Mini-workshop on

Quantum Technologies with Ultrastrong Couplings

Satellite Meeting of the Conference FisMat2019

Catania, Laboratori Nazionali del Sud, October 4, 2019

Chaired by Elisabetta Paladino and Jukka Pekola

QUANTERA

The mini-workshop will host the preparatory Meeting of the Quantera2-funded project ***SiUCs - Superinductor-based Quantum Technologies with Ultrastrong Couplings***, involving research groups from Barcelona, Karlsruhe, Regensburg, Bratislava, Grenoble, and Catania.

Sponsored by

University of Catania – Department of Physics and Astronomy "Ettore Majorana"

Hosted by

Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali del Sud

Friday, October 4		
12:45	Meeting of partecipants at the entrance hall of DFA to enter LNS	
Chairman: Jukka Pekola		
13:00	Pol Forn-Diaz	The Quantera-funded SiUCs consortium
13:30	Milena Grifoni	Transmission spectra of an ultrastrongly coupled qubit-dissipative resonator system
14:00	Miroslav Grajcar	Photon detectors based on array of Josephson junctions and disordered superconducting thin films.
14:30	Giuseppe Falci	Coherent amplification of virtual photon conversion in ultrastrongly coupled matter an light
15:00	Sebastien Leger	Observation of quantum many-body effects due to zero point fluctuations in superconducting circuits.
15:30	Coffee break	
Chairman: Elisabetta Paladino		
16:00	Salvatore Savasta	Light-matter interaction in the ultra-strong coupling regime
16:30	Juan José Garcia Ripoll	Numerical methods for USC problems
17:00	Alessandro Ridolfo	Adiabatic quantum operations with ultrastrongly coupled matter and light
17:30	Giuliano Benenti	Dynamical Casimir effect in quantum thermodynamics
18:00	Francesco Plastina	The role of coherence in the thermodynamics of quantum systems

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Pol Forn-Diaz – The Quantera-funded SiUCs consortium

In this talk, I will present the Quantera-funded SiUCs consortium, its main ideas and its goals. SiUCs (Superinductor-based Quantum Technologies with Ultrastrong Couplings) is the very first large-scale project with both theory and experimental teams entirely dedicated to studying ultrastrong coupling physics. The project presents a work plan to engineer a novel set of components to enhance light-matter coupling and study the potential applications of USC physics in all types of Quantum Technologies. The key ingredient in the project is the integration of superinductors as light-matter couplers in superconducting circuits. This linear, low-loss, and versatile circuit element presents a very attractive potential to engineer high quality, highly anharmonic qubits with ultrastrong coupling to microwave fields, both in closed as well as in open system settings. With this new circuit element, the consortium will study coherence properties in the USC regime, quantum simulators, improved qubit state control and readout techniques and finally microwave single photon sensing.

Milena Grifoni – Transmission spectra of an ultrastrongly coupled qubit-dissipative resonator system

We calculate the transmission spectra of a flux qubit coupled to a dissipative resonator in the ultrastrong coupling regime. Such a qubit-oscillator system constitutes the building block of superconducting circuit QED platforms. The calculated transmission of a weak probe field quantifies the response of the qubit in frequency domain, under the sole influence of the oscillator and of its dissipative environment, an Ohmic heat bath. We find the distinctive features of the qubit-resonator system, namely two-dip structures in the calculated transmission, modified by the presence of the dissipative environment. The relative magnitude, positions, and broadening of the dips are determined by the interplay among qubit-oscillator detuning, the strength of their coupling, and the interaction with the heat bath [1].

[1] Luca Magazzu and Milena Grifoni, arXiv:1906.05808

Miroslav Grajcar – Photon detectors based on array of Josephson junctions and disordered superconducting thin films.

We will provide basic arguments for the necessity of an array of Josephson junctions in order to achieve highly efficient photon detection in microwave frequency domain. We will present experimental results obtained on a unit cell of such Josephson junction array. We will demonstrate some of our experimental and theoretical results from the field of condensed matter physics, which can influence the performance of photon detectors in a wide frequency range—from microwave up to optical frequencies.

Giuseppe Falci – Coherent amplification of virtual photon conversion in ultrastrongly coupled matter an light

We will describe a recent proposal of dynamical detection of virtual photons, whose presence marks the onset of the ultrastrong coupling (USC) regime. We show that a coherent protocol based on Stimulated Raman adiabatic passage (STIRAP) may provide a unique smoking gun for USC [1,2]. We discuss several aspects of the proposal, and in particular design constraints on realistic multilevel state-of the art architectures, showing

that a strategy based on V-STIRAP [3] is expected to provide the desired “smoking-gun” detection of virtual photons in excited states. Then we discuss two promising strategies involving architectures with superinductors., based on an unconventional design of the device and on using techniques of advanced pulsed control.

[1] G. Falci, P.G. Di Stefano, A. Ridolfo, A. D’Arrigo, G.S. Paraoanu, E. Paladino, Fort. Phys. 65, 1600077 (2017)

[2] A. Ridolfo, G. Falci, F.M.D. Pellegrino, G.D. Maccarrone, E. Paladino, Eur. Phys. Jour. 227, 2183 (2019).

[3] G. Falci, A. Ridolfo, P.G. Di Stefano, E. Paladino, Sci. Rep. 9, 9249 (2019)

Sebastien Leger – Observation of quantum many-body effects due to zero point fuctuations in superconducting circuits.

Because of the value of the hyperfine constant (~ 1/137) observing many body effects in light-matter interaction is challenging. Reaching this regime is now possible using the tools of circuit Quantum ElectroDynamics (cQED) [1,2].

In this work we investigate the interactions between the plasma modes propagating in arrays of more than 4000 SQUIDs (which simulate the light) and a small Josephson junction (the matter). The first effect of these modes is to broaden the energy levels of the Josephson junction [1,2]. More interestingly they can also induce strong phase fluctuations across the junction, which directly affects the Cooper pair tunneling. We will present our on-going experimental efforts aimed at observing this purely quantum many-body effect.

[1] P. Forn-Díaz, et al. “Ultrastrong coupling of a single artificial atom to an electromagnetic continuum in the nonperturbative regime,” Nature Physics, 13(1), 39–43 (2016).

[2] J. Puertas Martínez, S.Léger, et al. “A tunable Josephson platform to explore many-body quantum optics in circuit-QED,” arXiv:1802.00633.

Salvatore Savasta – Light-matter interaction in the ultra-strong coupling regime

MIFT Department, University of Messina – Italy

Ultrastrong coupling between light and matter has, in the past decade, transitioned from a theoretical idea to an experimental reality. It is a new regime of quantum light–matter interaction, which goes beyond weak and strong coupling to make the coupling strength comparable to the transition frequencies in the system [1]. The achievement of weak and strong coupling has led to increased control of quantum systems and to applications such as lasers, quantum sensing, and quantum information processing. Here I review the theory of quantum systems with ultrastrong coupling, discussing entangled ground states with virtual excitations, new avenues for nonlinear optics, and connections to several important physical models. I also overview the multitude of experimental setups, including superconducting circuits, organic molecules, semiconductor polaritons, and optomechanical systems, that have now achieved ultrastrong coupling. I conclude by discussing the many novel physical effects that these achievements enable, which can be useful for the development of new quantum technologies. In particular, I will show how a large number of well-known nonlinear-optics phenomena can be realized with one or more two-level atoms coupled to one or more resonator modes. In contrast to most conventional implementations of nonlinear optics, these analogs can reach unit efficiency, only use a minimal number of photons (they do not require any strong external drive), and do not require more than two atomic levels [2-5]. Finally, I will present some recent result sheding light on gauge invariance in the nonperturbative and extreme interaction regimes [6].

[1] Ultrastrong coupling between light and matter, A.F. Kockum, A. Miranowicz, S. De Liberato, S. Savasta, and F. Nori, Nat. Rev. Phys. 1, 19 (2019)

[2] One photon can simultaneously excite two or more atoms, L. Garziano, V. Macrì, R. Stassi, O. Di Stefano, F. Nori and S. Savasta, Phys. Rev. Lett. 94 (1), 117 (4), 043601 (2016)

[3] Deterministic quantum nonlinear optics with single atoms and virtual photons, A.F. Kockum, A. Miranowicz, V.Macrì, S. Savasta, and F. Nori, Phys. Rev. A 95, 063849 (2017)

[4] Quantum nonlinear optics without photons, R. Stassi, V. Macrì, A. F. Kockum,1 O. Di Stefano, A. Miranowicz, S.Savasta, and F. Nori 96, 023818 (2017)

[5] V. Macrì, F. Nori, S. Savasta, and D. Zueco, arXiv:1902.10377 (2019)
[6] O. Di Stefano et al., Resolution of gauge ambiguities in ultrastrong-coupling cavity QED, Nat. Phys. 15, 803, 2019)

Juan José García Ripoll – Numerical methods for USC problems

Institute of Fundamental Physics – CSIC Madrid, Spain

In this talk I will discuss how we simulate Quantum Optics problems in the ultrastrong coupling regime, using techniques from DMRG and renormalization group, in combination with polaron transformations and non-perturbative transformations. As a result from this, I will discuss results on light trapping with quantum emitters in 1, 2 and 3 dimensions.

Alessandro Ridolfo – Adiabatic quantum operations with ultrastrongly coupled matter and light

The ultrastrong coupling (USC) regime of matter and light may in principle allow to perform quantum operation with clock rates much larger than in architectures based on atom-cavity couplings in the rotating wave approximation. However fidelity of the operations is deteriorated, ultimatelu due to the Dynamical Casimir effect. We propose that adiabatic protocols for multiqubit quantum operations may mitigate this drawback, and design advanced control allowing to reach infidelities less than 10^{-4} deep in the USC regime.

Giuliano Benenti – Dynamical Casimir effect in quantum thermodynamics

We show that the dynamical Casimir effect, namely the generation of photons from the vacuum due to time-dependent boundary conditions or more generally as a consequence of the nonadiabatic change of some parameters of a system, forbids the attainability of the absolute zero of temperature in finite-time thermodynamic cycles, even in the limit of an infinite number of cycles. Our results are illustrated in the case of a qubit interacting with a single mode of the electromagnetic field.

Francesco Plastina – The role of coherence in the thermodynamics of quantum systems

Exploiting the relative entropy of coherence, we isolate the coherent contribution in the energetics of a driven nonequilibrium quantum system. We prove that a division of the irreversible work can be made into a coherent and incoherent part. This provides an operational criterion for quantifying the coherent contribution in a generic nonequilibrium transformation on a closed quantum system. We then study such a contribution in two physical models of a driven qubit and kicked rotor. In addition, we also show that coherence generation is connected to the nonadiabaticity of a processes, for which it gives the dominant contribution for slow-enough transformations. The amount of generated coherence in the energy eigenbasis is equivalent to the change in diagonal entropy, and here we show that it fulfills a fluctuation theorem.

Disclaimer

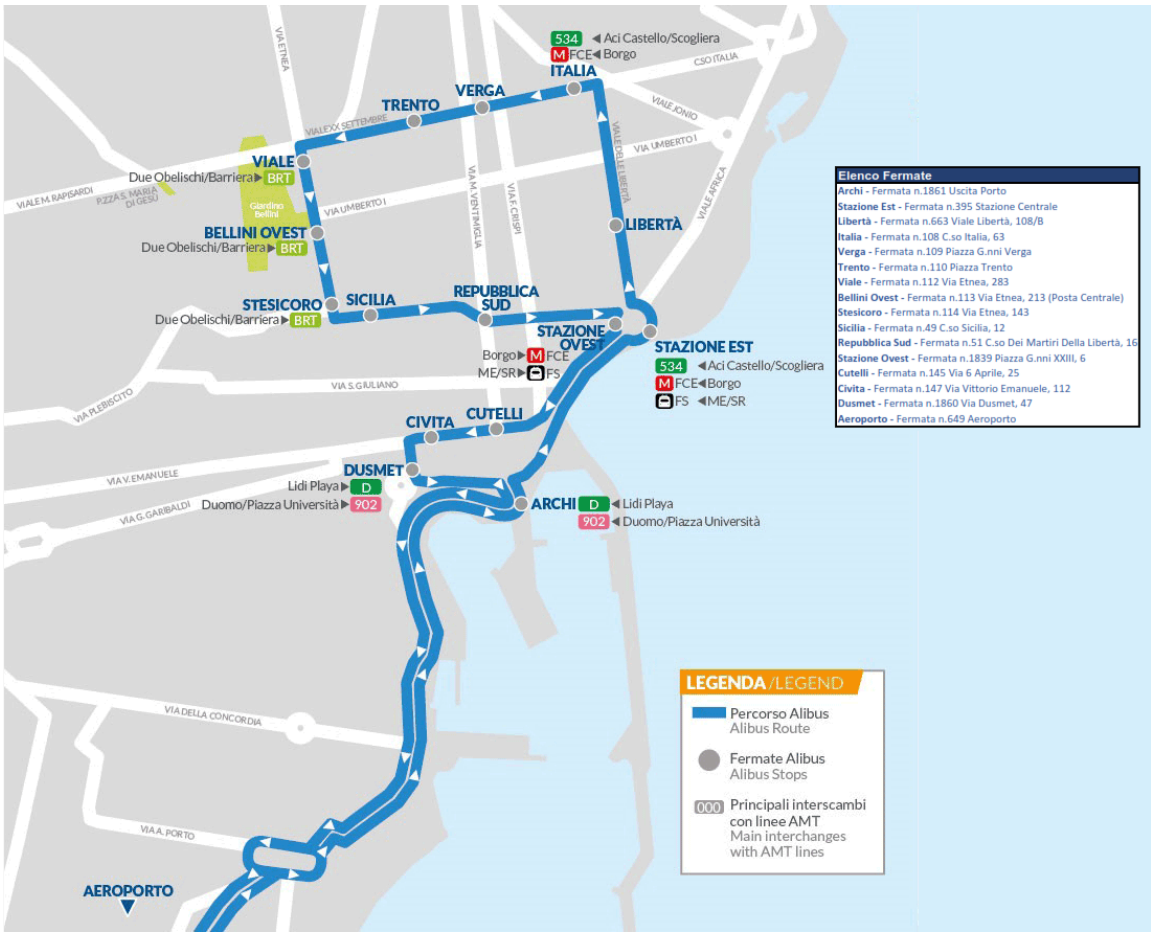
What is written in this file are suggestions based on our personal experience. We may be wrong or have a different taste and we decline any responsibility concerning to that. **We decline any responsibility for** the reliability of informations contained in additional files not produced by us, which are downloadable from our site and/or enclosed in the welcome kit for USC-QTech19.

Airport ↔ Catania transportation

Adapted from

Catania-Fontanarossa Airport, is an international airport in Sicily located about 4.3 km southwest of Catania. It is the busiest airport in Sicily and in 2015 handled more than 7 million passengers.

Travelling to and from the airport is easy, due to its vicinity to the city center. To/from the city center (via Etnea) the Airport shuttle is the best solution. To/from the Airport to the Campus (città Universitaria) it is possible to combine the Airport shuttle and public transportation (underground+uni-shuttle or BRT bus), but it is better to take a taxi, which is the only viable solution in the evening or early in the morning.



Taxi services – Taxis are available from Catania airport and you will find them in front of the terminal building, Arrivals area. However, **to avoid being scammed, we suggest to use only the authorized taxi service called Radio Taxi Catania**. You should call them (+39095330966) from the airport or even the night befor your arrival (apparently they can speak english). The price for the Campus is € 26, and € 22 for the very center. They will pick you up/leave at the Departure Area (1-st floor) of the Airport. If you go to the Campus ask for via

santa Sofia, specifying “Laboratori del Sud” if you are directed to the Guesthouse (Foresteria) or “Fisica, Edificio 6” for the FisMat Conference site.

Airport shuttle bus – There is a shuttle service with **AMT Alibus** from Catania International Airport to the city center and the main train station. The bus goes every 20 minutes, from 5.00 AM to midnight. **The ticket costs 4 euro** and is valid for 90 minutes, but you have to validate it in the electronic ticket machine on the bus. You can buy it at the airport, chash on the bus, by POS, by UP MOBILE, in AMT points and in many hotels.

- The Journey trip is circular. Alibus has 20 stops and the total trip duration for this route is approximately 50 minutes in normal traffic conditions. Relevant stops (and very roughly estimated journey times) are: Aeroporto (0), Train Station East (15’, underground connection), Viale (25’, the closest to the campus and BRT), Stesicoro (29’, underground connection), Train Station West (35’, underground connection), Aeroporto (50’).
- Via Etnea is the main road of Catania and there are three stops (Viale, Bellini West and Stesicoro).
- Buses start from the Airport (old building) from 04:40 to 24:00 every 25 minutes. If you miss the last bus you still have the taxi or you can pre-order a transfer.
- Going to the Campus:
    - leave the Alibus at Train Station East (recommended) or at Stesicoro, and take the undrground to Milo. From there there is a shuttle bus to the Campus.
    - Leave the Alibus at Viale and take the BRT bus (the stop is nearby, ask to people) to the University Campus (ask), then follow the student’s stream.

Renting a car at Catania airport – There are several car rental companies located at and around the airport, mostly local companies and three larger companies – Sixt, Budget and Hertz. There is also Avis rental company, located a bit away from the terminal building (1.4 km), next to the Catania International Airport Hotel. The easiest way to rent a car is to compare the prices on the following link, save time and book online.

Technical info for presentations and posters

The schedule of the Conference is tight therefore we would prefer to use a single PC with presentations in “standard” format (**Microsoft Power Point or in pdf format**). Please let us know in advance if you prefer a different solution, e.g. using your laptop. For the projection **the VGA and HDMI ports** are available. To stay on the safe side **bring along your connector**.

Power plugs: make sure to have the correct one for Italy

Administrative infos

Please let us know in advance by email (indicating your data) if you need some declaration the you participated to the mini-workshop. Preparing it afterwards may require some time.