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NQSTI
National Quantum Science and Technology Institute

NQSTI International School 2025

Advances in Solid-State Quantum Technologies

June 30 - July 4 2025
Catania, Italy

Book of Abstracts

INTERNATIONAL YEAR OF
Quantum Science and Technology

NQSTI International School: advances in solid-state quantum technologies

Monday June 30		Tuesday July 1		Wednsday July 2		Thursday July 3		Friday July 4	
8.30	Registration + drinks	8.30	Jens Koch	8.30	Anasua Chatterjee	8.30	Nicole Fabbri		
9.00	Opening							9.00	Rosario Fazio
9.10	Bernard van Heck								
		###	Mauro Paternostro	###	Jens Koch	###	David Vitali		
10.50	Break + registration + install posters	###	Break maxi + posters	###	Break maxi + posters	###	Break maxi + posters	###	Break maxi + posters
11.30	Mauro Paternostro	###	Mauro Paternostro	###	Nicole Fabbri	###	Rosario Fazio	###	Michael Thorwart
13:20	Lunch@Camplus	12:30	Federico Mattei					###	Remove posters
		###	Free time for lunch seaside or for dicussions, Qtris, mini-presentations	###	Lunch@Camplus	###	Free time for lunch seaside or for dicussions, Qtris, mini-presentations	###	Lunch@Camplus
14.40	Jens Koch			###	Gian Marcello Andolina			###	Martina Esposito
16.20	Michela Nazzaro	###	Anasua Chatterjee			###	Michael Thorwart	###	Conclusions
17.00	Break maxi e in cobtemoranea			###	Break			###	Still time for the seaside or for further discussions, if you prefer (rooms will be available)
	Qtris Poster presentations	###	Break	####	Guided tour	###	Break		
		###	Leonardo Banchi			###	Luigi Giannelli		
19.10	End	###	End			###	End		
						20:40	School dinner		

Lectures 45'+5' + 45'+5'	seminar 50'+10'	Time, for seaside or for dicussions, Qtris, mini-presentations	Coffee Breaks	Social activities

Lectures

Jens Koch (Northwestern University – USA)
Superconducting quantum platform

Anasua Chatterjee (Niels Bohr Institute – DK)
Semiconducting quantum platform

Nicole Fabbri (LENS-CNR-INO Firenze)
Impurities in solids and quantum sensing

Rosario Fazio (ICTP Trieste & University of Napoli)
Phase transitions in open quantum systems

Leonardo Banchi (University of Firenze)
Introduction to quantum machine learning

Luigi Giannelli (University of Catania)
Control and Machine Learning for Quantum

Michael Thorwart (University of Hamburg)
Analytic and numeric path-integral for open quantum systems

Martina Esposito (CNR-SPIN Napoli)
Measuring superconducting quantum architectures

Federico Mattei (IBM Quantum Ambassador)
Concepts in Modular Quantum Computing

Bernard van Heck (University of Roma Sapienza)
Topological Systems for Quantum Technologies

David Vitali (University of Camerino)
Microwave to optical quantum transduction

Mauro Paternostro (University of Palermo)
Quantum Thermodynamics

Michela Nazzaro (University of Napoli)
Quantum Meaning-Making. Core Concepts for Real Understanding

Gian Marcello Andolina (JEIP, CNRS - Collège de France)
Light-matter interaction and the ultrastrong coupling regime

Post Quantum Cryptography

Muhammad Abdul Aleem

The poster focuses on developing cryptographic algorithms that are secure against attacks from quantum computers. As quantum computing advances, PQC plays a critical role in ensuring long term data security and is being standardized by organizations to future-proof digital communication systems.

Selective decoupling in multi-level quantum systems by the SU(2) sign anomaly

Giorgio Anfuso, Giulia Piccitto, Vittorio Romano, Elisabetta Paladino, Giuseppe A. Falci

University of Catania, Italy

We investigate dynamical decoupling operated by 2π-pulses in a two-level subspaces of a multilevel system showing that it may leads to selective decoupling. This provides a flexible strategy for decoupling transitions in a quantum network, when control to directly address them is not available which can be use to control internode interaction or actively suppress decoherence.

Spectroscopy of near-magic-angle twisted bilayer graphene by chemical vapor deposition

G. Baiardi, L. Cavicchi, A. Boschi, G. Piccinini, A. Rossi, S. Forti, A. Bostwick, C. Jozwiak, E. Rotenberg, K. Watanabe, T. Taniguchi, M. Polini, S. Pezzini, C. Coletti

Scuola Normale Superiore and Italian Institute of Technology

We present nano angle-resolved photoemission spectroscopy (nARPES) and Raman data from the first near-magic-angle twisted bilayer graphene (MATBG) samples realized by stacking graphene grown by chemical vapor deposition (CVD). MATBG by exfoliation and stacking was the first moiré system to exhibit flat dispersion and strong correlations in the lowest-energy hole and electron minibands. Here, we report on flat bands very close to the Fermi level and thus experimentally accessible. CVD is a versatile and scalable 2D-materials deposition technique that holds the potential to bridge the gap between research and industrial applications. ARPES, conversely, can directly image the dispersion of a crystal band structure by photoelectric effect. Being surface sensitive, it is particularly suited for non-encapsulated 2D materials such as our picked-and-flipped samples. The use of nARPES with a spot size of about 1 μm2 allows us to prove the presence of flat bands extended over such surface area, while simultaneously providing knowledge on how the stacking relaxation affects the band structure.

Scalable effective models for complex superconducting nanodevices

Daniel Bobok(1), Lukáš Frk(1), Martin Žonda(1)

(1) Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

We have derived a Chain Expansion (ChE) method that maps superconducting leads onto finite chains for systems describable by the Superconducting Anderson Impurity Model (SCIAM). We show that ChE-based effective models closely match the Numerical Renormalization Group (NRG) solutions of the full SCIAM across a broad parameter range, already for short chains solvable via Exact Diagonalization (ED). In more challenging regimes, the agreement between NRG and ChE calculations systematically improves with increasing chain length. The one-dimensional nature of ChE enables the use of effective models with longer chains, inaccessible to ED, via the Density Matrix Renormalization Group. Interestingly, simpler systems, such as a single quantum dot on a superconductor, require longer chains for converged ground-state expectation values in certain experimentally relevant regimes. Conversely, for more complex configurations, such as three coupled dots (trimers), shorter chains often suffice even there. Our findings demonstrate that ChE is a powerful tool for studying intricate superconducting systems, including those inaccessible to NRG.

Spin-Orbit coupling effects in a graphene Josephson junction

Federico Bonasera, Giuseppe A. Falci, Elisabetta Paladino, and Francesco M. D. Pellegrino

University of Catania, Italy

We study a graphene Josephson junction where the inner graphene layer is subjected to a strong Spin-Orbit Coupling (SOC) by proximity effect. This could be achieved, for example, by growing the graphene layer on top of a transition metal dichalcogenide. The SOC terms heavily modify the band structure of the inner graphene layer, inducing different topological phases with associated helical or quasi-helical edge modes. We focus on the ballistic and short junction limits and study the effects of the SOC interaction on the supercurrent. For the bulk contribution, we follow an analytical approach based on the continuum model. We find combinations of SOCs that significantly suppress the supercurrent by opening a gap in the graphene band structure. Other combinations, instead, enhance it, acting as an effective spin-valley resolved chemical potential. We also find that a strong Rashba spin-orbit coupling leads to a junction with a highly voltage tunable harmonic content. Finally, we study the edge contribution using a tight-binding procedure. We find it to be very robust on all graphene terminations, even showing some disorder-induced transport on previously insulating armchair edge.

Tunnel ferromagnetic Josephson junctions for hybrid superconducting qubit

F. Calloni1, R. Satariano1, H. G. Ahmad1,2, R. Ferraiuolo3, G. Serpico1, D. Montemurro1,2, A. Vettoliere4, G. Ausanio1,2, L. Parlato1,2, G.P. Pepe1,2,C. Granata4, A.Bruno3, F. Tafuri1, and D.Massarotti5

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Superconducting qubits are currently considered to be among the leading candidates for quantum computing [1]. In order to enhance the coherence times of qubits, two approaches are currently being pursued : improving materials and manufacturing [2][3][4]. Recently, a hybrid ferromagnetic qubit, the so-called Ferrotransmon, has been proposed, where the use of tunnel magnetic Josephson junctions allows for an alternative tuning the qubit frequency [5]. In standard transmon qubits, the frequency is tuned with a static out-of-plane magnetic field, thereby introducing flux noise [6] [7]. The Ferrotransmon architecture comprises a single tunnel-ferromagnetic junction, which functions as the active element of the circuit. This junction is tuned via a pulsed flux line, thus eliminating the need for static magnetic fields. In the case of a ferromagnetic junction, in-plane flux is contingent on the magnetization within the plane of the junction. The present work delineates the fundamental steps for the implementation of the hybrid ferromagnetic transmon. A central theme of this study is the optimisation of tunnel magnetic Josephson junctions in terms of their transport and magnetic properties down to submicrometric sizes in order to fall into a transmon regime and enhance the overall circuit scalability. The design, simulations and preliminary measurements of superconducting lines generating in-plane magnetic fields are also emphasised, as these are crucial for controlling qubit frequencies in the Ferrotransmon architecture.

"[1] F. A. et al., ""Quantum supremacy using a programmable superconducting

processor,"" Nature,vol. 574, pp. 505–510, oct 2019. [2] M. Will et al., ""High Quality Factor Graphene-Based Two Dimensional Heterostructure Mechanical Resonator"", DOI:10.1021/acs.nanolett.7b01845, Nano Lett. 2017, 17, 5950-5955 [3] Wang, J.IJ., Rodan-Legrain, D., Bretheau, L. et al. Coherent control of a hybrid superconducting circuit made with graphene-based van der Waals heterostructures. Nature Nanotech 14, 120–125 (2019). https://doi.org/10.1038/s41565-018-0329-2 [4] A. K. Feofanov, V. A. Oboznov, V. V. Bol'ginov, J. Lisenfeld, S. Poletto, V. V. Ryazanov, A. N. Rossolenko, M. Khabipov, D. Balashov, A. B. Zorin, P. N. Dmitriev, V. P. Koshelets, and A. V. Ustinov, ""Implementation of superconductor/ferromagnet/superconductor p-shifters in superconducting digital and quantum circuits,"" Nat. Phys. 6, 593–597 (2010). [5] Halima Giovanna Ahmad et al. ""Hybrid ferromagnetic transmon qubit: Circuit design, feasibility, and detection protocols for magnetic fluctuations"". In: Phys. Rev. B 105 (21 2022), p. 214522. [6] Jens Koch et al. ""Charge-insensitive qubit design de rived from the Cooper pair box"". In: Phys.Rev. A (2007). doi: 10.1103/PhysRevA.76.042319. https://link.aps.org/doi/10.1103/PhysRevA.76.042319. [7] P. Krantz et al. ""A quantum engineer's guide to superconducting qubits"". In: Applied Physics Reviews (2019)". doi:10.1063/1.5089550."

Machine learning-aided optimal control of a qubit under non-Markovian dynamics

Riccardo Cantone, Shreyasi Mukherjee, Luigi Giannelli, Elisabetta Paladino, Giuseppe Falci

"Dipartimento di Fisica e Astronomia ""Ettore Majorana"", Università di Catania, Via S. Sofia 64, I-95123, Catania, Italy"

We apply a graybox machine-learning framework to model and control a qubit undergoing Markovian and non-Markovian dynamics from environmental noise. The approach combines physics-informed equations with a lightweight transformer neural network trained on tomographically complete simulated data. It learns an effective operator that predicts observables accurately, even with strong memory effects. We study Random Telegraph and Ornstein–Uhlenbeck noise, both inducing pure dephasing, across a range of coupling strengths. At weak coupling, the model achieves prediction errors below 1% and maintains good accuracy in more challenging regimes. The trained emulator supports gradient-based quantum optimal control, achieving gate fidelities above 90%, and exceeding 99% in certain regimes. As quantum technologies near practical deployment, data-efficient models grounded in physics are increasingly valuable for scalable, noise-aware control.

Thermodynamics of Discrete-Time Crystals

Gabriele Cenedese (Presenter, Università degli Studi dell'Insubria), Samuel Mister, Mauro Antezza, Giuliano Benenti, Gabriele De Chiara

Discrete-time crystals (DTCs) are quantum systems that exhibit time-translation symmetry breaking, a non-equilibrium phenomenon analogous to spatial symmetry breaking in ordinary crystals. Despite their promise for quantum technologies, DTCs suffer from decoherence and short lifetimes. In this work, we study DTCs coupled to a bosonic Markovian environment via a Lindblad master equation and analyze their thermodynamic properties. We propose a repeated measurement protocol that extends the DTC lifetime, as confirmed by numerical simulations. Our results not only enhance the understanding of DTC thermodynamics but also suggest a novel strategy for protecting their coherence, opening new perspectives for applications in quantum sensing and computation. The behaviour of many dissipative systems is generally described by a non-Markovian dynamics. Memory effects associated to non-Markovianity may lead to revival of coherence and entanglement and may be exploited as resources for quantum computation. In this work, we study a phenomenological model system of a qubit coupled to an incoherent impurity which has been shown to exhibit a cross-over from a Markovian to a non-Markovian regime of dynamics, depending on the tunability of the parameters characterizing the system. We investigate this behaviour by quantifying the non-Markovianity and by studying the frequency spectrum of the qubit coherence. We study the behaviour of the dynamics in several regimes by using two non-Markovianity measures: the Breuer-Laine-Piilo and the Luo-Fu-Song. We show that the cross-over is tuned by the qubit-impurity interaction strength and by the temperature of the impurity. In addition, our work aims at introducing a more comfortable observable based on the Fourier transform of the coherence of the qubit than the non-Markovianity measures to quantify the non-Markovianity of the system.

Channel capacity of small modular quantum networks in the ultrastrongly coupled regime

Salvatore Alex Cordovana, Luigi Giannelli, Nicola Macrì, Giuliano Benenti, Elisabetta Paladino, Giuseppe A. Falci

"Dipartimento di Fisica e Astronomia ""Ettore Majorana"", Università di Catania, Via Santa Sofia 64, Catania, 95123, Italy"

We investigate state-transfer in modular quantum computer architectures exploiting the ultrastrong coupling regime of interaction between quantum processing units and ICs. We show that protocols based on adiabatic coherent transport may achieve near-ideal single-letter quantum capacity and robustness against parametric fluctuations suppressing leakage induced by the dynamical Casimir effect.

Emitter-Enhanced Scalable Photon Blockade in Nonlinear Cavity-Qubit System

Lijuan Dong (1), Aanal Jayesh Shah (2), Peter Kirton (3), Hadiseh Alaeian (4, 5), Simone Felicetti (6,7)

(1) Physics Department, Sapienza University, P.le A. Moro 2, 00185 Rome, Italy (2) Department of Physics and Astronomy, Purdue University, West Lafayette, IN 47906, USA (3) Department of Physics and SUPA, University of Strathclyde, Glasgow, G4 0NG, United Kingdom (4) Elmore Family School of Electrical and Computer Engineering, Purdue University, West Lafayette, IN 47906, USA (5) Department of Physics and Astronomy, Purdue University, West Lafayette, IN 47906, USA (6) Institute for Complex Systems, National Research Council (ISC-CNR), Via dei Taurini 19, 00185 Rome, Italy (7) Physics Department, Sapienza University, P.le A. Moro 2, 00185 Rome, Italy

We explore the phenomenon of Photon Blockade (PB) in the Tavis-Cummings model, two-photon coupling, and compare the effects of non-linear coupling in this model with the standard one-photon Tavis-Cummings model. We compare the exact quantum model with the analytical results obtained after implementing the Holstein-Primakoff (HP) transformation. Due to weak external drive, we can inculcate the non-Hermitian approximation, which enables us to get an analytical expression. In this work, we study two different drives, one case with only cavity drive and the other with qubit drive, and we report the results for transmission and $g^2(0)$ correlation function under these drives for resonant and off-resonant cavities. Our results indicate that the second-order correlation function can show a system-size-dependent scaling where it can be made inversely proportional to system size for the two-photon Tavis-Cummings model, which can have potential applications in creating efficient single-photon sources.

The shocks, the kinks and the solitons in nonlinear transmission lines

Eugene Kogan

Bar-Ilan University

We would like to present the results of our approximately 10 papers published during last 3 years on waves in nonlinear transmission lines. If the time permits we would also present our published very recently paper with the exact solution of Fisher -KPP equation

Detection of noise correlations in two qubit system by Machine Learning

Dario Fasone (1,2), Shreyasi Mukherjee, Dario Penna, Fabio Cirinnà, Mauro Paternostro, Elisabetta Paladino, Luigi Giannelli, and Giuseppe Falci

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We propose a method to detect spatial noise correlations affecting two qubits. Our detector consists in two ultra-strongly coupled qubits driven by a two-tone field. The dynamics is reduced to an effective three-level system in a ladder configuration. We analyze the parameters regime for which it is possible to effectively apply the STIRAP protocol transfers population from the ground state of the two-qubits to the doubly excited state. By analyzing the efficiency under different pulse conditions, we show it is possible to classify the correlations of noise affecting the two qubits. This, in turn, provides insight into the Markovian or non-Markovian nature of the environmental noise.

Spectral Density Modulation and Universal Markovian Closure of Fermionic Environments

Davide Ferracin (presenter, Università degli Studi di Milano), Andrea Smirne, Susana F. Huelga, Martin B. Plenio, Dario Tamascelli

Chain-mapping and tensor-network techniques provide a powerful tool for the numerically exact simulation of open quantum systems interacting with structured environments. However, these methods suffer from a quadratic scaling with the physical simulation time, and they become challenging in the presence of multiple environments. This is particularly true when fermionic environments, well-known to be highly correlated, are considered. In this work we first illustrate how a transformation of the spectral density allows replacing the original fermionic environments with equivalent, but simpler, ones. Moreover, we show how this procedure reduces the number of chains needed to model multiple environments. We provide a derivation of the fermionic Markovian closure construction, consisting of a small collection of damped fermionic modes undergoing a Lindblad-type dynamics and mimicking a continuum of bath modes. We describe how this allows for a polynomial reduction of the time complexity of chain-mapping based algorithms when long-time dynamics are needed.

Entanglement and coherence dynamics in photonic quantum memristors

Ferrara Alberto, Lo Franco Rosario

Dipartimento di Ingegneria, Università degli studi di Palermo, Palermo, Italia

Memristive systems exhibit dynamics that depend on their past states, making them useful as memory units. Recently, quantum memristor models have been proposed, and notably, a photonic quantum memristor (PQM) has been experimentally proven. In this work, we explore and characterize various quantum properties that emerge from this specific model of PQM. First, we find that a single PQM displays memristive dynamics on its quantum coherence. Second, we analytically show that a network made of two independent PQMs can manifest memory effects on the dynamics of both entanglement and coherence of correlated photons traveling through the network, regardless of their distance, in the hypothesis of negligible external disturbances. Additionally, we build and run a circuit-model of the PQM on a real qubit-based quantum computer (IBM-Q), showing that (1) this system can effectively be used for nonlinear quantum computing under specific conditions and (2) digital quantum simulations can reproduce the dynamics of a memristive quantum system in a non-Markovian regime.

Title to be provided

Golkar Sareh

INO CNR, Naples, Italy

We develop a hybrid fiber-free space optical link based on Orbital Angular Momentum (OAM) for advanced multiplexing. The link operates across two distinct wavelength ranges, connected through a coherent conversion process. We focus on designing and implementing a stable nonlinear cavity to coherently transfer OAM beams from NIR spectral regions to MIR spectral regions, ensuring the preservation of mode quality throughout the conversion.

Adiabatic gauge potential approach to characterize the onset of chaos in a many-body quantum system

Julio Cesar Texca Garcia, Dr. Eduardo Jonathan Torres Herrera

IFUAP-BUAP

In this work we study the so-called adiabatic gauge potential (AGP) as a diagnostic of quantum many-body chaos. For our porpoises we employ a paramagnetic model of many-body quantum systems, the one-dimensional Aubry-Andre model. The first part of the work consists in characterizing the behavior of this model with conventional tools of random matrix theory. In particular, we focus on describing the spectrum as well as the eigenstates. Finally, we study the transition to chaos in the model by means of the AGP.

Spin-wave theory for quantum trajectories

Zejian Li, Anna Delmonte, Xhek Turkeshi, Rosario Fazio

ICTP, Trieste, Italy

Measurement-induced phases exhibit unconventional dynamics as emergent collective phenomena, yet their behavior in tailored interacting systems – crucial for quantum technologies – remains less understood. We develop a systematic toolbox to analyze monitored dynamics in long-range interacting systems, relevant to platforms like trapped ions and Rydberg atoms. Our method extends spin-wave theory to general dynamical generators at the quantum trajectory level, enabling access to a broader class of states than approaches based on density matrices. This allows efficient simulation of large-scale interacting spins and captures nonlinear dynamical features such as entanglement and trajectory correlations. We showcase the versatility of our framework by exploring entanglement phase transitions in a monitored spin system with power-law interactions in one and two dimensions, where the entanglement scaling changes from logarithm to volume law as the interaction range shortens, and by dwelling on how our method mitigates experimental post-selection challenges in detecting monitored quantum phases.[1]

[1] Nature Communications 16, 4329 (2025), https://www.nature.com/articles/s41467-025-59557-w

Testing generalized Bell inequalities using molecular spin qudits

Silvia Macedonio (1,2), Luca Lepori (1, 2), Simone Chicco (1, 2), Alessandro Chiesa (1, 2) Augusto Smerzi (3) and Stefano Carretta (1, 2, 4)

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Entanglement is a fundamental resource for quantum information processing. While Bell inequalities are well studied in qubits, their extension to qudits—systems with dimension greater than 2—has received less attention, particularly in solid-state platforms. This is significant, because qudits offer significant advantages, such as increased computational power, higher information density, and improved error resilience. Molecular nanomagnets, with well-defined spin states and long coherence times, provide an ideal platform for investigating high-dimensional quantum correlations. I will focus on two realizable approaches to probe generalized Bell inequalities in molecular spin systems. The first approach explores the violation of the CHSH inequality in the Yb(trenpvan) system, where entanglement is created between a qubit (electronic spin) and a qudit (nuclear spin). The second approach examines the CGLMP inequality in a spin-3/2–spin-3/2 system, where a switchable interaction between two qudits is mediated by a qubit. Numerical simulations, including decoherence effects, confirm the feasibility of these protocols, highlighting the potential of molecular nanomagnets for studying high-dimensional quantum correlations.

Spectrum degeneracy effects in open Markovian dynamics of three-level systems

Nicola Macrì, Alessandro Verga, Elisabetta Paladino, Giuseppe Falci

DFA UniCT, Catania, Italy

We investigate the open quantum dynamics of three-level systems with degenerate or near-degenerate spectrum. Standard phenomenological Lindblad equations fail to fully capture the interplay between degeneracy and dissipation. We address the problem by exploiting the microscopic treatment, which leads to the operatorial generalized Bloch-Redfield (BR) master equation. We compare the former to master equation obtained via degenerate and non-degenerate Lindbladians. By analyzing regimes of different spectral structures and using partial secular approximations, we show how degeneracy affects the steady-state properties and coherence preservation. Our results reveal that, while all models converge to similar steady states, the transient dynamics vary significantly. These findings are particularly relevant for solid-state quantum devices where level degeneracy and structured environments naturally arise.

Fokker-Plank approach for magnetic fluctuations in 2D antoferromagnetic semiconductors

E. Martello1 G. Falci1,2,3 E. Paladino1,2,3 F. M. D. Pellegrino1,2,3

"1. Department of Physics and Astronomy ""E. Majorana"", University of Catania, Via Santa Sofia, 64, 95123 Catania, Italy 2. INFN, Sez. di Catania, 95123, Italy 3. CNR-IMM, UoS Università, 95123, Italy"

Antiferromagnets (AFMs) are critical for electron-based quantum technologies due to ultrafast spin dynamics and no stray fields. Inspired by MPX3 experiments, we analytically explore their Nèel temperature behavior and spin wave dynamics in 2D materials.

Noise classification in three-level/ four-level quantum systems by Machine Learning

Shreyasi Mukherjee, Dario, Fasone, Dario Penna, Fabio Cirinnà, Mauro Paternostro, Elisabetta Paladino, Giuseppe Falci and Luigi Giannelli

University of Catania

We investigate a machine learning based classification of noise acting on a three-level system with the aim of detecting spatial or multilevel correlations, and the interplay with Markovianity. We control a three-level system by inducing coherent population transfer exploiting different pulse amplitude combinations as inputs to train a feedforward neural network. We show that supervised learning can classify different types of classical dephasing noise affecting the system. Three non-Markovian ((1) quasi-static correlated, (2) quasi-static anti-correlated and (3) quasi-static uncorrelated) and (4) Markovian noises are classified with more than 99% accuracy. On the contrary, Markovian (4a) correlated and (4b) anti-correlated noise cannot be discriminated with our method. We applied the same method to a two ultrastrongly coupled qubit system, and have shown that population transfer using STIRAP like protocol is also possible in a four level system. Furthermore, in this system we are able to succesfully distinguish between Markovian noise classes as well.

Quantum Meaning-Making: Core Concepts for Real Understanding through Game-Based Formalism

Alioscia Hamma, Immacolata De Simone, Michela Nazzaro, Michele Viscardi

Department of Physics Ettore Pancini, University of Naples Federico II

We present QTris, a quantum board game developed as a formal model for outreach grounded in quantum information theory. The game encodes the operational triad of quantum mechanics—preparation, operation and measurement—into distinct gameplay phases. States and operations are represented through tile configurations and gate cards on a 3×3 grid, isomorphic to a 9-qubit composite system. The operations form a closed algebra under the action of single and two-qubit Clifford gates, enabling simulation of entanglement and mixed states. This structure allows players to engage directly with core quantum concepts—probability, incompatibility, entanglement—without resorting to metaphor. Inspired by foundational work on quantum games (Eisert et al.) and resource theories of magic (Hamma et al.), QTris supports quantum meaning-making through structured abstraction and strategic interaction, fostering a cognitively grounded understanding of quantum phenomena.

Magneto-levitating Systems: Theory of Feedback Cooling and Intrinsic Dissipation

Pietro Oreglia (presenter), G. Catelani, D. Contessi, A. Recati, A. Vinante, G. Rastelli

Trento University

I study theoretically the fluctuation dynamics in the presence of feedback and the intrinsic mechanism of dissipation of a magneto-levitated system formed by a spherical micromagnet suspended in a superconducting trap. For the study of the feedback, I analyzed the cold damping method and applied it to describe a first experiment realized here in Trento, in which the microsphere, initially at the temperatures of a few kelvins, is cooled down up to tens of mK. Moreover, I am also exploring the use of a machine learning approach, in which an agent learns the optimal way to induce the feedback in the loop, to improve the lowest achievable temperature. In parallel, I investigate the dissipative effect due to the quasi-particle excitations hosted in the superconductor to set an upper bound to the intrinsic dissipation in this kind of system. I present a system of planar molecules described in the tight-binding approximation coupled to a single quantized magnetic mode in the presence of the Coulomb repulsion. In the single-electron case, the system displays the photon condensation phase transition when the paramagnetic response of the molecules is sufficiently strong, and the phase diagram of the system in the many-electron regime results strongly affected by the electron-electron interaction, which we found can change the nature of the photon condensation form a second order phase transition to a first order one.

Fabrication of diamond membrane with temperature sensitive color centers

Andrea Pegoretti (Fondazione Bruno Kessler), Alessandro Cian, Damiano Giubertoni, Elena Missale, Andrea Pedrielli, Antonino Picciotto, Elia Scattolo, Giorgio Speranza and Rossana Dell'Anna

Diamond is a promising platform for quantum sensors. Defects such as nitrogen (NV) and silicon (SiV) vacancies can form optically active centers, called color centers, whose electronic structure is sensitive to electric and magnetic fields, lattice strain, and temperature. The diamond platform is particularly suitable for applications in biological nano-thermometry. Indeed, in this context, temperature measurements can be performed by monitoring the color center zero-phonon line shift. This study focuses on the nanofabrication of micro-thick diamond membranes containing NV centers, achieved using a Plasma Focused Xenon Ion Beam (P-FIB). A co-localized setup combines a Scanning Probe Microscope (SPM) and a Raman spectrometer to control the positioning of the membrane with nanometric precision, while simultaneously performing a spectral analysis on it. Raman measure monitors P-FIB amorphization and annealing-induced graphitization effects. Photoluminescence analyzes NV emission and surface-induced NV^- charge loss, which negatively affects the temperature sensing. Indeed, oxygen plasma etching removes the graphitic residues and functionalizes the surface, preserving the NV^- charge state and enhancing its emission. The etching effects and surface termination were monitored using angle-resolved X-ray Photoelectron Spectroscopy (ARXPS) and Raman spectroscopy.

Reliable quantum advantage in quantum battery charging

Davide Rinaldi, Radim Filip, Dario Gerace, Giacomo Guarnieri

Quantum batteries are quantum systems, such as superconducting qubits or trapped ions, that can store energy after being charged, and eventually deliver it on demand. Such systems can be described by a thermodynamic point of view, hence favoring the study of energy exchanges and, most of all, energy fluctuations. In our work, we study a Jaynes-Cummings quantum battery (JCQB), i.e., a device consisting of a flying qubit interacting with an optical resonator. By employing the Full Counting Statistics, we analytically find that it is possible to enhance the charging performance of the battery by preparing the single-mode resonator in a genuine quantum and non-Gaussian state. In fact, if the cavity mode is initialized in a Fock state, the charging process is more efficient than other protocols, e.g., processes involving a cavity in a "classical" coherent state or in a Gaussian (yet quantum) squeezed state. The evaluation of the signal-to-noise ratio (SNR) associated with the exchanged energy shows that such advantage is reliable, since it takes into account the dynamical energy fluctuations occurring during the process.

Optimizing GaN Surface Morphology Through Controlled Photo-Electroless Etching for Enhanced Optical Properties

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Nanostructured gallium nitride (GaN) shows strong potential in enhancing ultraviolet (UV) photodetectors through improved sensitivity and in light-emitting diodes through better spatial resolution. It is also promising for quantum photonics, particularly as a scalable, room-temperature single-photon emitter, vital for quantum communication and sensing. A cost-effective photo-electroless etching (PEE) technique was used to fabricate diverse GaN nanostructures, including vertically aligned nanowires (NWs; average length $1.72 \pm 0.04 \mu$m, diameter 33.15 ± 2.64 nm) and uniform porous layers. The study evaluated how different illumination conditions, power levels, and etching durations influenced etching efficiency and surface morphology. Scanning electron microscopy and atomic force microscopy analyses revealed the transition from porous layers to vertical NWs, which eventually detached from the substrate. Energy-dispersive X-ray spectroscopy confirmed the structures consisted primarily of GaN. Optical properties were examined using photoluminescence and cathodoluminescence spectroscopies, showing that UV photon emission efficiency depends strongly on morphology. These results prove how PEE enhances photon extraction, positioning GaN as a versatile platform for future quantum technologies. Preliminary work has begun on introducing single-photon-emitting defects into these platforms through ion implantation, to be followed by comprehensive characterization.

Experimental implementation of Quantum Gaussian Sampling algorithm

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"Quantum computers offer powerful information-processing capabilities that open up new ways to address complex problems in many fields. One key application area of quantum algorithms, particularly in quantum finance and in quantum system Hamiltonians simulation, involves generating probability distributions using quantum circuits (Quantum Gaussian Sampling) [1]. In this experimental work, we implement and optimize QGS circuits on the first Italian academic superconducting Computing Center (Partenope), hosted by the Quantum Computing Napoli (QCN) Laboratory at the University of Napoli ""Federico II""[2][3]. Partenope hosts a 25-qubit flux-tunable transmon-based superconducting Quantum Processing Unit (QPU), operating as a NISQ (Noisy Intermediate-Scale Quantum) device [4]. This is the first prototype of its kind in Italy, and among the very few in Europe, offering such complexity in terms of coupled qubits on a single chip. After a careful calibration of control, readout, and two-qubit gates implementation, which is essential to achieve high-fidelity measurements [5][6][7], the comparison between the experimentally implemented gaussian distributions and the theoretical models demonstrates the fundamental role played by the knowledge of the hardware platform when developing quantum algorithms, and validate our system as an open source development platform for researchers, and partners in companies, promising the implementation of more complex quantum algorithms in the near future."

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Advances in non-equilibrium quantum thermometry

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We present results on non-equilibrium quantum thermometry using ensembles of quantum-correlated qubits. Our analysis identifies regimes in which accurate estimation of a thermal bath's temperature can be achieved, particularly when the quantum Fisher information (QFI) displays a peak during the transient that exceeds its asymptotic, equilibrium value. We investigate how the purity, correlations, local coherences, and populations of the initial ensemble state enhance the precision of temperature estimation. Furthermore, we examine the scaling of the QFI with the number of thermometers for some relevant initial states comprising quantum correlations, and propose possible strategies to achieve superlinear scaling. These findings provide insight into the role of quantum resources in enhancing thermometric performance in non-equilibrium scenarios.

Quantum frequency resampling

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In signal processing, resampling algorithms can modify the number of resources encoding a collection of data points, adjusting the signal to fit operational or hardware constraints: downsampling reduces the cost of storage and communication, while upsampling interpolates new data from limited existing one. We present and rigorously characterize a suite of quantum protocols to resample data encoded in the probabilities of a multipartite quantum state, by leveraging the quantum Fourier transform to control the number of high- frequency qubits of the encoding register. We discuss their advantage over classical resampling algorithms, showing their exponential efficiency when integrated into an end-to-end quantum signal processing workflow.

"This work is based on ""Quantum frequency resampling"", arXiv:2501.16283

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Circuit Quantum Electrodynamics with two-dimensional material based devices

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Hybrid superconductor-semiconductor systems are platforms where superconducting cavities are coherently coupled to semiconductor devices. Lately, they have become promising platforms for quantum information processing since they have opened the possibility of realizing noise-protected qubits. In the above framework, devices composed of graphene combined with superconductors, such as the so-called graphene Josephson junction, embedded in nanocircuits have shown exciting potential applications in quantum technologies due to the possibility of tuning resonant frequencies and couplings in situ by exploiting the gate voltage tunability and the peculiar low energy characteristics of 2D materials. In this work, we study the inductive interaction between a superconducting loop with an embedded short ballistic graphene Josephson junction and a quantum LC resonator. Specifically, within a mean-field approach, we analyse how the properties of the global system ground state are affected by the light-matter coupling strength and the graphene chemical potential. Our result shows that the current-phase relation of the equilibrium supercurrent exhibits signatures relatable to a spontaneous time-reversal symmetry breaking. Furthermore, we compute the hybridized light-matter excitations spectrum by calculating the retarded linear response function of the quantum LC resonator flux.

Quantum Time Crystal Clock and its Performance

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Understanding different aspects of time is at the core of many areas in theoretical physics. Minimal models of continuous stochastic and quantum clocks have been proposed to explore fundamental limitations on the performance of timekeeping devices, which show trade-offs whose characterization remains an open challenge. Indeed, even conceptual designs for thermodynamically efficient quantum clocks are not yet fully understood. Meanwhile, time-crystals were found as an exciting phase of matter featuring oscillations in (pseudo)-equilibrium, with first experimental observations appearing recently. This prompts the questions: can time crystals be used as quantum clocks? And what is their performance from a thermodynamic perspective? We find that time crystals can indeed make genuine quantum clocks with a performance enhanced by the spontaneous breaking of time-translation symmetry.

Study of Shortcuts to Adiabaticity on QAOA

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The Quantum Approximate Optimization Algorithm (QAOA) is a promising hybrid quantum-classical algorithm that can solve combinatorial optimization problems [1]. The quantum part of the algorithm involves using parametric unitary operations on a quantum computer to prepare a trial solution state. The parametric QAOA angles are variationally optimized minimizing a cost function using classical methods. We study a generalized QAOA ansatz that includes corrections to the Trotter expansion at the first and second order based on the Baker-Campbell-Hausdorff (BCH) expansion [2], that we call QAOA-2CD [3]. In our work, we have better performances of QAOA-2CD with respect to QAOA. In a regime in which QAOA is close to Quantum Annealing (QA) [4], these new unitaries correspond to the countediabatic potential of Shortcuts to Adiabaticity [5]. The latter assists the adiabatic evolution limiting excited state hoppings of the ground state and making the evolution time-independent. In our work, we reveal an expected connection between a property valid for QAOA-2CD and QA. A system with a huge minimal gap Δ_{eg} can be treated easily not only in QA but also in QAOA and QAOA-2CD.

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Localized fabrication of color centers in silicon carbide by means of kev and MeV ion irradiation

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The uncertainties in fabricating lattice defects of the appropriate type, position and number are among the greatest technological challenges standing before a widespread adoption of devices based on color centers in semiconductors. The present work focuses on optimizing the localized fabrication of color centers in silicon carbide, a wide bandgap semiconductor which has been gaining interest in recent years as a host of infrared single photon emitters. Furthermore, 4H silicon carbide is a mature platform for integrated electronics and shows potential for wafer-scale waveguides fabrication. First, the combination of MeV ion implantation and nanosecond-laser annealing is quantitatively explored. Next, the employment of a focused ion beam for localized fabrication is presented. Finally, the prospects of combining the two techniques are explained.

Quantum-Enhanced Fluxgate: Superparamagnetic Nanoparticles for Ultra-Fast, Wearable Magnetic Sensing

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Abstract:

This study investigates the design of a new class of fluxgate magnetometers that exploit the quantum-related properties of superparamagnetic iron oxide nanoparticles (IONPs) to achieve improved flexibility, speed, and sensitivity in the detection of quasi-static magnetic fields. The proposed device replaces the conventional ferromagnetic core with functionalized cotton or nylon threads, where the magnetic sensing capability is entirely provided by IONPs uniformly deposited on the fiber surface.

The IONPs were synthesized via a rapid and eco-friendly pulsed laser ablation process in aqueous media, completed in just eight minutes. Three stabilization conditions were explored (pure water, citrate, and glutathione solutions) yielding nanoparticles with distinct morphological and magnetic profiles. High-resolution TEM and Raman spectroscopy confirmed the formation of mixed-phase particles (magnetite and hematite), with TEM revealing primary dimensions around 10 nm and SEM indicating the presence of larger aggregates (~100 nm) in water-based samples. Citrate and glutathione (GSH) stabilization significantly reduced aggregation, promoting better dispersion and more uniform functionalization of the threads.

Magnetic characterization via M(H) and M(T) measurements at 5 K and 300 K revealed that citrate- and GSH-functionalized IONPs exhibit clear superparamagnetic behavior, characterized by the absence of hysteresis and coercivity at room temperature. These features stem from quantum confinement effects and single-domain spin dynamics, where the thermal energy is sufficient to induce rapid magnetization reversal, a hallmark of superparamagnetic systems. In contrast, water-synthesized nanoparticles showed residual ferromagnetic traits at low temperature due to larger particle sizes and aggregation.

The superparamagnetic state of these nanoparticles offers distinct advantages over conventional ferromagnetic materials used in fluxgates: minimal magnetic remanence, reduced noise, and fast response to external fields. These characteristics are important for developing low-power, high-resolution, wearable magnetic sensors capable of operating in real-world environments. SEM analysis confirmed consistent surface coverage on the textile cores.

The use of superparamagnetic nanomaterials, governed by quantum spin dynamics, makes these devices a compelling example of how quantum-scale effects can be harnessed in next-generation sensor architectures. The resulting fluxgate magnetometer design offers a flexible, lightweight, and sustainable platform for high-precision magnetic field detection in biomedical diagnostics, geophysical surveys, and emerging quantum technologies.

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Optimizing GaN Surface Morphology Through Controlled Photo-Electroless Etching for Enhanced Optical Properties

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Nanostructured gallium nitride (GaN) is a promising material for quantum photonics, particularly as a scalable, room-temperature single-photon emitter, vital for quantum communication and sensing. A cost-effective photo-electroless etching (PEE) technique was used to fabricate vertically aligned nanowires and uniform porous layers. The study evaluated how different illumination conditions, power levels, and etching durations influenced etching efficiency and surface morphology. Scanning electron microscopy (SEM) analyses revealed the transition from porous layers to vertical NWs, which eventually detached from the substrate. Optical properties were examined using photoluminescence (PL) and cathodoluminescence (CL) spectroscopies, showing that UV photon emission efficiency depends strongly on morphology. These results prove how PEE enhances photon extraction, positioning GaN as a versatile platform for future quantum technologies.

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Photon Correlations from a Driven Qubit-Cavity Ultrastrongly coupled System

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The interaction between light and matter in confined geometries lies at the core of cavity quantum electrodynamics (QED), and has become a powerful platform for probing nonclassical phenomena and quantum correlations in strongly coupled systems [1]. In this work, we study a driven-dissipative qubit-cavity system under monochromatic (single-tone) coherent driving. To characterize its steady-state behavior, we employ a suitable technique based on the Fourier decomposition of the density matrix in the Floquet representation, which allows for an efficient and physically transparent treatment of periodically driven open systems. Additionally, we explore photon-photon correlations in the emitted radiation by introducing two weakly coupled quantum sensors, following a quantum-jump based measurement protocol [2,3]. This approach enables a direct characterization of emission spectra and nonclassical correlations in the output field.

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