asi.it

Nowadays, Time and Frequency Metrology are key elements in optics, spectroscopy, geodesy and Quantum Technologies. In particular, coherent fiber links (up to 1800 km) have been demonstrated powerful for frequency dissemination on ultra low noise scales. Laser stabilization is therefore crucial for frequency metrology and for high accuracy measurements. Here, we will present how these tools can be crucial in quantum technologies. A couple of examples regarding quantum communication and quantum sensing will be shown.

Students Talks 1 / 86

Quantum Illumination of Phase conjugate Receiver using Neyman Pearson target detecton test

Theerthagiri Lakshmanan[1] ; David Vitali[2]

[1] *Research Scholar*

[2] *Profeesor*

Corresponding Author(s): theerthag.lakshmanan@unicam.it

To detect the presence or absence of an object in concealed thermal noise, a parametric down conversion of a Gaussian squeezed entangled state is sent to space. In the environmental background, the quantum illumination (QI) entangled state is always much better than the optimal classical illumination (CI) target detection. We can easily provide the prior probability using the Neyman-Pearson technique rather than the Bayesian method. One of the primary advantages of quantum illumination receiver operating characteristics is the ability to compare the superior performance of two experimental setups. This paper compares the receiver operating characteristics of classical homodyne detection, optical parametric amplifier (OPA), and phase conjugate (PCR) photon counts. We demonstrate that the P CR configuration outperforms the other two scenarios and that the approximations of Ns $\ll$ 1 and NB $\gg$ 1 are compatible with the classical Gaussian distribution.

Students Talks 1 / 87

Trace-molecule detection below the ppt level with cavity-enhanced photoacoustic spectroscopy

Author(s): Jacopo Pelini [1] ; Zhen Wang [2]

Co-author(s): Mario Siciliani De Cumis [3] ; Paolo De Natale [2] ; Simone Borri [2] ; Wei Ren [4]

[1] *University of Naples "Federico II", CNR-INO Florence*

[2] *CNR-INO Florence*

[3] *ASI Matera*

[4] *Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong*

Corresponding Author(s): jacopo.pelini@unina.it

Trace-gas detection plays an important role in our modern society, impacting sectors as energy production, environmental monitoring, transportation, agriculture, safety, and security. During the last decade, optical detection with ultra-high sensitivity, down to the ppq level, was demonstrated with cavity-ring down techniques [1], enabling laser sensors to enter areas as archaeology (radiocarbon dating), climate change monitoring, biofuel control, contaminant assessment for semiconductor industry and so on. More recently, photoacoustic sensors based on quartz tuning forks and silicon cantilever have shown great potential in achieving a sensitivity at the level of the techniques mentioned above, especially when combined with narrow-linewidth mid-infrared lasers and high-finesse optical cavities [2-5]. In addition, they have unique characteristics of robustness, wide dynamic range and compact size, which make them particularly attractive for in-field applications. Here, the recent developments in photoacoustic sensing combined with resonant cavities are discussed, showing the potentiality of the technique towards sub-ppt trace-gas detection. The setup is based on a silicon cantilever as acoustic transducer, whose displacement is measured with a balanced Michelson interferometer. The cantilever is mounted in a home-made photoacoustic cell consisting of a high-Q-factor acoustic resonator placed inside a high-finesse optical resonator. This design, leveraging on a double standing wave effect, achieves a combined acoustic and optical amplification factor of several orders of magnitude with respect to the standard configuration, thus strongly enhancing the final detection sensitivity. For our proof-of-principle demonstration of the technique, a mid-infrared quantum cascade laser at 4.5 μm is used, addressing N2O rovibrational transitions.

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Students Talks 1 / 88

Practical Limits on Large-Momentum-Transfer Clock Atom Interferometers

Author(s): Mauro Chiarotti[1]

Co-author(s): Jonathan N. Tinsley [2] ; Satvika Bandarupally [2] ; Shamaila Manzoor [2] ; Michele Sacco [2] ; Leonardo Salvi [3] ; Nicola Poli [4]

[1] *Università Degli Studi di Firenze, Dipartimento di Fisica e Astronomia*

[2] *Università degli Studi di Firenze, Dipartimento di Fisica e Astronomia e LENS*

[3] *Università degli Studi di Firenze, Dipartimento di Fisica e Astronomia e LENS; INFN-Sezione di Firenze*

[4] *Università degli Studi di Firenze, Dipartimento di Fisica e Astronomia e LENS; INFN-Sezione di Firenze; CNR-INO*

Corresponding Author(s): chiarotti@lens.unifi.it

Atom interferometry utilising single-photon optical transitions represents an emerging technology with the ability to probe physics in a variety of previously untested regimes. Multiple experiments based upon the clock transition of Sr at 698 nm have been proposed to search for a wide set of fundamental physics goals, such as gravitational wave detection. Crucial to meeting these experiments' required sensitivities is the implementation of large momentum transfer (LMT), with very large enhancements of 1000-10000 $\hbar k$ ultimately proposed for terrestrial experiments currently in the development stage. In practice, this typically means increasing the momentum separation between the two paths of the wavepacket by applying a series of π pulses. Such a manipulation of the atom samples is highly susceptible to the noise performance of the interferometry laser: within the quantum community-framework of the operational fidelity, we have been simulating the effect of the intensity and frequency noise on a single atom at rest interacting with resonant light. Our results, considering a typical square pulse sequence, show the challenging nature of the proposed experiments, suggesting that the limiting role played by the laser frequency spectrum must be accounted for when studying the practical feasibility of a gravimeter sequence. Particularly, the equivalent laser linewidth is required be considerably lower than has previously been suggested. Within this framework, we further present and analyse two high-power, frequency-stabilised laser sources designed to perform interferometry on the 1S0 -3P0 clock transitions of cadmium and strontium, respectively operating at 332 nm and 698 nm.

Students Talks 1 / 93

A new programmable quantum simulator with two-electron Rydberg atoms in optical tweezer arrays

Luca Guariento[1]

[1] *University of Naples Federico II, CNR-INO*

Corresponding Author(s): guariento@lens.unifi.it

I will present a new programmable quantum simulator based on Rydberg strontium atoms trapped in optical tweezers arrays at CNR-INO and Department of Physics in Florence. This new experimental setup, supported by an infrastructural program of CNR, is now under construction in our laboratories as a joint effort of CNR and the University of Florence. I will present the main features of the apparatus, including the techniques that will be employed for the generation of programmable arrays of optical tweezers and for the control of the different sources of decoherence. I will also discuss the advantages offered by two-electron atoms, including narrow optical transitions that can be exploited for effective atomic cooling schemes, and the existence of a metastable state that provides an additional degree of freedom for the manipulation of individual atoms, as well as a direct connection to frequency metrology. I will finally discuss the applications that we envision for this new setup, in particular the simulation of quantum spin models with different types of interactions and topologies, and the realization of multi-particle entangled states.

Students Talks 1 / 96

Geometric corrections to cosmological entanglement

Alessio Belfiglio[1] ; Stefano Mancini[None] ; Orlando Luongo [1]

[1] *University of Camerino*

Corresponding Author(s): alessio.belfiglio@unicam.it

We investigate entanglement production by inhomogeneous perturbations over a homogeneous and isotropic cosmic background, demonstrating that the interplay between quantum and geometric effects can have relevant consequences on entanglement entropy, with respect to homogeneous scenarios. To do so, we focus on a conformally coupled scalar field and discuss how geometric production of scalar particles leads to entanglement. Perturbatively, at first order we find oscillations in entropy correction, whereas at second order the underlying geometry induces mode-mixing on entanglement production. We thus quantify entanglement solely due to geometrical contribution and compare our outcomes with previous findings. We characterize the geometric contribution through geometric (quasi)-particles, interpreted as dark matter candidates.

Students Talks 1 / 102

Persistent Tensors: Multiqudit Version of Multiqubit W State and Multiqudit Entanglement Transformation

Author(s): Masoud Gharahighahi[None]

Co-author(s): MASOUD GHARAHIGHAHI [1]

[1] *University of Camerino*

Corresponding Author(s): masoud.gharahighahi@unina.it

We construct a lower bound of the tensor rank for a class of tensors that we call them persistent tensors. In this class, there is a specific subclass of tensors that the lower bound is tight. Indeed, this subclass is n-qudit version of n-qubit W states (we call them n-qudit M states denoted by $|\mathrm{M}(d,n)\rangle$ and we have $\mathcal{M}(2,n) = \mathcal{W}_n$). Consequently, we show that one can obtain n-qudit M states from a generalized n-qudit GHZ state via asymptotic Stochastic Local Operations and Classical Communication (SLOCC) with a rate approaching unity. We also show that the tensor rank of Kronecker product, and hence, tensor product of m-qudit GHZ and n-qudit M states is equal to the product of their tensor ranks, i.e., $R\big(\mathcal{G}(d_1,m) \otimes \mathcal{M}(d_2,n)\big) = d_1\big((n-1)d_2 - n + 2\big)$.

Students Talks 1 / 101

Accelerating Monte Carlo Simulations via Quantum Annealers

Author(s): Giuseppe Scriva[1]

Co-author(s): Emanuele Costa [1] ; Sebastiano Pilati [1]

[1] *University of Camerino*

Corresponding Author(s): giuseppe.scriva@unicam.it

Simulating the low-temperature equilibrium properties of a spin glass is notoriously a hard computational task. It plays a central role in condensed matter physics, and it is also related to relevant NP-hard optimization problems which can be mapped into spin models.

Deep Learning (DL) models, such as generative neural networks can be used to accurately mimic Boltzmann distributions and to accelerate Monte Carlo simulations of classical statistical models. One of the bottlenecks of deep neural networks is the effort to generate a proper dataset: in the spin glass, for instance, classical method to obtain data fail. Therefore, we exploit D-Wave quantum annealer to produce adequate training datasets for the generative models.

Hybrid neural Metropolis algorithms will be described, as well as the use of hybrid quantum-classical training dataset. We obtain a remarkable suppression of the long correlation times that plague spin-glass simulations in the low-temperature regime and a precise reconstruction of the configuration energy distribution. These results demonstrate that quantum devices, combined with DL algorithms, allow tackling otherwise intractable computational problem.

Session 2 / 131

Quantum transport in open spin chains

Laleh Memarzadeh[1]

[1] *Sharif University of Technology*

Corresponding Author(s): l.memarzadeh@gmail.com

After reviewing the general mathematical framework for describing dynamics of open quantum systems, we focus on quantum Markovian processes. We recall two main approaches for deriving Markovian master equation within the weak-coupling limit, namely "local" and "global" approaches.

After highlighting the results of investigations for comparing the virtues and weaknesses of each approach, we focus on transport properties of a spin chain when either approach is used to describe the dynamics. More specifically we use these two approaches for describing the dynamics of a spin chain with XX Hamiltonian in an external field when the two ends of the spin chain are coupled to two thermal baths at different temperatures. This enables us to compare the predictions of each approach for transport properties of the open spin chain. In the global approach non-local effects of local baths are observed in the spin continuity equation as sink/source terms. These non-local features are missed in the local approach. Furthermore, we see that the asymptotic transport properties of the chain in the local approach can not be derived from the asymptotic properties of the global approach when interaction between spins in the chain tends to zero. We finish the discussion by discussing how varying Hamiltonian parameters leads to having negative transition frequencies and as a result the asymptotic spin and heat flows exhibit discontinuities.

Session 3 / 97

Entanglement for quantum technologies

Augusto Smerzi[1]

[1] *INO-CNR*

Corresponding Author(s): augusto.smerzi@ino.it

I will first briefly introduce the concept of quantum entanglement, highlighting its differences with classical correlations. I'll therefore discuss the concept of Bell non-locality, which plays a central role in quantum cryptography and device independent certification, using a diagrammatic causal inference analysis. This approach will allow us to investigate the physical meaning of the free-will, realism, and locality assumptions used to derive the Bell inequalities. I'll conclude the course by introducing the concept of metrological entanglement, namely the class of entangled states that can provide sub shot-noise sensitivities in generic phase estimation problems. I'll demonstrate that this class of states is witnessed by the Fisher information.

Session 4 / 133

Quantum transport in open spin chains - part 2 - Prof. Laleh Memarzadeh

Students Talks 2 / 95

Digital qubit readout with a flux-switchable superconducting circuit

Author(s): LUIGI DI PALMA[1]

Co-author(s): Alessandro Miano [2] ; Pasquale Mastrovito [3] ; Davide Massarotti [4] ; Marco Arzeo [5] ; HALIMA GIOVANNA AHMAD [6] ; DOMENICO MONTEMURRO ; GIOVANNI PIERO PEPE [7] ; Francesco Tafuri [8] ; Oleg Mukhanov [5]

[1] *Università Federico II Napoli*

[2] *Department of Applied Physics, Yale University, New Haven, Connecticut 06520, USA*

[3] *University of Naples Federico II*

[4] *Dipartimento di Ingegneria Elettrica e delle Tecnologie dell'Informazione, Università degli Studi di Napoli Federico II*

[5] *SeeQC*

[6] *Department of Physics "Ettore Pancini", University of Naples "Federico II", CNR-SPIN, Naples and Seeqc*

[7] *University of Napoli Federico II*

[8] *Università di Napoli Federico II*

Corresponding Author(s): luigi.dipalma@unina.it

Quantum computing platforms based on superconducting qubits have emerged as one of the most promising candidates in the race to build a large scale quantum computer [1]. Controllability, standard chips fabrication techniques combined with the possibility of exploring unconventional hybrid systems [2] are well established advantages of superconducting qubits architectures as quantum processors. However, while the performance of small superconducting quantum processors has advanced the threshold necessary for fault tolerance, the current technique to control and readout the qubit state imposes severe system scaling challenges [3]. Within this framework, digital control based on cryogenic energy-efficient superconducting Single Flux Quantum (SFQ) logic is being adapted to perform qubit control and readout for scalable quantum 3D-architectures [4]. This is leading to the development of innovative concepts for quantum processor control and benchmarking in this integrated digital-quantum hybrid system.

Here, we propose an SFQ-compatible approach to accomplish diabatic readout of superconducting qubits based on a Josephson Digital Phase Detector (JDPD). When properly excited by flux bias pulse, the JDPD is able to quickly switch from a single-minima to a double-minima potential and, consequently, relax in one of the two stable configurations discriminating between two phase values of a coherent input tone at GHz frequency. The basic concepts behind this new readout scheme have been experimentally verified with a preliminary version of the JDPD. The capability to work as a phase detector has been demonstrated up to 100kHz tone with a remarkable agreement between the experimental outcomes and simulations [5].

By choosing design parameters, the JDPD will be sensitive at frequency in the range of GHz, the typical frequency of superconducting qubits. These characteristics make the JDPD suitable for the implementation of a high speed platform integrated with superconducting digital electronics for both control and readout the qubit's state directly at 20 mK, providing a solid solution for highly scalable superconducting quantum processors.

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on single flux quantum digital logic", Quantum Science and technology 3 (2018). [5] Di Palma et al., "Discriminating the phase of a weak coherent tone with a flux-switchable superconducting circuit", in prep.

Students Talks 2 / 104

Harmonic generation in SNAIL TWPA

Author(s): ANNA LEVOCHKINA[1]

Co-author(s): MARTINA ESPOSITO [2] ; GIOVANNI PIERO PEPE [3]

[1] *University of Naples, Federico ii, Physics department*

[2] *CNR SPIN Insitute, Naples, Italy*

[3] *University of Naples Federico II, Physics Department*

Corresponding Author(s): anna.levochkina@unina.it

A Josephson Travelling Wave Parametric Amplifier (TWPA) is a non-linear device which consists of a long array of repeating unit cells containing Josephson junctions. In our case the unit cell consists of a superconducting loop with three large (high critical current) and one small (low critical current) Josephson junctions (so-called SNAIL-cell - superconducting nonlinear asymmetric inductive element [1]). The nonlinearity of this device gives rise to parametric amplification: namely in presence of an intense input pump at frequency ωp and a weak input signal at frequency ωs, the output signal will be amplified and the idler tone at frequency ωi = ωp − ωs will be generated. In addition, due to the nonlinearity harmonic generation takes place, affecting amplification performance of TWPAs. In this work, the appearance of harmonics in such device is studied in detail.

Our experiment was carried out in the laboratory of Quantum Technologies of Naples University Federico II. The TWPA was placed in a Triton cryostat of Oxford Instruments which was cooled down to 7 mK in order to achieve the necessary amplification. We used SNAIL TWPA consists of 700 unit cells [2]. The device was fabricated at Neel Institute, CNRS in Grenoble. For this device we experimentally observe the appearance of second and third order harmonics in presence of pump and signal for different values of the external magnetic flux threading the SNAILs. We study harmonic generation at both zero and half magnetic flux quantum. The results of experiment are in agreement with the theory according to which the presence of second harmonic depends on nonlinearity β (three-wave mixing coefficient) and third harmonic generation depends on γ (four-wave mixing coefficient) [3]. Both β and γ depend on applied magnetic flux.

Simulation of SNAIL TWPAs with PSCAN2 software package (a circuit analyzer that supports Josephson junctions) was also performed for comparison with experimental data and analytic predictions.

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Students Talks 2 / 117

Interfacing superconducting digital read-out circuit for optimal control

Pasquale Mastrovito[1] ; Luigi Di Palma[2] ; Alessandro Miano[3] ; Davide Massarotti[4] ; Domenico Montemurro[5] ; Giampiero Pepe[5] ; Marco Arzeo[6] ; Francesco Tafuri[7] ; Oleg Mukhanov[6]

[1] *University of Naples Federico II*

[2] *Università Federico II Napoli*

[3] *Department of Applied Physics, Yale University, New Haven, Connecticut 06520, USA*

[4] *Dipartimento di Ingegneria Elettrica e delle Tecnologie dell'Informazione, Università degli Studi di Napoli Federico II*

[5] *Università degli studi di Napoli Federico II, Consiglio Nazionale delle Ricerche- SPIN*

[6] *SeeQC*

[7] *Università di Napoli Federico II*

Corresponding Author(s): p.mastrovito97@hotmail.com

In the last years, superconducting circuits have passed from being interesting physical devices to becoming one of the most promising contenders in the race towards the first fault-tolerant quantum computer [1]. In this context Quantum Non-Demolition (QND) read-out of superconducting qubits becomes an essential step in most computational operations and in protecting quantum information throughout them. QND read-out of superconducting qubits is usually achieved by detecting the frequency shift of a microwave resonator coupled to the qubit under test [2]. Improvements in terms of latency and scalability are not often discussed, despite the increase in size and complexity of modern quantum processors [3]. In this context, the phase detection capability of Josephson junctions can be exploited to develop alternative schemes [4]. We have successfully characterized [5] a flux tunable Josephson phase detector, called Josephson Digital Phase Detector (JDPD), that can be used to perform QND qubit read-out in situ by dynamically changing the applied flux through the two loops that define its structure. Here we present a study about optimization of control and read-out fidelity of the circuit. The optimization is based on finely engineering the coupling between the circuit loops and external flux sources. We show that the system can be inserted in a Single Flux Quantum (SFQ) logic [6] environment thanks to the JDPD ability to project the qubit state in one of his two flux states in the double well regime. Thanks to the SFQ technology we are able to reach sampling frequencies in the GHz range. In addition to that we show that thanks to the double-loop layout of the JDPD it is possible to protect the system from unwanted asymmetries due to flux noise or fabrication issues.

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Students Talks 2 / 105

Self-induced Josephson junction in a supersolid dipolar quantum gas

Beatrice Donelli[1] ; Augusto Smerzi[2] ; Luca Pezzè[2]

[1] *QSTAR, INO-CNR, LENS, Università degli studi di Napoli Federico II*

[2] *QSTAR, INO-CNR, LENS*

Corresponding Author(s): donelli@lens.unifi.it

Supersolid is a state of matter in which coexist both a periodic modulation, characteristic of the solid state, and the ability of the superfluid to flow without any friction. Its theoretical prediction dates back to 1960s, but it was experimentally observed for the first time few years ago, in a dipolar quantum gas. This work is based on the idea of searching for coherent tunneling phenomena, such as Josephson oscillations, in this dipolar supersolid, to demonstrate the superfluidity of the system. This phenomenon usually requires an external potential barrier through which the tunneling arises, but the intrinsic modulation of the supersolid creates minima in the potential, which act as a self-induced barrier. This gives rise to a junction that can support Josephson oscillations and the Macroscopic Quantum Self-Trapping regime. We have observed both phenomena using a 3D numerical simulation of an extended Gross-Pitaevskii equation (i.e. with the addition of first-order quantum fluctuations) and predicted the location of this transtition through a theoretical model.

Students Talks 2 / 106

Distributed Quantum Sensing for optical and atom interferometry

Marco Malitesta[1] ; Augusto Smerzi[2] ; Luca Pezzè[2]

[1] *QSTAR, INO-CNR and University of Naples "Federico II"*

[2] *QSTAR, INO-CNR and LENS*

Corresponding Author(s): marco.malitesta@unina.it

We propose an estimation scheme based on the distribution of a single squeezed state among d interferometers to achieve highly sensitive estimation of multiple parameters. The scheme admits different implementations ranging from optical to atom interferometry. The fundamental component of our scheme is the "quantum circuit" (QC), a linear network that optimally distributes the squeezing generated at one of its inputs among d simple (Mach-Zehnder or Ramsey) interferometers, where d unknown parameters are then imprinted and the number of particles at the outputs finally measured. For any given linear combination of the parameters, we identify the optimal configuration of the QC that allows its estimation with maximal, sub-shot-noise sensitivity. Our "entangled" strategy, based on the mode-entanglement created by the QC, outperforms the rival and more common "separable" strategy, in which the same unknown parameters are estimated independently: the sensitivity gain being a factor d, at most. We show that these results are robust against the noise which may arise in the sensor network. Our new scheme paves the ways to a variety of applications in distributed quantum sensing.

Students Talks 2 / 111

A new experimental apparatus for trapping ytterbium atoms in optical tweezer arrays

Omar Abdel Karim[1]

[1] *CNR-INO*

Corresponding Author(s): omar.abdelkarim@ino.cnr.it

Ultracold neutral atoms trapped in optical lattices and optical tweezers have emerged as ground-breaking tools to realize new systems for quantum information processing, precision measurements and quantum simulation. Optical tweezer arrays provide the ability to spatially manipulate ultracold atoms and control tunneling and interaction at the single-particle level, allowing the study of many-body physics phenomena in presence of impurities. The ytterbium atom reveals as a perfect candidate for studying this kind of physics due to its rich level structure providing very low temperature cooling and due to the presence of both bosonic and fermionic isotopes. My PhD project inserts in this context, in an experiment started in 2021 from the collaboration of the University of Trieste (UniTs) and CNR-INO unit of Basovizza (TS). Here, we designed (and at the moment we are realizing) a novel experimental apparatus for trapping ultracold Yb atoms in optical tweezer micro-traps, comprehensive of lasers paths used for cooling, trapping and manipulating atoms, and the UHV vacuum system, which is connected to the science cell.

Students Talks 2 / 114

Single Molecules in Integrated Optical Cavities and Waveguides

Ramin Emadi[1]

[1] *University of Naples Federico II*

Corresponding Author(s): emadi.ram@gmail.com

On-chip integration of deterministic single photon sources is of major significance in different emerging areas of quantum technologies like computing, sensing and so forth. In this talk, we are going to discuss some approaches towards integration of an organic-based single photon source, namely dibenzo-terrylene/anthracene nano-crystals to inorganic photonic structures to boost collection efficiency in addition to having multiple single photon sources on a single platform. Besides, we will present our findings regarding implementation of two photon interference experiment from two distinct single photon sources on a single chip which is of great importance for quantum computation.

Session 5 / 112

Quantum thermodynamics in circuits

Bayan Karimi[1]

[1] *University of Helsinki*

Corresponding Author(s): bayan.karimi@aalto.fi

In the two lectures, we investigate both experimentally and theoretically phenomena and devices in quantum thermodynamics realized by superconducting and metal circuits on a chip at low millikelvin temperatures, which is a novel area of research that we call circuit quantum thermodynamics, cQTD.

We start by briefly introducing the building blocks in the experiments such as harmonic oscillators (superconducting cavities), non-linear oscillators (Josephson junctions), and heat baths formed of resistors and phonons on the chip substrate, thermometers and local coolers. Then we build useful devices out of them including heat valves, rectifiers, refrigerators, and detectors with ultimate resolution and try to give a full thermal description of them.

Session 6 / 126

Entanglement for Quantum Technologies - part 2 - Prof. Augusto Smerzi

Session 6 / 135

Handling Atomic Quantum States

Francesco Cataliotti[1]

[1] *CNR - INO*

Corresponding Author(s): francescosaverio.cataliotti@ino.cnr.it

Handling Atomic Quantum States

Session 7 / 128

Quantum thermodynamics in circuits - part 2 - Dr. Bayan Karimi

Session 8 / 98

Circuit QED: from microwave quantum optics to quantum computation

Gasparinetti Simone[1]

[1] *Chalmers University of Technology*

Corresponding Author(s): simoneg@chalmers.se

In the last twenty years, circuit quantum electrodynamics (QED) has emerged as a leading architecture for quantum computation. Circuit QED is based on superconducting circuits resonating at microwave frequencies. Its enabling element is the Josephson junction, which endows these modes with a tunable nonlinearity without adding losses. This way one can define modes with tailored energy spectra ("artificial matter") and have them interact with microwave resonators and waveguides ("light"). The possibility to engineer these interactions with an unprecedented degree of control and tunability is key to circuit QED's success. In this first lecture I will give a general introduction to the field and to some of its applications, also beyond quantum computation.

Session 9 / 94

Introduction to quantum control methods for Quantum Technologies

Luigi Giannelli[1]

[1] *CNR-IMM, Catania*

Corresponding Author(s): luigi.giannelli@dfa.unict.it

The ability to accurately control a quantum system (Quantum Control) is a fundamental requirement in the development of quantum technologies, with applications ranging from quantum information processing to high-precision measurements. Very often quantum control aims at reaching a given target state, implementing a quantum gate, or the cooling of atomic ensembles and nanomechanical oscillators. In these lectures I will introduce some well established methods as well as some recently developed methods that are used to perform Quantum Control. In particular I will explain: 1) Transitionless Quantum Driving (or Shortcut to Adiabaticity), 2) Quantum Optimal Control, and 3) Reinforcement Learning. As an example, I will show the application of these methods to the problem of population transfer in a three-level Λ system.

Session 10 / 100

The SQUID: Fundamentals and Applications

John Clarke[1]

[1] *University of California, Berkeley*

Corresponding Author(s): jclarke@berkeley.edu

Superconducting electronics was born in a remarkably short, three-year period that began one-half century after the discovery of superconductivity. The crucial steps were the observation of flux quantization in 1961, the prediction and observation of Josephson tunneling in 1962 and 1963, respectively, and the demonstration of quantum interference in a superconducting ring containing two Josephson junctions in 1964—the Superconducting QUantum Interference Device. I briefly review my early work as a research student at the University of Cambridge. Today's SQUIDs, fabricated from patterned, multilayer thin films on silicon wafers, offer extraordinary sensitivity to magnetic flux and have a broad range of applications. I describe experiments to image distent galaxy clusters, to search for the axion—a candidate particle for cold dark matter— and to perform magnetic resonance imaging (MRI) in microtesla magnetic fields.

Session 10 / 110

The half-integer flux quantum effect

John R. Kirtley[1]

[1] *Stanford University*

Corresponding Author(s): kirtleyj@gmail.com

This talk is a personal history of the half-integer flux quantum effect, and its role in the demonstration of d-wave pairing symmetry in the cuprate high-temperature superconductors.

Session 11 / 113

Superfluids of atoms and of light as analog models of gravity: a fruitful synergy of gravity and quantum optics

Iacopo Carusotto[1]

[1] *INO-CNR BEC Center*

Corresponding Author(s): iacopo.carusotto@unitn.it

In these lectures, I will present the state of the art and the new perspectives in the theoretical and experimental study of analog models of quantum field theories in flat, curved, or time-dependent backgrounds using condensed matter and optical systems.

After a brief presentation of the general concept of analog model, I will review milestone theoretical and experimental works on Hawking emission of phonons from acoustic horizons in trans-sonic flows of ultracold atoms. In particular, I will highlight the crucial role of density correlations in providing an unambiguous signature of Hawking emission - the so-called Balbinot-Fabbri moustache.

After introducing the general concept of quantum fluid of light and reviewing milestone experiments in Bose-Einstein condensation and superfluidity, I will sketch the on-going efforts towards the observation of Hawking emission in these optical systems and the advantages/disadvantages introduced by their intrinsically non-equilibrium condition. In particular, I will outline an unexpected interplay between Hawking emission and the quasi-normal modes of the black hole and I will discuss its possible consequences on the zero-point fluctuations of the gravitational field around astrophysical black holes.

I will then move to superradiant effects in different geometries. Based on the textbook theory of parametric amplification and oscillation in optics, I will first introduce the general concepts of superradiant scattering, superradiant quantum emission and superradiant instabilities in quantum field theories, then I will move to specific geometries: in rotating configurations, the concept of ergoregion instability provides an intuitive understanding of the well-known instability of multiply charged vortices; introduction of synthetic gauge fields in planar geometries extends the range of space-time metrics that can be generated and allows for analytical insight into superradiant phenomena using quantum optics concepts. This shines new light on the subtle relations between superradiant scattering, quantum superradiant emission and superradiant instabilities and suggests how quantum optical phenomena might play a role in astrophysical processes.

Finally, I will outline the on-going investigations in the direction of observing back-reaction effects of the quantum field onto the background: the crucial impact of quantum fluctuations of the quantum friction force is first highlighted in single-mode configurations amenable to circuit-QED realizations for which microscopic theoretical insight is available. I will then switch to cosmological models that may be investigated on cold atom platforms, in particular to investigate the preheating stage of the early Universe at the end of inflation: here, quantum-fluctuation-induced mechanisms for the decay of the inflaton field are identified, as well as unexpected channels for decoherence under the effect of quantum fluctuations of the parametric particle creation effect. I will conclude by sketching the outstanding problem of the back-reaction of Hawking emission onto a black hole and its relation to celebrated information paradoxes in gravity.

Session 12 / 99

Quantum control of a harmonic oscillator using a superconducting qubit

Simone Gasparinetti[1]

[1] *Chalmers University of Technology*

Corresponding Author(s): simoneg@chalmers.se

In quantum information processing, a bit of information is customarily represented using a pair of energy levels acting as a quantum two-level system. As an alternative strategy, one can encode the quantum bits in nonclassical states of harmonic oscillators ("bosonic modes"), while still relying on nonlinear elements for state manipulation and readout. This latter approach presents advantages such as longer coherence times, resource-efficient quantum error correction, and well-understood loss channels. In particular, hosting non-classical states of light in three-dimensional microwave cavities has emerged as a promising paradigm for continuous-variable quantum computation. In this paradigm, superconducting qubits play the role of “quantum controllers” of the states in these cavities. In this second lecture I will outline this approach and review recent advances, including our own work.

Session 13 / 118

Gate Model Quantum Computing and Waveguide QED with Superconducting Qubits

William D. Oliver[1]

[1] *MIT Lincoln Laboratory*

Corresponding Author(s): william.oliver@mit.edu

Quantum computers are fundamentally different from conventional computers. They promise to address problems that are practically prohibitive and even impossible to solve using today's supercomputers. The challenge is building one that is large enough to be useful. In this talk, we will study two topics: 1) we will consider gate-model quantum computation and the engineering of high-performance superconducting qubits, and 2) we will consider experimental waveguide QED and its application to extensible systems.

Students Talks 3 / 109

Fabrication and characterization of magnetic Josephson Junction towards quantum circuits

Author(s): Roberta Satariano[1]

Co-author(s): Antonio Vettoliere [2] ; Carmine Granata [3] ; DOMENICO MONTEMURRO ; Davide Massarotti [4] ; Francesco Tafuri [5] ; GIOVANNI PIERO PEPE [6] ; Giovanni Ausanio [7] ; Halima Giovanna Ahmad [8] ; LUIGI DI PALMA [9] ; Loredana Parlato [8] ; Raffaella Ferraiuolo

[1] *University of Naples Federico II*

[2] *Consiglio Nazionale delle Ricerche – ISASI*

[3] *Consiglio Nazionale delle Ricerche – ISASI, 3Dipartimento di Matematica e Fisica, Università della Campania "L. Vanvitelli",*

[4] *Dipartimento di Ingegneria Elettrica e delle Tecnologie dell'Informazione, Università degli Studi di Napoli Federico II*

[5] *Università di Napoli Federico II*

[6] *University of Napoli Federico II*

[7] *Università degli studi di Napoli Federico II*

[8] *Università degli studi di Napoli Federico II, Consiglio Nazionale delle Ricerche- SPIN*

[9] *Università Federico II Napoli*

Corresponding Author(s): roberta.satariano@unina.it

The competition between superconducting and ferromagnetic orders in magnetic Josephson Junctions (JJs) has paved the way for advances in superconducting digital technology, cryogenic memories, and potentially for quantum computing, where the possibility of switching between different critical currents states by means of magnetic pulses is a crucial advantage. We have shown that our approach to use a strong ferromagnet Permalloy (Py) as F-barrier in tunnel SISFS (Superconductor/Insulator/superconductor/Ferromagnet/Superconductor) JJs based on Nb technology allows to scale the junctions' dimensions down to a few µm2 and we have demonstrated their functionality as memory elements compatible in speed and power dissipation with standard single flux quantum (SFQ) circuitry. In principle, these junctions are scalable down to sub-micrometer dimensions: in the framework of the quantum computation, a high-density cryogenic classical memory technology is sought to provide supporting functions for qubit circuits such as read out, control and error-correction. Moreover, we have transferred our knowledge from the Nb-based to Al-based lithography process and demonstrated the hysteretic behavior of the magnetic field pattern in very low quasi-particle dissipation SISFS JJs with Al electrodes. Since superconducting quantum circuits rely almost exclusively on Al based JJs, these results are an important steps in promoting alternative control and readout schemes in superconducting qubits.

Students Talks 3 / 108

Ferro-Transmon Qubit: prospective and feasibility

Raffaella Ferraiuolo[1] ; Giuseppe Serpico[1] ; Carmine Granata[2] ; Antonio Vettoliere[3] ; Roberta Satariano[1] ; Halima Giovanna Ahmad[4] ; Loredana Parlato[4] ; Giovanni Ausanio[1] ; Giampiero Pepe[4] ; Francesco Tafuri[5] ; Davide Massarotti[4] ; Domenico Montemurro[4]

[1] *Università degli studi di Napoli Federico II*

[2] *Consiglio Nazionale delle Ricerche – ISASI, 3Dipartimento di Matematica e Fisica, Università della Campania "L. Vanvitelli",*

[3] *Consiglio Nazionale delle Ricerche – ISASI*

[4] *Università degli studi di Napoli Federico II, Consiglio Nazionale delle Ricerche- SPIN*

[5] *Università degli studi di Napoli Federico II,*

Corresponding Author(s): dors.algea@gmail.com

The technological and scientific advancements over the last decade in the Quantum Computing field have seen the outbreak of several qubit layouts whose goal has been to enhance their performances [1,2]. In this context, our work focuses on the development of a new Qu-bit prototype that goes beyond conventional transmon architecture where a resonator is capacitively coupled with a SQUID loop [2]. Our proposal aims to evaluate a new concept of qubit design based on a Ferromagnetic Josephson junction (MJJ) employed in the transmon architecture that allows having a device that we call Ferro-Transmon Qu-bit. Due to the presence of a ferromagnetic layer, MJJs allow switching the state of the system with dependence on the applied magnetic field [3]. Moreover, MMJs in an RF circuit, have shown compelling perspectives such as the possibility to add a new degree of freedom to control their states by single RF magnetic pulses [4]. The feasibility to employ MMJs to build a Ferro-Transmon Qu-bit has been already proved by Ahmad et al. [5]. It will discuss the characterization of MJJs based on niobium and aluminum technologies, to investigate and compare their novel features to evaluate their suitable implementation in quantum circuits like that of transmon Qu-bit design [6]. Then will be analyzed the needed steps for the realization of the proposed Ferro-Transmon device such as the development of a coplanar waveguide resonator and its capacitive coupling to the designed MJJs in SQUID configuration [7].

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Students Talks 3 / 116

Molecular Photons based Quantum Key Distribution at Room Temperature

Ghulam Murtaza[1]

[1] *UNINA & National Optical Institute (CNR-INO)*

Corresponding Author(s): murtaza@lens.unifi.it

Quantum key distribution (QKD) renders long-term solution for information-theoretic secure communication by exploiting basic laws of quantum physics. However, hardware imperfections limit unconditional security in QKD, for instance the presence of pulses containing multiple photons in BB84 protocol. Weak coherent pulses, defects in diamonds and quantum dots bases QKD is already under discussion but molecule-based single photon source for QKD haven't been reported to date. We present single molecules of polyaromatic hydrocarbons integrated in suitable hosts emitting narrow-band and indistinguishable single-photons at 785nm with high quantum efficiency. Proof-of-concept BB84 protocol employing single photons on demands at room temperature achieves secret key rate of 0.5 Mbps. Our molecular single photon source with high purity and scalable system operating at room temperature paves the way for future quantum cryptography.

Students Talks 3 / 89

(Causal)-Activation of Complex Entanglement Structures in Quantum Networks

Angela Sara Cacciapuoti[None] ; Marcello Caleffi[None] ; Seid Koudia[None]

Corresponding Author(s):

Entanglement represents "the" key resource for several applications of quantum information processing, ranging from quantum communications to distributed quantum computing. Despite its fundamental importance, deterministic generation of maximally entangled qubits represents an ongoing open problem. Here, we design a novel generation scheme exhibiting two attractive features, namely, i) deterministically generating different classes – namely, GHZ-like, W-like and graph states – of genuinely multipartite entangled states, ii) without requiring any direct interaction between the qubits. Indeed, the only necessary condition is the possibility of coherently controlling – according to the indefinite causal order framework – the causal order among the unitaries acting on the qubits. Through the paper, we analyze and derive the conditions on the unitaries for deterministic generation, and we provide examples for unitaries practical implementation. We conclude the paper by discussing the scalability of the proposed scheme to higher dimensional GME states and by introducing some possible applications of the proposal for quantum networks. In particular, distributed entanglement generation of graph states in quantum networks based on indefinite causal ordering will be highlighted.

Students Talks 3 / 103

On the Implementation of Fuzzy Inference Engines on Quantum Computers

Giovanni Acampora[1] ; Roberto Schiattarella[1] ; Autilia Vitiello[1]

[1] *Department of Physics 'Ettore Pancini', University of Naples Federico II*

Corresponding Author(s): roberto.schiattarella@unina.it

Quantum computers can be a revolutionary tool to implement inference engines for fuzzy rule-based systems. In fact, the use of quantum mechanical principles can enable parallel execution of fuzzy rules and allow them to be used efficiently in complex contexts such as distributed and big data environments. Our research introduces the very first quantum-based fuzzy inference engine that is capable of providing exponential acceleration in fuzzy rule execution compared to its classical

counterpart, and allows a quantum computer to be programmed by fuzzy linguistic rules. The proposed inference engine was implemented using a quantum algorithm design scheme based on the oracle notion. This scheme allows the modeling of a fuzzy rule-based system as a Boolean function, the oracle, which is able to reconstruct the relationships between the antecedent and consequent parts of fuzzy rules, and can be efficiently computed on a quantum computer. The suitability of the proposed quantum algorithm for use as a fuzzy inference engine was tested in typical benchmark scenarios, such as that provided by inverted pendulum control.

Students Talks 3 / 107

Deep learning density functionals for gradient descent optimization

Author(s): Emanuele Costa[1]

Co-author(s): Giuseppe Scriva [1] ; Pilati Sebastiano [2] ; Rosario Fazio [3]

[1] *University of Camerino*

[2] *University of Camerino, INFN (Perugia)*

[3] *Abdus Salam ICTP (Trieste), Universit'a di Napoli "Federico II"*

Corresponding Author(s): emanuele.costa@unicam.it

Machine-learned regression models represent a promising tool to implement accurate and computationally affordable energy-density functionals to solve quantum many-body problems via density functional theory. However, in continuous systems, while they can easily be trained to accurately map ground-state density profiles to the corresponding energies, their functional derivatives often turn out to be too noisy, leading to instabilities in self-consistent iterations and in gradient-based searches of the ground-state density profile. We investigate how these instabilities occur when standard deep neural networks are adopted as regression models, and we show how to avoid them using an ad-hoc convolutional archi- tecture featuring an inter-channel averaging layer. Furthermore we study how this methods can be extended to spin models relevant for quantum simulators, considering a 1d quantum transverse Ising model with nearest-neighbours interaction. We study the conditions for applying DFT in quantum discrete systems and we implement a different kind of architecture (U-NET) to map the magnetization per site to the functional per site. noninteracting atoms in optical speckle disorder. With the inter-channel average, accurate and sys- tematically improvable ground-state energies and density profiles are obtained via gradient-descent optimization, without instabilities nor violations of the variational principle.

Students Talks 3 / 115

Dissipative stabilization of entangled qubit pairs in quantum arrays

JACOPO ANGELETTI[1]

[1] *Università di Camerino*

Corresponding Author(s): jacopo.angeletti@unina.it

We study the dissipative stabilisation of entangled states in arrays of quantum systems. Specifically, we are interested in the states of qubits (spins-1/2) which may or may not interact with one or more cavities (bosonic modes). In all cases only one element, either a cavity or a qubit, is lossy and irreversibly coupled to a reservoir. When the lossy element is a cavity, we consider a squeezed reservoir and only interactions which conserve the number of cavity excitations. Instead, when the lossy element is a qubit, we consider pure decay and a properly selected structure of XX- and

XY-interactions. We show that in all cases, in the steady state, many pairs of distant, non-directly interacting qubits, which cover the whole array, can get entangled.

Session 14 / 129

Introduction to quantum control methods for Quantum Technologies-part 2 - Dr. Luigi Giannelli

Session 15 / 130

Superfluids of atoms and of light as analog models of gravity: a fruitful synergy of gravity and quantum optics - part 2- Dr. Iacopo Carusotto