IQIS 2023

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Abstracts of Keynote Speakers

Daniel Braun

University of Tübingen

Principles of Quantum Functional Testing

Abstract: With increasing complexity of quantum-information-processing devices, testing their functionality becomes a pressing and difficult problem. "Quantum Functional Testing" refers to the decision problem of accepting or rejecting a quantum device based on specifications provided by the producer and limited experimental evidence. The decision should be reached as quickly as possible, yet with as high confidence as possible. The task is therefore fundamentally different from quantum tomography, where one seeks as complete characterization of a quantum state or a quantum channel as possible. Here we review and propose several tools and principles for quantum functional testing, ranging from the formalism of truncated moment sequences, over statistics of the lengths of measurement sequences, to coherent enhancement of deterministic errors, and automated experimental design for maximum information gain with non-greedy Bayesian parameter estimation.

Peter Lodahl

University of Copenhagen

Deterministic photon-emitter interfaces

Abstract:

Giovanna Morigi

Saarland University

Search as (quantum) selforganized process

Abstract: Efficient retrieval of information is a core operation in the world wide web, is essential for the sustainance of living organism, and is a paradigm for optimization algorithms. Inspired by the food search dynamics of living organisms, we discuss a search on a graph with multiple constraints where the dynamics is a selforganized process resulting from the interplay of coherent dynamics and Gaussian noise. We show that Gaussian noise can be beneficial to the search dynamics leading to significantly faster convergence to the optimal solution. We then analyse adiabatic quantum searches that are assisted by stochastic dynamics and discuss when their efficiency can outperform the one of coherent quantum search protocols.

Valentina Parigi

Laboratoire Kastler Brossel, Sorbonne Université

Spectrally shaped and pulse-by-pulse multiplexed CV quantum networks

Abstract: Spectral- and time-multiplexing are currently explored to generate large multipartite quantum states of light for quantum technologies. In the continuous variable approach, the deterministic generation of scalable entangled states requires the generation of a scalable number of squeezed modes. We demonstrate the simultaneous generation of 21 squeezed spectral modes at the repetition rate of our laser, i.e., 156 MHz at near-infrared wavelength [1]. We exploit the full repetition rate and the pulse shaping of a femtosecond light source to combine, for the first time, frequency- and time-multiplexing in multimode squeezing. Moreover, a second setup at telecom wavelength showed significant squeezing in more than 21 frequency modes, with a maximum squeezing value over 2.5 dB [2]. This result paves the way for the implementation of continuous variable quantum information protocols and simulation of complex quantum environment [3] or routing in quantum networks [4].

[1] T. Kouadou, F. Sansavini, M. Ansquer, J. Henaff, N. Treps, V. Parigi, *Spectrally shaped and pulse-by-pulse multiplexed multimode squeezed states of light, APL Photonics* **8**, 086113 (2023)

[2] V. Roman-Rodriguez, D. Fainsin, G. L Zanin, N. Treps, E. Diamanti, V. Parigi *Spectrally multimode squeezed states generation at telecom wavelengths*, arXiv:2306.07267 (2023)

[3] P. Renault, J. Nokkala, G. Roeland, N. Joly, R. Zambrini, S. Maniscalco, J. Piilo, N. Treps, V. Parigi *Experimental optical simulator of reconfigurable and complex quantum environment* arXiv:2302.12674 (2023) accepted in PRX Quantum

[4] F. Centrone, F. Grosshans, and V.Parigi *Cost and routing of continuous variable quantum networks* arXiv:2108.08176

Guido Pupillo

University of Strasbourg

Multi-qubit gates for quantum computing with neutral atoms

Abstract: Neutral atoms have emerged as a competitive platform for digital quantum simulations and computing. In this talk, we discuss recent results on the design and experimental realization of time-optimal and robust multi-qubit gates for neutral atoms. We present a family of high-fidelity Rydberg blockade gates that are robust against common experimental imperfections and demonstrate that they outperform existing gates for moderate or large imperfections. In the context of logical qubits, these gate protocols may significantly reduce the laser stability and atomic temperature requirements to achieve fault-tolerant quantum computing for certain types of neutral atoms qubits. We discuss alternative schemes for achieving fast deterministic non-local multi-qubit quantum gates on qubits coupled to a common driven cavity mode and suggest possible applications for quantum simulations and error correction.

Abstract of Contributed Talks

Alessia Allevi

University of Insubria

Mutual information of a homodyne-like detection scheme for binary phase-shift keyed communication protocols

Abstract: Binary phase-shift keyed (PSK) communication protocols have been proposed and implemented to transmit information in a reliable way by using PSK coherent states. In particular, discrimination strategies based on different receivers to correctly detect the sent signals have been devised, and their successful exploitation has been proved even in the presence of phase noise. Recently, we have demonstrated that a homodyne-like detection scheme employing photon-number-resolving (PNR) detectors operated at room temperature allows for a quasi-optimal coherent-state discrimination affected by uniform phase noise. In order to make the system more compact and portable, we are now implementing the scheme with a different class of PNR detectors, namely Silicon photomultipliers. At the same time, we have developed a theoretical model that takes into account all the features of these detectors to obtain a more reliable response of the detection scheme in view of practical discrimination protocols. Thanks to these preliminary studies, we are able, both theoretically and experimentally, to retrieve the mutual information of our system and to understand which parameters are the most critical to maximize its value.

Daniele Bajoni

University of Pavia

Programmable silicon devices for the generation of frequency bin entangled qudit states

Abstract: The ability to encode and control quantum information in systems with high dimensionality of the Hilbert space (qudits) is important in the development of large scale architectures for many quantum technologies. This strategy is particularly suitable when using photons as carriers of quantum information, due to the variety of degrees of freedom they possess. The frequency bin encoding in particular, i.e. the use of different frequency bands to encode logical states, has been shown to be very effective in creating qudits by means of integrated quantum optical micro-combs. In this work we report on the realization of silicon integrated devices capable of emitting entangled photon pairs using frequency-bin encoded qudits with dimension up to 4. The source is based on a combination of 4 ring resonators, one for each level of the qudits, and cascaded Mach-Zehnder interferometers and on chip phase shifters to individually address the ring resonators and electrically control the output state. We demonstrate the capability of the device to access non-trivial states via full quantum state tomography. To certify entanglement, we also computed the high-dimensional CGLMP inequalities from the reconstructed density matrices, proving their violations by tens of standard deviations in all cases.

Soumik Bandyopadhyay

University of Trento

Towards quantum simulation of holographic matter in cavity QED setup

Abstract: The quest for a quantum theory of gravity has led to the discovery of quantum many-body systems that are dual to gravitational models with quantum characteristics. Amongst these the Sachdev-Ye-Kitaev (SYK) model has received tremendous research interest in recent years. The model features maximal scrambling of quantum information, and opens a potential inroad to experimentally investigating aspects of quantum gravity. A scalable laboratory realisation of this model, however, remains outstanding. In this talk, we shall be discussing a feasible implementation of the SYK model in cavity quantum electrodynamics platforms. Our detailed analytical and numerical analysis reveals that a cloud of fermionic atoms trapped in a multi-mode optical cavity subjected to a spatially disordered AC-Stark shift retrieves the physics of the SYK model, with random all-to-all interactions and fast scrambling. Furthermore, our work demonstrates that for local observables the out-of-equilibrium dynamics of the model is universal with respect to generic initial conditions. To reveal this, we develop a general open quantum system frame-work for the disorder averaged closed evolution, and reveal the universality through the spectral characteristics of the corresponding Liouvillian. Our works provide a blueprint for realising the SYK model in a scalable system, with the prospect of studying holographic quantum matter in the laboratory, and shed light on challenging questions for systems far from equilibrium, such as, thermalization of closed and disordered quantum systems.

Bruno Bellomo

UTINAM - Université de Franche-Comté

Optimal control of qubits interacting with a dissipative cavity

Abstract: In this talk I will present two studies concerning the optimal control of qubits interacting with a dissipative cavity. The first study [1] concerns the generation of nonclassical states of qubits using a collective driving consisting of short coherent and squeezing pulses, the goal being either to reach a well-defined target state or a state maximizing a measure of nonclassicality. The parameters of the control sequence are found using optimization algorithms, as a function of the cavity damping and the qubit detunings for several configurations of two and four qubits. The second study [2] concerns the optimal control of a qubit driven by its frequency modulation and interacting with a structured bosonic reservoir modelling a dissipative cavity at zero temperature. After a numerical study concerning the states reachable by a shaped control with a fixed maximum intensity, the selectivity problem of two uncoupled qubits interacting with local baths is considered. The goal is to bring one qubit to the ground state while preventing the relaxation of the second qubit.

[1] Q. Ansel, D. Sugny, and B. Bellomo, Phys. Rev. A 105, 042618 (2022).

[2] Q. Ansel, J. Fischer, D. Sugny, and B. Bellomo, Phys. Rev. A 106, 043702 (2022).

Valentina Brosco

University of Rome "La Sapienza"

Unconventional superconducting quantum devices

Abstract: Recent advances in creating van der Waals heterostructures hosting ultrathin electronic states and in the fabrication of hybrid Josephson nanostructures opened new research pathways aimed at understanding and controlling the rich array of exotic electronic properties and functionalities emerging in these hybrid superconducting systems. In this talk, after bird's eye introduction on superconducting quantum devices, we focus on the potentialities offered by the integration of van der Waals heterostrustures and hybrid Josephson junctions in standard quantum superconducting nanocircuits. We discuss in particular the possibility to exploit conventional superconducting qubits as probes of noise fluctuations [1,2] and to realize novel qubit designs.

[1]. H. G. Ahmad, et al. Phys. Rev. B 105, 214522 (2022)

[2]. V. Brosco, N. Poccia, G. Serpico, V. Vinokour and U. Vool, in preparation (2023)

Matteo Brunelli

University of Basel

Optomechanical realization of the bosonic Kitaev-Majorana chain

Abstract: The Kitaev chain is a canonical model of topological superconductors that predicts the existence of protected Majorana zero modes in a fermionic chain. Recently, a bosonic analogue of the Kitaev-Majorana chain, or bosonic Kitaev chain (BKC) for short, has been proposed [1], and the existence of Majorana bosons speculated. In this contribution, I will report on the experimental realization of the BKC in a nano-optomechanical network [2]. The system consists of a small network of nano-mechanical resonators that are formed and controlled with laser light, where strong parametric optomechanical interactions induce two-mode squeezing and beamsplitter couplings between nanomechanical modes, equivalent to hopping and superconductor pairing terms in the fermionic case. I will show the experimental signatures of the salient properties of the BKC: quadrature-dependent chiral transport and amplification, non-Hermitian spectral topology, extreme sensitivity to boundary conditions (non-Hermitian skin effect) and exponentially-enhanced response to a small perturbation. I will discuss these observations in connection with the recently introduced framework of quadrature nonreciprocity [3]- a form of unidirectional propagation without breaking time-reversal symmetry that establishes a mechanism for non-Hermitian topological phases.

[1] A. McDonald, et al, Phys. Rev. X 8, 041031 (2018)

[2] JJ Slim, C. C. Wanjura, M Brunelli, J del Pino, A Nunnenkamp, E Verhagen (in preparation)

[3] C. C. Wanjura, JJ Slim, J del Pino, M Brunelli, E Verhagen, A Nunnenkamp, arXiv:2207.08523 (Nature Physics in press)

Natalia Bruno

CNR - INO & LENS Firenze

Photon-atom interfaces at telecom wavelengths

Abstract: Enabling communication between quantum devices, such as clocks, computers, and simulators has the potential to significantly enhance the capabilities of their applications, such as quantum sensing and computing. The key to achieving this lies in establishing efficient communication channels among these quantum devices even over a long distance, which involves the exchange of qubits encoded in light at telecom wavelengths through optical fibers. In this context, I will present an overview of the new experiment that we are building in Florence, which focuses on interfacing single photons at telecom wavelengths with individual neutral ytterbium atoms trapped in optical tweezers. By leveraging the unique properties of the ytterbium clock state and its telecom transitions, our objective is to interface a long-lived "matter" qubit and resonant light, including heralded single photons or photons forming entangled pairs. I will discuss the motivation for exploring this research line and its impact as a crucial foundation for distributing entanglement between light and matter.

Michele Burrello

University of Copenhagen

Readout of parafermionic states by transport measurements

Abstract: With recent developments in the experimental control of graphene-based fractional quantum Hall systems, it has now been demonstrated possible to induce superconducting pairing between counterpropagating fractional edge modes. Theoretical works predict that such systems could host parafermionic modes; non-Abelian anyons which share a fractional charge, thus quantum information, in a nonlocal way. These modes can potentially be exploited for topological quantum computing. In this talk I will propose setups, based on recent experiments, that allow for the readout of the topologically protected state shared by a pair of parafermions. The protocols I will present, in particular, are based on conductance measurements through metallic leads. I will also discuss the possible quasiparticle poisoning which can characterize these systems lead to a peculiar three-state telegraph noise. I will present simulations of the dynamics of these open parafermion systems based on the Lindblad formalism and the quantum jump approach. The above investigations are relevant to study more complex systems with more than two parafermions which are required for quantum computing. In particular, a minimal setup of four modes is necessary to investigate their associativity fusion rules.

Giacomo Cappellini

CNR - INO & LENS

A programmable quantum simulator with Rydberg strontium atoms in optical tweezer arrays

Abstract: I will present recent progresses on the realization of a new programmable quantum simulator based on Rydberg strontium atoms trapped in optical tweezers arrays realized as a joint effort of CNR-INO, LENS and the Physics Department of the University of Florence. I will discuss the most recent experimental achievements of the group and the main features of this new setup, including the techniques for the realization of programmable atomic arrays and the advantages offered by the narrow optical transitions and metastable states of strontium for the implementation of effective cooling scheme and novel Rydberg excitation protocols. I will also introduce the applications that we envision for this new setup, in particular the simulation of quantum spin models with different types of interactions and topologies.

Angelo Carollo

University of Palermo

Exotic effects in non-Hermitian quantum optics

Abstract: Non-Hermitian photonic reservoirs provides a testbed for intriguing phenomena which cannot be observed in an Hermitian environment. We investigate exotic effects due to the interaction of atoms with such reservoirs. We study the effective interactions between atoms mediated by the photonic modes of a lossy photonic lattice. We show in a paradigmatic case study that when these losses are suitably structured, exotic emission properties can be observed. Photons can mediate dissipative, fully non-reciprocal, interactions between the emitters with range critically dependent on the loss rate. When this loss rate corresponds to specific point in the spectrum of the reservoir, called "exceptional points", the effective couplings are exactly nearest-neighbour, implementing a dissipative, fully non-reciprocal effective interaction between atom, called Hatano-Nelson model. Counter-intuitively, this occurs irrespective of the lattice boundary conditions. Thus photons can mediate an effective emitters' Hamiltonian which is translationally- invariant despite the fact that the field is not. We interpret these effects in terms of metastable atom-photon dressed states, which can be exactly localized on only two lattice cells or extended across the entire lattice.

Federico Carollo

University of Tübingen

Thermodynamics of quantum trajectories on a quantum computer

Abstract: Quantum computers have recently become available as noisy intermediate-scale quantum devices. Already these machines yield a useful environment for research on quantum systems and dynamics. Building on this opportunity, we investigate open-system dynamics that are simulated on a quantum computer by coupling a system of interest to an ancilla. After each interaction the ancilla is measured and the sequence of measurements defines a quantum trajectory. Using a thermodynamic analogy, which identifies trajectories as microstates, we show how to bias the dynamics of the open system in order to enhance the probability of quantum trajectories with desired properties, e.g., particular measurement patterns or temporal correlations. We discuss how such a biased --- generally non-Markovian --- dynamics can be implemented on a unitary, gate-based quantum computer and show proof-of-principle results on the publicly accessible ibmq_jakarta machine. While our study is solely conducted on small systems, it highlights the challenges in controlling complex aspects of open-system dynamics on digital quantum computers.

Alberto Catalano

Institut Ruđer Bošković

Frustrating quantum batteries

Abstract: We are at the verge of the Quantum Technology Revolution: quantum mechanics allows for phenomena that have no classical counterparts and which can be harvested for new technologies. An example of the emerging quantum technologies are quantum batteries (QB), i.e. quantum mechanical systems that can store and transfer energy in a coherent way. While the practical implementation of such devices is still far from becoming reality, a serious effort is being devoted to understanding their advantages and limitations, using different platforms and protocols. As it has been recently demonstrated that the introduction of topological frustration in one-dimensional spin-1\/2 chains can strongly modify the low energy properties of these systems, we investigate the performance of a quantum battery realized through such frustrated chains and introduce a novel, natural, decoherence mechanism that show their superiority compared to their unfrustrated counterpart. We quantify this superiority using the notion of ergotropy, that is, the amount of energy that can be extracted from a battery with a unitary transformation.

Giovanni Chesi

INFN Pavia

Work fluctuations in ergotropic heat engines

Abstract: A thermodynamic quantity that attracts a natural zest is the maximum work that can be extracted from a two-stroke Otto engine, which is also well-known as ergotropy. We focused on a system of two equally-spaced qutrits in initial Gibbs state, classified all the transformations that extract the ergotropy from such system and investigated the statistics of the extracted work. We show that the work relative fluctuations produced by each transformation can violate specific thermodynamic uncertainty relations and discuss the physical meaning of that by inspecting the fluctuation theorem in its most general formulation.

Alessandro Chiesa

University of Parma

Molecular spin qudits: a viable path for quantum information processing

Abstract: Molecular spin clusters are very promising building blocks of future quantum computers. The fundamental advantage they offer is the availability of many accessible low-energy states, which opens the possibility to go beyond the binary logic and to use molecular spins as qudits. I will show that the use of molecular spin qudits offers remarkable advantages for the realization of near-term quantum devices [1], yielding an impressive reduction of two-body gates in many algorithms, such as the quantum simulation of boson fields and of fermionic models [2]. But the groundbreaking advantage of spin qudits is the possibility to encode qubits with embedded quantum error correction within a single object [3], thus overcoming the tremendous overhead of physical resources of multi-qubit encodings. The high tunability typical of these systems also allows us to design molecules where decoherence is dramatically suppressed and does not increase with the qudit size [4] and to manipulate an error-protected qubit in a fault-tolerant manner.

[1] Appl. Phys. Lett. 118, 240501 (2021)

[2] J. Mater. Chem. C 9, 10266 (2021)

[3] J. Phys. Chem. Lett. 11, 8610 (2020)

[4] J. Phys. Chem. Lett. 13, 6468-6474 (2022)

Dario Alexander Chisholm

Queen's University Belfast

Quantifying quantum objectivity: redundancy, consensus and the average mutual information

Abstract: While the terms ``redundancy'' and ``consensus'' are often used as synonyms in the context of quantum objectivity, these should be understood as two related but distinct notions, that quantify different features of the quantum-to-classical transition. The two main frameworks used in quantum objectivity, namely spectrum broadcast structure and quantum Darwinism, naturally emerge from these quantifiers. Quantum Darwinism in particular relies on the estimation of the mutual information between a system and fractions of its environment. Many of the existing tools to quantify quantum objectivity rely on the assumption that information about the system leaks symmetrically into its environment. Here, we will highlight the relevance of this assumption, and the consequences of relaxing it: by analyzing explicit examples of states with asymmetrically encoded information, we highlight the potentially stark difference between the degrees of redundancy and consensus, as well as the misleading nature of the non-averaged quantum mutual information as a quantifier of quantum objectivity. Our framework provides a new perspective to interpret known and future results in the context of quantum objectivity, and therefore the emergence of classicality from the quantum realm.

[1] D.A. Chisholm,et. al.,arXiv:2211.09150, (accepted in Quantum)

[2] D.A. Chisholm,et. al., (Manuscript being finalised)

Mario Arnolfo Ciampini

University of Wien

Quantum control and quantum interference of a nanoparticle via optical potential control

Abstract: Optical levitation has shown that it is possible to control the motional state of massive solid objects to the quantum level. Recently, multiple levitation experiments have shown ground-state cooling of a dielectric nanoparticle in the mass range of 10^8 atomic mass units. Mechanical squeezing, non-gaussian states and even spatial superposition of massive objects manifest truly quantum features that can be exploited for a wide range of applications, from force sensing to investigating the quantum-gravity interface. Here, I will present a scheme to prepare and detect non-gaussian quantum states of an optically levitated particle via the interaction with a light pulse that generates cubic and inverted potentials. I will show that this approach allows operating on short times- and length scales, significantly reducing the demands on decoherence rates in such experiments. I will discuss the prospect (and the challenges) of using this approach for coherently splitting the wavepacket of massive dielectric objects using neither projective measurements nor an internal level structure.

Stefano Cusumano

ICTQT, Gdansk University

Collision models with structured ancillae and the thermodynamic cost of coherence

Abstract: Collision models normally assume a system interacting with a set of ancillary systems representing the environment. While these ancillary systems are usually assumed to be either two level systems (TLS) or harmonic oscillators, in this work we move further and represent each ancillary system as a structured system, i.e., a system made out of two or more subsystems. We show how this scenario modifies the kind of master equation that one can obtain for the evolution of the open systems. Moreover, we consider a situation where the state of the ancilla is thermal, yet possesses some coherence, which can be transfered to the system through an appropriate interaction, leading to the presence of coherence in the steady state of the open quantum system. Moreover, we are able to quantify the thermodynamic cost of creating coherence in an open quantum system, specifically showing that letting the system interact with the coherent degrees of freedom requires a work cost, leading to the natural fulfillment of the first and second law of thermodynamics without the necessity of {\\it ad hoc} formulations.

Nicolò Defenu

Institute for theoretical physics, ETH Zurich

Stabilization of discrete time-crystaline response on a superconducting quantum computer by increasing the interaction range

Abstract: Quasi-static transformations, or slow quenches, of many-body quantum systems across quantum critical points create topological defects. The Kibble-Zurek mechanism regulates the appearance of defects in a local quantum system through a classical combinatorial process. However, long-range interactions disrupt the conventional Kibble-Zurek scaling and lead to a density of defects that is independent of the rate of the transformation. In this study, we analytically determine the complete full counting statistics of defects generated by slow annealing a strong long-range system across its quantum critical point. We demonstrate that the mechanism of defect generation in long-range systems is a purely quantum process with no classical equivalent. Furthermore, universality is not only observed in the defect density but also in all the moments of the distribution. Our findings can be tested on various experimental platforms, including Rydberg gases and trapped ions.

Grazia Di Bello

University of Napoli

Dynamics of open quantum systems: from the quantum Rabi model to coupled qubits

Abstract: Using the worldline Monte Carlo technique, Matrix Product State simulations, and a variational approach, we studied the equilibrium properties and relaxation features of the dissipative quantum Rabi model. This model involves a two-level system coupled to a harmonic oscillator in turn coupled to an Ohmic bath. By adjusting the qubit-oscillator interaction, we proved a Beretzinski-Kosterlitz-Thouless quantum phase transition in low bath coupling. We explored the dynamics of a slow qubit coupled to a fast oscillator and derived functional relationships between them. We examined the effects of internal and external couplings and evaluated the qubit Bloch vector. Interestingly, weak to intermediate bath coupling simplifies qubit state evaluation. In the ultra-strong coupling regime, we observe non-Markovian effects and entanglement growth. We also focused on the effect of the environment on other many-body open quantum systems, particularly two interacting qubits in an Ohmic bath. We demonstrate a method for obtaining quasi-fully non-decoherent qubit encoding. Our work sheds light on the behavior of open quantum systems and their potential for quantum computing and quantum communication.

Francesco Di Colandrea

University of Ottawa

Retrieving complex polarization transformations via optimized quantum process tomography

Abstract: The possibility of fine-tuning the couplings between optical modes is a key requirement in photonic circuits for quantum simulations. In these architectures, emulating the long-time evolution of particles across large lattices requires sophisticated setups, that are intrinsically lossy. Quantum walks (QWs) are prototypical quantum evolutions modeling the discrete-time dynamics of a particle moving on a lattice. The standard approach to photonic simulations of QWs requires a number of optical elements (or, equivalently, optical operations) linearly increasing with the number of time steps. Here we report ultra-long photonic quantum walks, obtained by propagating a light beam through very few closely stacked liquid-crystal metasurfaces. These are patterned waveplates, whose optic-axis orientation is non-uniform in space, thus allowing us to implement arbitrary position-dependent polarization transformations. The diffractive action of these metasurfaces maps into a QW on optical modes carrying a quantized amount of transverse momentum. Our setup is compact, efficient, and does not rely upon any optical amplification mechanism. It grants experimental access to large-scale unitary evolutions while keeping optical losses at a minimum, thereby paving the way to massive multi-photon multi-mode quantum simulations.

Marco Di Liberto

University of Padova

Simulating chiral orbital order without higher bands

Abstract: Ultracold atoms loaded into higher Bloch bands provide an elegant setting for realizing many-body quantum states that spontaneously break time-reversal symmetry through the formation of chiral orbital order. The applicability of this strategy remains nonetheless limited due to the finite lifetime of atoms in high-energy bands. Here we introduce an alternative framework, suitable for bosonic gases, which builds on assembling square plaquettes pierced by a pi-flux (half a magnetic-flux quantum). This setting is shown to be formally equivalent to an interacting bosonic gas loaded into p-orbitals, and we explore the consequences of the resulting chiral orbital order, both for weak and strong on-site interactions. We demonstrate the emergence of a chiral superfluid vortex lattice, exhibiting a long-lived gapped collective mode that is characterized by local chiral currents. This chiral superfluid phase is shown to undergo a phase transition to a chiral Mott insulator for sufficiently strong interactions and we show how this strategy can generate topological collective excitations and edge modes. Our work establishes coupled pi-flux plaquettes as a practical route for the emergence of orbital order and chiral phases of matter.

Emanuele Distante

Max Planck Institute of Quantum Optics

A quantum network module based on single-atom arrays in an optical cavity

Abstract: An envisioned quantum network relies on a quantum network module capable of storing and distributing quantum information across long distances. Among other approaches, using single atoms trapped in an optical resonator has emerged as a promising solution. Single atoms serve as long-term memories of quantum information, and the resonator enables efficient entanglement between atoms and photons. Traveling over fiber, the latter enables connecting the distant modules over the network. Until now, experiments in the field have been limited to systems with only one or two atoms confined within a cavity. Here we introduce a novel setup capable of generating ordered arrays of individually addressable single atoms trapped at the center of an optical resonator. This opens the door to a multitude of applications, including efficient storage of multiparticle quantum states, entanglement distillation over a network, and the generation of complex entangled states of light and matter. As a first application in the field of quantum networks, we demonstrate that the single-site addressability of the atomic array enables multiplexed photon generation strongly enhancing the in-fiber single-photon generation probability. This can be extended to achieve multiplexed atom-photon entanglement, substantially enhancing the rate at which entanglement can be distributed across a quantum network.

Pietro Faccioli

University of Milan Bicocca

All-atom simulation of rare protein conformational transitions and folding, using a quantum computer

Abstract: We discuss a recently developed paradigm for all-atom molecular simulations based on integrating statistical mechanics, machine learning, and quantum computing [1,2]. The result is a hybrid scheme that exploits the advantages of both classical and quantum computing platforms to enhance the simulation of rare events. In particular, we harness the unique features of quantum annealing machines to efficiently explore the functional space of transition paths. After benchmarking our scheme on alanine dipeptide [2] using the DWAVE quantum computer, we report on applications of the same scheme to simulate realistic biologically relevant transitions [3]. First, we further validate our approach by studying small structural rearrangements in the native state of protein BPTI. These transitions are too rare to be simulated by plain MD on conventional HPC machines, but have been characterised by ultra-long MD simulations performed on the Anton supercomputer. Finally, we use our approach to simulate the folding of protein BPTI with an all-atom force field , a process that is far too complex and rare to be investigated by plain MD, even resorting to the Anton supercomputer.

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Simone Felicetti

CNR-ISC

Waveguide QED with quadratic light-matter interactions

Abstract: Quadratic light-matter interactions are nonlinear couplings such that quantum emitters interact with photonic or phononic modes exclusively via the exchange of excitation pairs. Implementable with atomic and solid-state systems, these couplings lead to a plethora of novel phenomena that have recently been characterized in the context of cavity QED, where quantum emitters interact with localized bosonic modes. Here, we explore for the first time quadratic light-matter interactions in a waveguide QED setting. We present a general scattering theory and discuss paradigmatic examples. Our analytical and semi-analytical results unveil fundamental differences with respect to conventional waveguide QED systems. This novel phenomenology unlocks new opportunities in quantum information processing with propagating photons. As a striking example, we show that a single quadratically-coupled emitter can implement a two-qubit gate with unit fidelity, circumventing a famous no-go theorem derived for conventional waveguide-QED interactions.

Alessandro Ferraro

University of Milan

Quantum computation with bosonic codes: quantum resources and classical simulation

Abstract: Determining the physical resources that enable quantum advantage is crucial for the development of quantum computing architectures. Notably, the specific resource depends on the underpinning architecture itself. Wigner negativity -- which has long been recognized as a genuine quantum feature from a fundamental standpoint -- serves as a valuable resource within continuous-variable computational models grounded on Gaussian protocols. However, despite their inherent quantum nature, I will present scenarios in which these Wigner-negative resources can be efficiently simulated using classical devices, specifically in architectures based on Gottesman-Kitaev-Preskill bosonic codes. This observation naturally leads to the concept of excess Wigner negativity, which in turn finds application in quantifying non-stabilizerness (magic) for qubit-based quantum computation. Furthermore, it leads to a quantum computing architecture wherein the vacuum state, typically considered as the simplest quantum state of a bosonic system, acts as the unlocking resource for quantum advantage. Lastly, we propose a strategy to determine whether other states, beyond the vacuum, can be regarded as resources in this particular architecture, thereby establishing the first known sufficient condition for determining the computational resourcefulness of continuous-variable states.

Dario Fioretto

Centre de Nanosciences et de Nanotechnologies (C2N), Université Paris-Saclay, CNRS, Quandela

High-rate entanglement between a semiconductor spin and indistinguishable photons

Abstract: Quantum dots have shown excellent properties as single-photon sources, including record levels of brightness, purity, and indistinguishability [1, 2]. In this work [3], we use a single electron confined in quantum dots embedded in micropillar cavities that enable us to achieve a state-of-the-art level of brightness that is crucial to perform multiphoton experiments. We exploit a phonon-assisted, off-resonant excitation scheme that preserves access to the polarization degree of freedom to produce entangled photons. With this technique, we successively excite a precessing single spin to generate deterministically spin-multiphoton-entangled states as proposed in Ref. [4]. We demonstrate spin-photon entanglement and spin-photon-photon entanglement with fidelity respectively of 80% and 63% with indistinguishable photons (VHOM>88%) and rates exceeding up to 3 orders of magnitude the state-of-the-art. This clears the path for producing multidimensional cluster states, key resources for real-world implementation of measurement-based quantum computation.

[1] Somaschi, N., Giesz, V., De Santis, L. et al., Nature Photon 10, 340–345(2016)

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[3] Coste, N., Fioretto, D.A., Belabas, N. et al. High-rate entanglement between a semiconductor spin and indistinguishable photons. Nat. Photon. (2023)

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Giulio Foletto

University of Padova

Sequential quantum information protocols

Abstract: Generalized quantum measurements are a powerful tool for the study of both foundational and applied aspects of quantum physics. In particular, weak measurements allow us to gain partial information about a quantum system without disturbing it too much. This enables sequential quantum information protocols, where we can reuse a quantum resource multiple times for different tasks. For example, we have studied how to use these schemes to improve device-independent or semi-device-independent security for quantum random-access codes, certification of nonlocality and entanglement, and generation of certified random numbers. However, these protocols are vulnerable to noise, which limits their practical applicability. To overcome this challenge and devise more robust schemes, we are studying how different physical laws and assumptions constrain the geometry of sequential correlations, and how these constraints are related to security. Our research aims to improve the noise robustness of sequential quantum protocols and to deepen our understanding of the nature of quantum correlations.

Valentin Gebhart

CNR - INO Firenze

Causal diagrams in quantum information

Abstract: The development of causal inference and causal diagrams represents an important breakthrough in the field of statistics, with many applications to other scientific fields such as medicine. In this talk, I will motivate why a causal-diagram perspective also promises new insights to the fields of quantum information and quantum foundations. After a brief introduction to causal diagrams and an overview of their applications to quantum physics, I will focus on Bell scenarios with postselection. Here, causal diagrams can be used to show that certain types of collective postselection strategies do not open a postselection loophole. Furthermore, I will show how causal diagrams can be used to give a visual explanation of the fair-sampling assumption that is widely used in Bell experiments.

Ilaria Gianani

University of “Roma Tre”

Ghost spectroscopy metrology and fast remote discrimination of spectral objects

Abstract: Ghost spectroscopy makes use of frequency correlations to perform remote spectral measurements. This is particularly useful if the objects to be measured are not easily accessible, or represent so-called chemical, biological, radiological, and nuclear (CBRN) threats. In these instances it is vital to extract information at a distance, both to ensure the safety of the users and for ease of measurement operations. Dangerous components are typically recognised by features in the absorbance spectrum, however, in order to fully retrieve the lineshape of such spectral objects a good signal to noise ratio is desirable and, given the typical efficiencies, this usually results in long accumulation times times. In this talk, I will first show from a metrological perspective that, while ghost spectrometry schemes can be realised also with classical multimode thermal light, exploiting quantum frequency correlations allows to achieve a better precision. Then, I will discuss how to overcome the long acquisition time limitations discussed above, in the instances where a full reconstruction of the spectrum is not required and it is sufficient to discriminate between the presence or absence of a spectral object. References: - A. Chiuri , I. Gianani, V. Cimini, L. De Dominicis , M. G. Genoni, and M. Barbieri, “Ghost imaging as loss estimation: Quantum versus classical schemes” Phys. Rev. A 105 013506, 2022 - A. Chiuri, M. Barbieri, I. Venditti, F. Angelini, C. Battocchio, M. G A Paris, and I. Gianani, “Fast remote spectral discrimination through ghost spectrometry” ,arXiv:2303.15120v

Luigi Giannelli

University of Catania

Measurement of virtual photons and adiabatic operations in ultra-strongly coupled quantum systems

Abstract: Light-matter interaction, and understanding of the fundamental physics behind it, is the scenario of emerging quantum technologies. Solid state devices may explore new regimes where coupling strengths are “ultrastrong”, i.e. comparable to the energies of the subsystems, such that fast quantum operations could be performed. However faster dynamics has a cost. Indeed USC breaks the symmetry associated with the conservation of the number of excitations, leading to a series of new physical effects of great fundamental interest but detrimental for quantum state processing. In particular the highly entangled nature of the eigenstates, dressed by a potentially very large number of virtual photons, leads to leakage of excitation via the dynamical Casimir effect (DCE) and via decay. In this seminar we will present several results regarding the physics and the applications of the "ultrastrong" coupling regime, including the design of a quantum circuit for the detection of virtual photons with currently available technology, a measurement scheme of the virtual photons based on adiabatic passage which takes into account also the temperature T>0, and an adiabatic protocol to perform state transfer between two qubits ultrastrongly coupled to the same resonator.

Taira Giordani

University of Rome “Sapienza”

Generation of entangled photonic states in different degrees of freedom exploiting semiconductor quantum dots

Abstract: Single-photon sources based on semiconductor quantum dots find several applications in quantum information processing due to their high single-photon indistinguishability, on-demand generation, and low multiphoton emission. In this context, the generation of entangled photons represents a challenging task. A possible solution relies on the interference in probabilistic gates of identical photons emitted at different pulses from the same source. In this work, we show the results of entangled state generation by using two different approaches. The first is based on a probabilistic gate that generates entangled photon pairs in the polarization and in the orbital angular momentum degree of freedom. We generate the single photons through two different pumping schemes, the resonant excited one, and the longitudinal-acoustic phonon-assisted configuration. We then characterize the entangled two-photon states by developing a complete model considering relevant experimental parameters, such as the second-order correlation function and photons indistinguishability. The second approach investigates the properties of the excitation scheme itself. The resonant configuration enables the generation of states in superposition on the photons number basis. We show the results regarding the quality of the generation of such quantum states of light together with possible protocols for teleportation tailored to such a degree of freedom.

Santiago Hernandez Gomez

MIT – RLE

Measuring Kirkwood-Dirac quasiprobabilities with an solid-state spin defect

Abstract: Quasiprobabilities are the natural extension of correlation functions in Quantum mechanics. Indeed, correlation functions between incompatible observables at different times are described by Kirkwood-Dirac quasiprobabilities (KDQs). KDQs have applications in linear response theory, information scrambling and Loschmidt echo experiments, quantum sensing, and quantum thermodynamics. Moreover, non-positive values of the KDQs are proofs of non-classicality (contextuality). However, measuring them is not a simple task. Therefore, it is imperative to identify and validate experimental methodologies that enable access to these quantities. Here we use a solid-state spin --a nitrogen-vacancy center in diamond-- to reconstruct the KDQ using (for the first time) two different techniques: The first technique is based on projective measurements applied to the system. The effect of these measurements is too strong, so we combine the results from independent experiments to reconstruct the KDQ. The second technique is an interferometric scheme, where the characteristic function of the KDQ is codified into the coherence of an ancillary qubit, in this case a nuclear spin coupled to the NV. Our results open the door for further studies on the effect of quantum coherence and quantum correlations on thermodynamic processes and information-exchange processes occurring at the nanoscale.

Giovanni Gramegna

University of Bari

Storage capacity of a quantum perceptron

Abstract: Artificial neural networks have proven to be an extremely efficient computational model in specific tasks such as pattern recognition or image classification and have revolutionized the field of data analysis on classical computers. At the same time, the advent of quantum computation has shown that purely quantum mechanical features such as coherence and entanglement allow for addressing hard computational tasks with an exponential improvement of the performances compared to classical computation. The great success achieved in these two fields has motivated a surge of interest in quantum machine learning, with the aim to understand whether the two fields can benefit from each other. Recent developments in this field have seen the introduction of several models to generalize the classical perceptron to the quantum regime. The capabilities of these quantum models need to be determined precisely in order to establish if a quantum advantage is achievable. Here we use a statistical physics approach to compute the pattern capacity of a particular model of quantum perceptron realized by means of a continuous variable quantum system.

Guglielmo Lami

SISSA Trieste

Quantum magic via perfect Pauli sampling of matrix product states

Abstract: We introduce a novel breakthrough approach to evaluate the nonstabilizerness of an N-qubits Matrix Product State (MPS) with bond dimension χ. In particular, we consider the recently introduced Stabilizer Rényi Entropies (SREs). We show that the exponentially hard evaluation of the SREs can be achieved by means of a simple perfect sampling of the many-body wave function over the Pauli string configurations. The sampling is achieved with a novel MPS technique, which enables to compute each sample in an efficient way with a computational cost O(N χ3). We benchmark our method over randomly generated magic states, as well as in the ground-state of the quantum Ising chain. Exploiting the extremely favourable scaling, we easily have access to the non-equilibrium dynamics of the SREs after a quantum quench.

Luca Leonforte

University of Salerno

The quantum conditional mutual information: detecting, characterizing, and discriminating topological and non-topological phase transitions

Abstract: The entanglement of the ground state (GS) can be used to determine the phase and the phase transition of symmetry-protected topological phase (SPTP). By investigating the behavior of the quantum conditional mutual information (QCMI), an upper bound to the squashed entanglement, we show that this quantity identifies the phase transitions and discriminates between topological order and the usual ordered phases associated with spontaneous symmetry breaking. Being the QCMI the mutual information between two subsystems given a third subsystem, one can consider different QCMIs for the same ground state. Evaluating the QCMI over all possible partitions, both considering open boundary conditions and periodic boundary conditions, for different one-dimensional systems, including the Ising model, the Kitaev chain and the SSH model, we find that the QCMI distinguishes efficiently the trivial phase from the non-trivial ones, discriminates topological transitions from symmetry-breaking ones, and assesses whether a topological phase admits Dirac or Majorana fermions at the edges. It turns out that the QCMI is quantized throughout the topologically ordered phases: therefore it identifies both a topological invariant and a non-local order parameter characterizing the ground-state physics of symmetry-protected topological systems.

Luca Lepori

University of Parma

Maximally-entangled states via drive spin molecules

Abstract: We discuss some spin Hamiltonians, feasible in current experiments (as involving molecules, optical resonators and ions), useful to product, via suitable time-dependent driving protocols, highly-entangled spin states as final targets. Also depending on the way they are prepared, these states can be used for quantum sensing, communication or computation.

Nicola Lo Gullo

University of Calabria

Enhancing qubit readout with Bayesian learning

Abstract: In recent years there has been an increasing interest in quantum computing from non-pundits, companies and researchers from fields other than quantum computing. This is undoubtedly due to the deployment of quantum computing resources to research institutions and companies, which fostered the search for new applications of quantum computing. Currently available quantum processing units (QPUs) are typically small and are plagued by noise. Two main solutions are being investigated to improve them: on the one hand there is an ongoing technological effort in scaling up these devices controlling the noise and, at the same time, develop error correction codes which will make the QPUs robust to errors; on the other hand there are efforts in making the current small and noisy devices useful. Quantum error mitigation is a class of techniques aiming at reducing the errors in running codes on quantum computers. Within this framework we introduce an efficient and accurate readout measurement scheme for single and multi-qubit states. Our method uses Bayesian inference to build an assignment probability distribution for each qubit state based on a reference characterization of the detector response functions. This allows us to account for system imperfections and thermal noise within the assignment of the computational basis. We benchmark our protocol on a quantum device with five superconducting qubits, testing initial state preparation for single and two-qubit states and an application of the Bernstein-Vazirani algorithm executed on five qubits. Our method shows a substantial reduction of the readout error and promises advantages for near-term and future quantum devices. Reference: F. Cosco, N. Lo Gullo, Enhancing qubit readout with Bayesian Learning, arXiv:2302.07725, https:\/\/arxiv.org\/abs\/2302.07725

Salvatore Lorenzo

University of Palermo

On the potential and limitations of quantum extreme learning machines

Abstract: We present a complete characterization of the information that can be exactly retrieved from linear post-processing of measurement probabilities in quantum extreme learning machine (QELM) schemes. Our analysis sheds light on the relationship between the ability of a device to retrieve nonlinear functionals of input states and the memory of the associated quantum channel. Our framework can be extended to analyze time-dependent signals encoded in quantum states in quantum reservoir computing (QRC). We found that the efficiency of QELM protocols depends on the properties of an effective positive operator valued measurement (POVM) describing the entire apparatus, comprising of a dynamical evolution and a measurement stage. Our work also shows that the sampling noise, inherent in any measurement data obtained from a quantum device, significantly affects estimation performances and cannot be ignored. Our study provides insight into the performance factors of QELMs and QRCs in experimental scenarios, and identifies ways to counter them. It also opens up avenues for future research, including the extension of our analysis to time-trace signals for dynamical QRCs and the optimization of POVMs for quantum state estimation.

Vito Giovanni Lucivero

University of Bari

Pound-Drever-Hall detection of atomic polarization in a microfabricated vapor cell

Abstract: In Optically Pumped Magnetometers (OPMs), an optical probe detects coherent precession of an atomic ensemble due to a magnetic field. Commonly employed optical probes employ optical polarization rotation or optical absorption. Here we study a probe based on optical phase shifts, implemented using a resonant cavity around a MEMS cell and Pound-Drever-Hall detection of the resulting line shift for a circularly polarized cavity mode. We present a theoretical model for the signal generated by this method, and demonstrate experimentally the detection of atomic spin polarization generated by optical pumping. The method appears well suited to improving the effective optical path in micro-fabricated atomic vapor cells and it is compatible with generation of atomic spin squeezing by quantum-non-demolition measurements.

Davide Massarotti

University of Napoli

Hybrid Josephson junctions and unconventional circuits for quantum hardware

Abstract: The modern era of Josephson devices is strongly influenced by the continuous progress in material science and nanotechnologies, thus providing unique solutions to frontier problems in solid state physics and to advanced applications in quantum technologies, where new efforts are focusing on the improvements and scalability in qubit control, total footprint, coupling and readout. We will report on special properties of smart superconducting circuits, which make possible alternative layouts for the superconducting modules inside a more general architecture. We will discuss how the macroscopic phase of a carefully designed superconducting circuit, namely the Josephson Digital Phase Detector (JDPD), can be manipulated to perform digital phase detection of weak coherent radiation, thus constituting a phase-readout protocol for a superconducting qubit, suitable for a digital and scalable architecture [1]. Moreover, we will classify some significant behaviors of tunnel-ferromagnetic Josephson junctions and we will discuss the capabilities and the feasibility of a ferro-transmon qubit [2] that employs such hybrid junctions coupled to a superconducting resonator, thus allowing for novel tuning mechanisms that are not susceptible to specific noise sources.

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Alice Meda

INRIM Torino

Channel length control for Twin-field QKD in a real-world network

Abstract: Quantum key distribution (QKD) is a technology that allows the sharing of secret cryptographic keys between two distant users (Alice and Bob), whose intrinsic security is guaranteed by fundamental principles of quantum mechanics. QKD is a mature technology and, in Europe, all the 27 member states are working in a European Commission initiative (EuroQCI) to design, develop and deploy a quantum communication infrastructure. In Italy, the project QUID is in charge to realize the Italian part of EuroQCI.

One of the main remaining challenges for QKD is the integration of different solutions in already deployed telecommunication fiber networks, in particular in long haul segments.

An approach able to cover long distances is the Twin-field QKD (TF-QKD) protocol; TF-QKD exploits interference of optical pulses in central untrusted node (Charlie), allowing to double the communication distance with respect to the conventional prepare-and-measure solutions; but this requires that the optical pulses are phase-coherent in Alice and Bob and preserve coherence throughout the path to Charlie. In deployed optical fibers, uncorrelated phase changes, introduced by length and refractive index fluctuations of the fibers compromise the stability of the interference measurement.

Here we present a solution to the phase stabilization problem, derived from atomic clocks comparison technology, that demonstrates a strong advantage in performances of real word TF- QKD [1]. We designed and developed an apparatus suitable for TF-QKD where the phase fluctuations of both the lasers and of the connecting fibers are actively cancelled. We tested our solution in a part of the Italian Quantum Backbone, the real-world network that will be used as a quantum communication testbed within the project QUID. We also analyzed in details the theoretical behavior of the key rate with respect to different variance of TF-QKD protocol and experimental parameters.

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Roberto Moretti

INFN Milan Bicocca

Enhancing Microwave Photon Counting: Superconducting Qubits and Traveling Wave Amplifiers in Quantum Sensing

Abstract: Quantum Sensing is a rapidly expanding field with applications in Fundamental Physics, including Dark Matter (DM) search. Recent progress in superconducting qubits has enhanced sensitivity and reduced dark count rates in microwave photon detection experiments. The INFN Qub-IT project aims to develop an itinerant qubit-based single-photon counter that exploits Quantum Non-Demolition techniques [1] in the search for axion-like DM. Qub-IT's superconducting qubits' design has been optimized through in-depth simulations leveraging Lumped Oscillator Model [2] and Energy Participation Ratio [3] using the Ansys HFSS and Ansys Q3D software. The devices will be fabricated at the Bruno Kessler Foundation (FBK) and the Institute of Photonics and Nanotechnology (CNR-IFN). Qub-IT will benefit from using Travelling Wave Parametric Amplifiers (TWPAs) developed within the DARTWARS project. Such devices will offer broadband amplification with quantum or near-quantum limited noise, crucial for high-fidelity and multiplexed qubit readout. To achieve efficient readout we rely on RF engineering and Qibo, a full-stack open source software under development by the University of Milan and the Technology Innovation Institute in Abu Dhabi. This collaboration aims to advance microwave single-photon detection and broaden the capabilities of qubit readout in Quantum Sensing.

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Giuseppe Ortolano

INRIM Torino

Recent progresses in optical quantum metrology and hypothesis testing, from wide-field phase retrieval to pattern recognition

Abstract: The use of quantum resources, such as entanglement and squeezing, allows to overcome limitations of conventional measurement schemes, essentially increasing the amount information extracted about a tested object for a fixed probing energy. Quantum metrology deals with the estimation of an unknown value of a parameter encoded in a state, while quantum hypothesis testing is concerned with the discrimination among a discrete set of hypotheses. Here, we give an overview on some recent notable experimental progresses in these fields in the optical domain. Wide field sub-shot-noise imaging can be enhanced using quantum correlation [1]. Recently we showed how the quantum enhancement in intensity measurements allows to achieve supersensitive phase retrieval [2]. Quantum advantage in hypothesis testing is showed in the protocols of quantum reading [3 ,4], concerned with the readout of a classical digital memory, and quantum conformance test, a protocol enhancing the monitoring of production processes [5 ,6]. The advantage gained in sensing can be sustained through more complex tasks, in which for example the relevant information is encoded in global spatial patterns, such as handwritten digit recognition, for which we proved a classification advantage enabled by sensing with quantum states [7].

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[6] G. Ortolano, I. Ruo-Berchera, Sensors 22, 2266 (2022). [7] G. Ortolano et al., arXiv:2304.05830 (2023).

Simone Paganelli

University of L'Aquila

Variational quantum eigensolver for topological systems

Abstract: We will give an introduction to topological systems by the discussion of a paradigmatic 1D noninteracting model, namely the Su-Schrieffer-Heeger (SSH) model. The SSH model describes the electronic properties of one-dimensional systems with alternating hopping in a tight-binding approximation. This is the simplest model exhibiting a symmetry-protected topological phase and can be considered a prototype of topological insulator. In the SSH model, distinct bulk properties may give rise to states localized on the edges (edge states) with almost degenerate energy levels localized in the middle of the band gap. A topological phase transition from a trivial phase typically occurs via energy gap closure, then edge modes appear, consistently with the so-called bulk-boundary correspondence.

The edge states of the SSH model have a very high long-distance entanglement and are almost degenerate, making them potentially more elusive to detect: even if a variational algorithm is expected to give a satisfactory estimation of the bulk's properties, it could be inadequate for the edge states. We will try to identify these critical issues and propose a strategy to implement a suitable VQE to deal with nontrivial topological states.

Emanuele Pelucchi

Tyndall National Institute - UCC

Quantum technologies: the potential of integrated photonics, challenges and perspectives

Abstract: Integrated quantum photonics uses classical integrated technologies for quantum applications. As in classical photonics, chip-scale integration has become critical for scaling up and translating laboratory demonstrators to real-life technologies. Efforts are centred around the development of monolithically, hybrid or heterogeneously integrated platforms. We discuss the value that integrated photonics brings to quantum technologies and discuss what may become possible overcoming current roadblocks. Our aim is to stimulate further research by outlining not only the scientific challenges of materials, devices and components associated with integrated photonics for quantum technologies but also those related to the development of the necessary manufacturing infrastructure and supply chains.

Paolo Perinotti

University of Pavia

Incompatibility and irreversibility: from Heisenberg to post-quantum theories

Abstract: In Heisenberg's work on the uncertainty principle, two facets of non classicality were discussed--- though at very different depths---that are manifest in quantum theory. One is the irreducible disturbance on a system that comes with every observation, and this was just touched upon in the intuitive argument involving the gamma ray microscope thought experiment. The second one, which is the real stuff the uncertainty principle proves, is incompatibility of different measurements on the same system. We will formulate and analyse the above features in the wide context of operational probabilistic theories, that are theories of information sharing with quantum and classical theory the structures describing parallel and sequential composition of processes, but allowing for a variety of new system types, with possibly odd properties. We will provide various conditions for the presence or absence of measurement disturbance and incompatibility, connecting them with other properties of the theory at hand. We will discuss, in particular, to what extent the two features are distinctive traits of non-classicality. While the presence of incompatible observations always implies irreversibility, the converse is not true. This will be shown through a theory that provides a concrete counterexample: Minimal Classical Theory (MCT). G. M. D'Ariano, P. Perinotti, A. Tosini, Information and disturbance in operational probabilistic theories, Quantum 4, 363 (2020). G. M. D'Ariano, P. Perinotti, A. Tosini, Incompatibility of observables, channels and instruments in information theories, J. Phys. A Math. Theor. 55 394006 (2022). M. Erba, P. Perinotti, D. Rolino and A. Tosini, Measurement incompatibility is strictly stronger than disturbance, arXiv:2305.16931.

Matteo Piccolini

University of Palermo

Interferometric robust engineering of maximally entangled states of identical particles

Abstract: Real-world preparations of entangled states are hindered by the unavoidable interaction with the surrounding environment, whose noisy action spoils the quantum correlations within the system. Given the key role played by entanglement in quantum technologies, many different techniques to circumvent the problem have been proposed over time. We present a general scheme, valid for both bosons and fermions, to prepare maximally entangled states of two identical qubits in a way that is robust under the effect of any type of local noise, both quantum and classical. Considering linear optics operations, the procedure utilizes externally-activated depolarizing channels and a pseudospin-insensitive, non-absorbing, parity check detector in an iterative process with probability which converges exponentially to one with the number of repetitions. The scheme is thus asymptotically deterministic. Distributing the particles over two distinct spatial modes, we further show that the elements of the basis composed of maximally entangled states can be divided in two sets according to an equivalence based on passive optical transformations. We demonstrate that the parity check detector can be used to connect these two sets of states. The proposed procedure can be ultimately exploited to prepare any pure state of two identical qubits which are maximally entangled in either the internal degree of freedom (Bell states) or the spatial mode (NOON states).

Lorenzo Piroli

University of Bologna

Stabilizer entropies and nonstabilizerness monotones

Abstract: Nonstabilizerness, also colloquially known as magic, quantifies the number of non-Clifford operations needed in order to prepare a quantum state. As typical measures either involve minimization procedures or a computational cost exponential in the number of qubits N, it is notoriously hard to characterize. Recently, a new quantity called stabilizer Rényi entropy (SRE) has been put forward as a useful measure of magic, with the advantage of being easily computable for a few qubits. After briefly reviewing the recent literature on the subject, I will first discuss the SRE in the context of resource theory, partially resolving previously open questions pertaining to its monotonicity under generic stabilizer protocols. I will then show how the SRE can be computed efficiently for tensor-network quantum states, exhibiting explicit algorithms with a computational cost growing only polynomially in N. Finally, I will present numerical results for the SRE in the ground state of simple one-dimensional spin chains, revealing an interesting behaviour of nonstabilizerness at quantum criticality.

Luca Razzoli

University of Insubria

Cooperative effects in a dynamical quantum heat engine

Abstract: A quantum thermal machine is a quantum machine that exploits work and heat to perform useful thermodynamic tasks, such as delivering power, cooling, or heating. Modulating the couplings between the working medium and the thermal baths, usually associated with a purely dissipative effect, can be engineered to perform thermodynamic tasks [1,2], even simultaneously in multiterminal configurations [3]. Periodically driving asymmetric system-bath couplings makes the quantum thermal machine highly flexible and tunable, paving the way for thermal management in quantum technologies. In this work, we consider a dynamical quantum heat engine where two non-interacting quantum harmonic oscillators (the working medium) are coupled to two common thermal reservoirs. Both the couplings to the Lorentzian bath are periodically driven and weak, while those to the Ohmic bath are static. We show that the proposed quantum heat engine can outperform two disjoint, uncorrelated harmonic oscillators working in parallel [4,5 in preparation]. Since the two quantum harmonic oscillators do not interact directly, results suggest the emergence of cooperative effects mediated by the common baths.

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Michele Rota

University of Rome “Sapienza”

Bright and tunable entangled-photon emitters based on cavity-enhaced GaAs quantum dots on micromachined piezoelectric actuators

Abstract: Semiconductor quantum dots (QDs) proved to be one of the best sources of single and entangled photons due to their potential to emit quantum light on demand and to tune the light emission properties via strain engineering. Still, the potential of QDs remains partially unexploited due to a few current limitations such as the low extraction efficiency due to refractive index mismatch and entanglement degradation due to anisotropies in the QD. The scientific efforts of the QD community produced a novel photonic device, i.e., the circular Bragg resonator or Bullseye cavity, that addresses most of the limitations of these light sources. Our aim is to create an improved device that combines Bullseye cavities with a piezoelectric actuator which can alter the optoelectronic properties of the QD with the controlled tuning of strain. I will show our results in the quantum optical characterization of the fabricated device with state-of-the-art values for multiphoton emission and indistinguishability. The shortening of the lifetime of the transitions due to the Purcell effect, in combination with the reduction of the fine structure splitting of the exciton level using the piezoelectric actuator, allowed also for the recovery of a high level of entanglement of the emitted photons.

Pasquale Scarlino

EPFL

High impedance superconducting technology for hybrid devices

Abstract: Photonic cavity arrays form the basis of one of the most promising paradigms for quantum simulation to study complex many-body physics [1]. We developed a non-trivial structured photonic environment that could enable a multimode strong and ultra-strong coupling with quantum emitters. This platform consists of a unidimensional metamaterial implemented by an array of coupled superconducting microwave cavities made from thin Niobium Nitride (NbN) thin films. Such disordered superconductor allows to reach a very high kinetic inductance, which presents a two-fold advantage: a) It allows to reach ultra-strong coupling with an artificial atom as the capacitive coupling is proportional to the square root of the resonators' impedance, which can be highly increased thanks to the kinetic inductance [2]; b) It allows to strongly reduce the resonator\/metamaterial footprint. We demonstrate control over the platform by engineering the band structure of the coupled-cavity arrays in different regimes: trivial, topological (SSH) [3], left-handednes. We have fabricated and characterized unidimensional metamaterials of up to 100 ultra-compact resonators. As a follow up step, we are combining transmon qubits with these structured environments. We show preliminary results of transmon qubits strongly interacting with these high-quality structured baths, displaying atom-photon bound states. In addition, high impedance and compact resonators are an ideal platform for coupling microwave photons to qubits defined in semiconducting quantum dots (QDs) in the form of a hybrid device. By making use of this hybrid technology, we realized a proof-of-concept experiment, where the coupling between a transmon and a double QD is mediated by virtual microwave photon excitations in a high impedance SQUID array resonator, which acts as a quantum bus enabling long-range coupling between dissimilar qubits [4]. Similarly, we achieved coherent coupling between two DQD charge qubits separated by approximately ~50 um [5]. In addition, I will further demonstrate a new strategy to tune in-situ the strength of the double QD electric dipole moment, which allows either to considerably reduce the charge noise-induced decoherence (down to MHz linewidth), either to maximize the coupling strength with the cavity, demonstrating the possibility of achieving the ultrastrong coupling regime (USC) for electrons hosted in a semiconductor DQD [6].

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Ilaria Siloi

University of Padova

Applications of tensor network methods to quantum emulators and optimization problems

Abstract: Tensor networks (TNs) have emerged as a powerful approach for efficiently representing the quantum many-body wave function and have been successfully applied in various fields ranging from quantum many-body systems to lattice gauge theories and machine learning. TNs methods have also played a vital role in supporting the development of quantum technologies as they lie at the core of classical emulators. In this work, we present our emulators for digital quantum computing and quantum simulators, focusing on the physically relevant setting of the Hubbard model on a two-dimensional square lattice. Our investigation comprises both equilibrium and out-of-equilibrium properties. Moreover, we employ TNs algorithms to address optimization problems of industrial significance. Specifically, we tackle the mission planning problem for earth observation, which involves optimizing the scheduling of satellite observations based on a given set of user requests. We map the classical cost function onto an Ising-like Hamiltonian, where the optimization variables are represented as a set of interacting spins. By leveraging TNs, we efficiently determine the ground state of the resulting Hamiltonian, effectively solving the optimization problem.

Andrea Smirne

University of Milan

Multi-time correlation functions in open quantum systems: a non-perturbative approach

Abstract: One of the main challenges towards a complete description of open quantum systems is represented by non-Markovian evolutions, in which the impact of strong coupling and memory effects makes the characterization of relevant open-system quantities considerably more demanding. While recently several results have been derived to analyze the dynamics of the reduced open-system state, i.e., of the single-time expectation values, very few methods are available to describe the evolution of multi-time correlation functions in general situations. In this talk, I will present a nonperturbative treatment of the multi-time expectation values of open quantum systems interacting with a continuous set of bosonic modes by means of a limited number of modes damped via a Lindblad equation [1,2]. The influence of the environment on the open system is divided into a non-Markovian core, which encloses all the memory effects during the evolution, and a further Markovian component, which accounts for the unidirectional leakage of information out of the non-Markovian core. Our approach sets the ground for the investigation of open-system multi-time quantities in fully general regimes, as shown by its recent use in the evaluation of 2D electronic spectra of a dimeric complex in realistic parameter regimes [3].

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Paolo Solinas

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Quantum non-demolition measures, quasi-probabilities, and their application to the measure of work and heat in quantum systems

Abstract: In addition to the usual strong projective measurements, quantum mechanics allows for alternative ways to extract information from a quantum system. The use of a quantum detector coupled to the system to be measured allows us to gain important information about the wave-function of the system and to point out its unique quantum feature. In the literature, these schemes have different names such as quantum non-demolition measurements and weak measurements but rely on the same ideas. I will discuss what are the advantages and disadvantages of this approach with a particular practical example: the measure of the work done on and the dissipated heat by a quantum system driven by an external field. I will show that instead of a probability distribution for the observables, we obtain a quasi-probability distribution that is not positively defined. The presence of negative regions in the distribution is related to the violation of the Leggett-Garg inequalities and, in perfect analogy with the Wigner function, can be used to spot pure quantum behaviors. I will present both the theoretical ideas and experimental data obtained on IBMQ quantum computers.

Claudia Stella

INRIM Torino

Nanodiamond probes detect local temperature variations in the neuron

Abstract: Temperature is one of the most relevant parameters for the regulation of intracellular processes. Measuring localized subcellular temperature gradients is fundamental for a deeper understanding of cell function, such as the genesis of action potentials, and cell metabolism. In this work I will review our latest progresses in NV-based thermometry ultimately leading to the first localized temperature increase detection in a firing neuronal network with precision under 0.1 K.

By exploiting ODMR techniques, temperature variations in cultured hippocampal neurons at the single-cell scale using NV color centers in nanodiamonds are probed. Our data show that, in the spontaneously firing network, 1K local temperature increases can be detected in association to a significant potentiation of the firing rate, whereas ODMR stimulation protocols do not affect cell viability and functionality.

In perspective, this techniques will provide an extremely promising mean of indirect detection of the action potential and study of temperature variations in proximity of specific cell regions by functionalizing nanodiamonds in order to target specific cell components (e.g. ion channels, mitochondrions, ER).

Ilaria Svampa

University of Camerino

p-Adic Lie groups: towards the p-adic qubit via representations of the p-adic rotation group

Abstract: We discuss p-adic quantum mechanics, where physics takes place in a three-dimensional p-adic - rather than Euclidean - space. In particular, we study the p-adic rotation group $SO(3)_p$, and we outline a program aimed at classifying its irreducible projective representations, by making use of the Haar measure on the group. These representations can be interpreted as a theory of p-adic angular momentum, where the p-adic qubit arises as a two-dimensional irreducible representation. We describe the foundations of this program, starting from the main features of $SO(3)_p$ (in parallel to its real counterpart), such as a parameterisation of p-adic rotations, and a p-adic analogue of the Cardano angles decomposition (aka nautical angles). Along the way, it is natural to address the only other compact p-adic special orthogonal groups, i.e. $SO(2)_p$ and $SO(4)_p$. We conclude by briefly outlining a method yielding to some simple representations of $SO(3)_p$, and by showing explicit p-adic qubit representations for every prime p. (Based on arXiv:2104.06228 and arXiv:2112.03362.)

Emanuele Tirrito

ICTP - University of Trento

Quantifying non-stabilizerness in many-body systems

Abstract: Non-stabilizerness - also colloquially referred to as magic - is a resource for advantage in quantum computing and lies in the access to non-Clifford operations. Developing a comprehensive understanding of how non-stabilizerness can be quantified and how it relates other quantum resources is crucial for studying and characterizing the origin of quantum complexity. In this presentation, I will establish a direct link between non-stabilizerness and entanglement spectrum flatness for a pure quantum state. This connection can be exploited to efficiently investigate non-stabilizerness, even in the presence of noise. Furthermore, I will illustrate a Monte Carlo approach applied to probability distribution of Pauli strings to estimate non-stabilizerness, which is quantified by the Stabilizer Renyi Entropies (SREs). This will provide an insightful and efficient method for characterizing and analyzing the role of non-stabilizerness in quantum many-body systems.

Viviana Viggiano

University of Bari – INFN Bari

Cooperative decay rates in random atomic clouds

Abstract: We investigate the properties of the cooperative decay modes of an atomic cloud, characterized by a Gaussian distribution in three dimensions, initially excited by a laser in the linear regime. Due to the randomness of atom positions, these properties are encoded in a family of random decay rate matrices S, whose dimension coincides with the number of atoms in the cloud. Each entry of such matrices depends on the distance between a given pair of atoms, thus classifying them in the category of Euclidean random matrices. The considered problem is essential in determining the dissipative dynamics of the cloud. We study the eigenvalue density of S, the nearest-neighbor spacing distribution and the eigenvector statistics. We find that, although the random matrices S are Euclidean, the bulk of their spectrum is characterized by level repulsion and delocalized eigenstates, and therefore exhibits the universal behavior of chaotic quantum systems. Joint work with R. Bachelard, F. D. Cunden, P. Facchi, R. Kaiser, S. Pascazio, and F. V. Pepe.

Vittorio Vitale

LPMMC, CNRS, Grenoble

Estimation of the quantum Fisher information on a superconducting devices

Abstract: We present experimental measurements of the Quantum Fisher Information (QFI) on a many-body platform of superconducting qubits, merging various methods and concepts under the umbrella of randomized measurements. We employ and improve upon the recently introduced robust shadows, batch shadows and common randomized measurements for enhancing the estimation of the QFI for the Greenberger–Horne–Zeilinger (GHZ) state and ground state of the transverse field Ising model (TFIM) prepared on noisy IBM quantum processors. We witness the entanglement depth and assert the presence of multipartite entanglement in the prepared states and we report the first experimental demonstration of Heisenberg scaling of the QFI with the number of qubits.

Alessandro Zavatta

CNR – INO Firenze

Recent developments in fibre-based quantum communications

Abstract: Quantum Communication has established itself as a reliable and effective method for ensuring unconditional confidentiality by leveraging quantum properties. We achieved a significant milestone by launching the first quantum network connecting three European states. During the G20 digital ministers' meeting held in Trieste, we successfully enabled the exchange of quantum keys between Italy, Croatia, and Slovenia. Furthermore, we established a QKD link employing a submarine optical fibre connecting Malta and Sicily. We tested a new single-photon detector by Politecnico di Milano, outperforming commercial detectors by extracting keys at a fourteen times higher rate. L'Aquila, utilising the first multicore fibre displaced in a metropolitan environment, we instigated a QKD protocol with high-dimensional quantum states, demonstrating, for the first time out of a physics laboratory, that the transmission rate is two times higher than standard low-dimensional protocols. Finally, quantum secure direct communication (QSDC) is a recently developed practical solution which transmits secret messages between legitimate parties without setting up a cryptographic key. We present a novel QSDC protocol based on coherent and squeezed state sources. We show the advantage of squeezed states over coherent states for achieving higher secrecy and robust, secure communications within lossy and noisy channels.

Stefano Zippilli

University of Camerino

Stationary entanglement in arrays of quantum systems

Abstract: We present various methods for controlling the steady state dynamics of arrays of quantum systems, allowing us to guide the entire array towards non-trivial entangled steady states. Specifically, we explore the preparation of bosonic cluster states through two approaches: by squeezing the local reservoir of a single element in the array, or by utilizing multi-frequency drivings. For qubits, we illustrate that it is feasible to entangle multiple pairs of non-directly interacting qubits by engineering the local environment of a single element. These results occurs when the quantum array exhibits specific geometries and symmetries.