BOOK OF ABSTRACTS

14TH ITALIAN QUANTUM INFORMATION SCIENCE CONFERENCE
12-16 SEPTEMBER 2022, UNIVERSITY OF PALERMO, ITALY

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Monday 12

Super and subradiance in cold atomic clouds

Saverio Pascazio

Physics Department, University of Bari, Italy

The study of cooperative effects in spontaneous radiation emission by atomic ensembles has attracted great attention since Dicke's 1954 seminal article on superradiance. The phenomenon of subradiance, on the other hand, is less understood, and has been observed less than 10 years ago (by Guerin, Araújo and Kaiser), who detected very slow decay, with lifetimes of the order of 100 times the natural lifetime of individual (independent) atoms. We study here, by using random matrices, the features of the spontaneous decay of a dilute cold atomic cloud, and analyze both super- and subradiant states.

Nonlinear quantum logic with colliding graphene plasmons

Giuseppe Calajò

Universitá di Padova - INFN

Graphene has emerged as a promising platform to bring nonlinear quantum optics to the nanoscale, where a large intrinsic optical nonlinearity enables long-lived and actively tunable plas- mon polaritons to strongly interact. Here we theoretically study the collision between two counter- propagating plasmons in a graphene nanoribbon, where transversal subwavelength confinement en- dows propagating plasmons with a flat band dispersion that enhances their interaction. This scenario presents interesting possibilities towards the implementation of multi-mode plasmon gates that cir- cumvent limitations imposed by the Shapiro no-go theorem for photonic gates in nonlinear optical fibers. As a paradigmatic example we demonstrate the feasibility of a high fidelity conditional π phase shift (CZ), where the gate performance is fundamentally limited only by the single plasmon lifetime. These results open new exciting avenues towards quantum information and many-body applications with strongly-interacting polaritons.

Detecting the symmetry breaking of the quantum vacuum in a circuit QED system

Salvatore Savasta

Università di Messina

Hybrid quantum systems in the ultrastrong, and even more in the deep-strong, coupling regimes can exhibit exotic physical phenomena and are promising for new applications in quantum technologies. In these nonperturbative regimes, a qubit resonator system has an entangled quantum vacuum with a nonzero average photon number in the resonator, where the photons are however virtual and cannot be directly detected. We have shown that the vacuum field is able to induce the symmetry breaking of a dispersively coupled probe qubit. A very recent experiment has observed this Higgs-like quantum-vacuum symmetry breaking induced by the field of a superconducting electromagnetic resonator deep-strongly coupled with a flux qubit. This result opens a way to experimentally explore the novel quantum-vacuum effects emerging in the deep-strong coupling regime, as well to explore the superradiance phase transitions in these systems.

Coherent Magnonics in the Ultrastrong Coupling Regime

Alberto Ghirri

1. Istituto Nanoscienze - CNR, via Campi 213/a, 41125 Modena, Italy

One of the objectives in the study of light-matter coupled systems is to push the coupling strength to the highest achievable values. In the ultrastrong coupling regime, which is reached when the ratio between the coupling strength (gc) and the frequency of the uncoupled transitions (ω0) exceeds 0.1, the conventional perturbative treatment of QED does not hold and higher-order processes are expected to produce relevant effects.

Scalable quantum computer with superconducting circuits in the ultrastrong coupling regime

Roberto Stassi

Università degli Studi di Messina

So far, superconducting quantum computers have certain constraints on qubit connectivity, such as nearest-neighbor couplings. To overcome this limitation, we propose a scalable architecture to simultaneously connect several pairs of distant qubits via a dispersively coupled quantum bus. The building block of the bus is composed of orthogonal coplanar waveguide resonators connected through ancillary flux qubits working in the ultrastrong coupling regime. This regime activates virtual processes that boost the effective qubit–qubit interaction, which results in quantum gates on the nanosecond timescale. The interaction is switchable and preserves the coherence of the qubits.

Detection of virtual photons in ultrastrongly coupled quantum systems

Luigi Giannelli

CNR-IMM, UoS Università, Catania

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.New exotic phenomena occur as the entangled vacuum contains virtual photons[1]. Despite more than a decade of research, the detection of ground-state virtual photons still awaits demonstration.In this work, we provide a solution for this long-standing problem.We find a design of a superconducting quantum circuit and a protocol of coherent amplification yielding a highly efficient, faithful and selective conversion of virtual photons of a ”false” ground state[2,3] to real ones enabling their detection with state-of-the-art quantum hardware.Supplemented by advanced control, our multilevel design can be exploited for further quantum tasks in the USC regime. [1] P.Forn-Diaz,et al.,RMP 91,025005 (2019);A.Kockum,et al.,Nat.Rev.Phys.1,19 (2019); [2] R.Stassi,et al.,PRL 110,243601 (2013);G.Falci,et al.,Fort.Phys.65,1600077 (2017); [3] G.Falci,et al.,Ssci.Rep.9,9249 (2019).

Critical Quantum Sensing

Simone Felicetti

Istituto dei Sistemi Complessi CNR-ISC

Quantum critical systems in proximity of phase transitions exhibit a divergent susceptibility, suggesting that an arbitrarily-high precision may be achieved when they are used as probes to estimate a physical parameter. However, such an improvement in sensitivity is counterbalanced by the critical slowing down, which implies an inevitable growth of the protocol duration time. Here, we present sensing protocols based on phase transitions observable in a broad class of quantum optical systems. We show that, in spite of the critical slowing down, critical quantum optical probes can achieve quantum advantage in sensing applications. Then, by going beyond the asymptotic regime of parameters, we show that Heisenberg-limited precision can be achieved with current quantum technologies. Finally, we propose specific applications for quantum magnetometry and for superconducting-qubit readout.

Characterization of integrated multiphase sensors via Neural Networks

Valeria Cimini

Università di Roma La Sapienza

Integrated photonic circuits represent a handy solution for studying multiparameter estimation problems. Such a platform indeed can be easily scaled, and it allows to implement complex and stable transformations with reconfiguration capabilities. However, when the system dimensions increase the characterization of its operation, necessary for most estimation protocols, becomes a particular hard task to solve. Usually, the calibration of the device is done through tomography, which is a resource and computational expensive procedure, requiring the capability of generating different classes of input states. Moreover, in a real scenario, the number of resources is always limited and not all the desired probe states can be prepared. Here, we start investigating Bayesian estimation bounds in a limited resources scenario and then we prove the effectiveness of machine learning algorithms, more specifically of neural networks, to overcome the need of retrieving an explicit model of the device functioning. We demonstrate that in such framework almost optimal estimation performances can be achieved in an actual noisy multiparameter estimation experiment performed at the single-photon level.

Quantum simulation of scattering processes

Alessandro Bisio

University of Pavia

We present a systematic treatment of scattering processes for quantum systems whose time evolution is discrete. We prove some general properties of the scattering operator and we develop two perturbative techniques for the power series expansion of scattering amplitudes. This formalism is used to assess the performance of discrete-time quantum simulators in recovering the scattering amplitudes of continuous-time models.

New frontiers in measurements in weak coupling regime

Enrico Rebufello

Istituto Nazionale di Ricerca Metrologica (INRIM)

Weak coupling regime allows for new quantum measurement paradigms showing unprecedented measurement capability, with possible applications spanning from quantum information to quantum metrology. Furthermore, if proper post-selection is added, one can retrieve the weak value of an observable, a peculiar quantity with many exotic traits, such as being not bounded to the observable eigenvalue spectrum (taking even imaginary values). In this regime, we achieved several results, e.g. sequential weak measurements of non-commuting observables and the first implementation of protective measurements. I will present our latest results in this field, namely Robust Weak Measurements (RWMs) [1] and One-Shot Bell Measurements (OSBM). RWM is an iterative measurement protocol in which, instead of averaging over multiple acquisitions, even a single reading of the measuring device provides a reliable estimate of a (anomalous) weak value. In OSBM, instead, we exploit weak couplings in sequence to sense the whole Bell parameter with each entangled photon pair produced, a paradigm shift with respect to traditional Bell inequality tests. [1] E. Rebufello et al. Light: Science & Applications (2021) 10:106

Generation of pseudo-random states on actual quantum hardware

Maria Bondani

CNR - Istituto di Fotonica e Nanotecnologie

An ideal quantum computer operating with more than fifty qubits could outperform a classical computer, and the quantum advantage for specific problems has been recently claimed. However, quantum advantage can only be reached with a high enough quantum gate precision and through processes generating a large enough amount of entanglement., In this work, we compare the effectiveness of different algorithms to generate pseudo-random quantum states, for which the multipartite entanglement is almost maximal, as characterized by the probability distribution of bipartite entanglement between all possible bipartitions of the system., The algorithms are finally tested in actual quantum hardware, based either on superconducting or on ion qubits.

Ground state preparation of lattice gauge theories with the quantum approximate optimization algorithm

Elisa Ercolessi

Dept. Physics and Astronomy, University of Bologna

The preparation of the ground state of a Lattice Gauge Theory is a challenging problem, due to the dimension of the Hilbert space and the presence of gauge constraints. We will discuss [1] how to prepare the ground state and study the quantum phase diagram of a two-dimensional □2 lattice gauge theory by means of the hybrid Quantum Approximate Optimization Algorithm, which requires a small number of parameters to reach high fidelities and can be efficiently scaled up on larger systems. Despite the reduced size of the considered lattices (up to 5x5), a transition between confined and deconfined regimes can be detected by measuring the expectation values of Wilson loop operators or the topological entropy. Moreover, if periodic boundary conditions are implemented, the same optimal solution is transferable among all four different topological sectors, without any need for further optimization on the variational parameters. These results show that variational quantum algorithms provide a useful technique to be added in the growing toolbox for digital simulations of lattice gauge theories, suitable for near-term quantum computers.

Bell nonlocality in quantum-gravity induced minimal-length quantum mechanics

Luciano Petruzziello

University of Salerno & INFN

Different approaches to quantum gravity converge in predicting the existence of a minimal scale of length. This raises the fundamental question as to whether and how an intrinsic limit to spatial resolution can affect quantum mechanical observables associated to internal degrees of freedom. In this talk, the question is answered in general terms by showing that the spin operator acquires a momentum-dependent contribution in quantum mechanics equipped with a minimal length. Among other consequences, this modification induces a form of scale-dependent quantum nonlocality stronger than the one arising in ordinary quantum mechanics. In particular, one can show that violations of the Bell inequality can exceed the maximum value allowed in ordinary quantum mechanics by a positive multiplicative function of the momentum operator.

Tuesday 13

Remedies for MAD channels:exact solutions for the quantum capacities calculations.

Vittorio Giovannetti

SNS

Capacities are figures of merit developed in the context of Quantum Shannon Theory which allows one to quantitatively measure the level of deterioration that a given noise process induces on the quantum system it acts upon. Unfortunately for the vast majority of cases such optimal rates are not computable neither analytically nor algorithmically due to superadditivity and superactivation effects. In this work we address the problem for a class of channels (the Multilevel Amplitude Damping Channels, or MAD channel in brief) which describe the dissipation effects for qu-dits systems

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Cooperative quantum information erasure

Michele Campisi

NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, Pisa

We demonstrate an information erasure protocol that resets N qubits at once. The method works (within the estimated error) at Landauer energy cost and sets the current record of energy-x-time cost. The method departs from the standard algorithmic cooling paradigm by exploiting cooperative effects associated to the mechanism of spontaneous symmetry breaking which are amplified by quantum tunnelling phenomena. Such cooperative quantum erasure protocol is demonstrated on a commercial quantum annealer and could be readily applied in next generation hybrid gate-based/quantum-annealing quantum computers, for fast, effective, and energy efficient initialisation of quantum processing units.

Exploiting Coherence in Quantum Thermodynamics

Gabriele De Chiara

Queen’s University Belfast

The study of out-of-equilibrium thermodynamics of quantum systems has received increasing attention in recent years thanks to tremendous theoretical and experimental progress. While most of the studies in quantum thermodynamics bear a close resemblance to their classical counterparts, especially close to equilibrium, there are only a few examples of genuine quantum features, e.g. coherence, squeezing and entanglement, that provide an advantage over classical thermodynamic devices. In this contribution, I will show how thermal equilibrium reservoirs equipped with an infinitesimal amount of quantum coherence exhibit such an advantage. In fact, reservoir quantum coherence allows the design of engine and refrigerators with efficiencies that exceed the corresponding Carnot’s efficiency of a classical machine operating with the same temperatures. Such thermal machines provide efficiencies at maximum power that exceed the classical Curzon-Ahlborn value. Moreover, the injected coherence allows for a hybrid refrigerators which extracts heat from the coldest bath and simultaneously produces work. [1] K. Hammam, H. Leitch, Y. Hassouni and G. De Chiara, arXiv:2202.07515

Power maximization of two-stroke quantum thermal machines

Bruno Bellomo

Institut UTINAM, Université de Franche-Comté, Besançon, France

Two different versions of a two-stroke quantum thermal machine are studied [1]. In both versions, two collections of identical systems with evenly spaced nonvariable energy levels can be put in contact, respectively, with a cold and a hot thermal bath. In the first version, a system of a collection interacts with a system of the other one, and then they thermalize. In the second one, a mediator system interacts alternately with one or more systems of each collection. We show that the efficiencies of these machines depend only on the energy gaps of the systems and are equal to the efficiency of “equivalent” Otto cycles. Focusing on the cases of qubits or harmonic oscillators for both models, we maximize the engine power and analyze, in the model without the mediator, the role of the waiting time between subsequent interactions. We find that in both cycles, the power peaks of qubit systems can surpass the Curzon-Ahlborn efficiency. Finally, we compare our cycle without the mediator with previous schemes of the quantum Otto cycle showing that high coupling is not required to achieve the same maximum power. [1] N. Piccione, G. De Chiara, and B. Bellomo, Phys. Rev. A 103, 032211 (2021).

Quantum and classical phase transitions in a two-impurity spin-boson model

Roberto Grimaudo

Università degli Studi di Palermo

The two-impurity spin-boson model (TISBM), consisting in two interacting spin-1/2's coupled with a common reservoir composed of quantum harmonic oscillators, is analysed. Several crucial and still open questions concerning the TISBM are currently under active consideration: i) the existence of critical points and then the presence of quantum and/or classical phase transitions; ii) if the eventual quantum phase transitions are of the Kosterlitz-Thouless type. We consider the class of TISBMs with no transverse fields applied to the spin pair. We show that the role of the tunneling parameter is played by the spin-spin coupling. We demonstrate the presence of: - A classical (finite temperature) phase transition characterized by a spin-spin coupling-dependent critical temperature. - A spin-spin coupling-based quantum (zero temperature) phase transition due to a level crossing with respect to the spin-bath coupling strength(s). - A Kosterlitz-Thouless (quantum) phase transition with a consequent localization phenomenon of the spin-system. - A decoherence-free subspace where the two coupled spins experience a dissipationless dynamics.

Environment-induced quantum phase transitions in dissipative systems

Loris Maria Cangemi

Bar-Ilan University

Quite recently,the issue of achieving a reliable theoretical description of open quantum systems in theintermediate up to strong system-environment coupling regime has regained interest.Indeed,it is relevant to a wide range of quantum technologies,including quantum annealers andfar-reaching quantum thermodynamics devices.Here we present a theoretical study of several prototypical instances of quantum systems that arestrongly interacting with their surroundings at low temperature.By employing the Caldeira-Leggett model,we analyze how their equilibrium and out-of-equilibrium properties change with increasing couplingstrength compared to the conventional weak-coupling scenario.We address the typical setting of single to many two-level systems coupled to a bath,as well as theinstance of a single two-level system coupled to a dissipative quantum harmonic oscillator.Our results point towards the occurrence of environment-induced quantum phase transition of theBerezinskii-Kosterlitz-Thouless (BKT) kind,which eventually leads to the absence of quantum tunneling and to the localization of the quantum degrees of freedom.

Observation of a non-equilibrium superradiant phase transition in free space

Giovanni Ferioli

Institut d'Optique

We observe a non-equilibrium phase transition in a driven dissipative quantum system consisting of an elongated cloud of N laser-cooled atoms in free space, optically excited along its main axis. We find that our data are well reproduced by the iconic Driven Dicke model, which assumes a sub-wavelength sample volume, by simply using an effective atom number. By measuring the excited state population of the atoms and the light emitted in the superradiant mode, we characterize the dynamics of the system and its steady-state properties. In particular, we observe the characteristic N^2 scaling of the photon emission rate in the superradiant phase, thus demonstrating steady-state superradiance in free space. Finally, we observe a modification of the statistics of the superradiant light as we cross the phase transition.

Photon Condensation: No-go and counter no-go theorems

Gian Marcello Andolina

ICFO

Equilibrium phase transitions between a normal and a photon condensate state (also known as superradiant phase transitions) are a highly debated research topic, where proposals for their occurrence and no-go theorems have chased each other for the past four decades. Previous no-go theorems have demonstrated that gauge invariance forbids phase transitions to a photon condensate state when the cavity-photon mode is assumed to be *spatially uniform*. However, it has been theoretically predicted that a collection of three-level systems coupled to light can display a first-order phase transition to a photon condensate state. It has also been recently shown that truncation of the Hilbert space of the matter system can affect the gauge invariance of the theory. However, it is always possible to obtain approximate Hamiltonians obeying the gauge principle in the truncated Hilbert space. Here, we demonstrate a general no-go theorem for truncated, gauge-invariant models, which forbids first-order *as well* as second-order superradiant phase transitions in the absence of a magnetic field, in agreement with the general theory.

Driving quantum thermal machines with optimal power/efficiency trade-offs using reinforcement learning

Paolo Andrea Erdman

Freie Universität Berlin, Germany

The optimal control of non-equilibrium open quantum systems is a challenging task but has a key role in improving existing quantum information processing technologies. We introduce a model-free framework, based on Reinforcement Learning (RL), to identify optimal protocols for driven quantum thermal machines [1,2]. Quantum thermal machines, such as heat engines and refrigerators, are quantum devices that convert between heat and work through time-dependent controls that are periodically driven to implement thermodynamic cycles. We introduce a general framework, based on state-of-the-art RL algorithms, to discover optimal cycles that are Pareto optimal trade-offs between power and efficiency. The method is model-free, and only requires the observation of the heat fluxes. We test our method on an experimentally realistic refrigerator based on a superconducting qubit, and on a heat engine based on a quantum harmonic oscillator. In both cases we find elaborate cycles that outperform previous literature proposals and the optimized Otto cycle. [1] P.A. Erdman and F. Noé, NPJ Quantum Inf. 8, 1 (2022). [2] P.A. Erdman and F. Noé, arXiv:2204.04785 (2022).

A learning theory for quantum photonic processors and beyond

Matteo Rosati

Technische Universität Berlin

We establish that quantum information processing architectures based on bosonic oscillators, such as photonic or mechanical ones, can be efficiently trained from examples to solve a broad class of tasks, including state reconstruction, discrimination and synthesis.,We consider a family of Gaussian and non-Gaussian continuous-variable (CV) circuits, suitable to describe state-of-the-art photonic processors, and evaluate its learning capabilities. ,Our basic learning problem is: given copies of an unknown quantum state, we apply to each of them a random quantum circuit from a given set C and obtain measurement outcomes. The objective is to approximate the unknown state using a state from a given hypothesis set S, using a small number of samples. The approximation is good if it reproduces the measurement statistics of all circuits in C on the unknown state, with small error and high probability. We show that a good approximation can be found with a number of samples polynomial in the number of modes of the CV circuit, which is a measure of its size. ,We apply our results to learning a decoder for optical communication, outperforming the state of the art.

On the potential and limitations of quantum extreme learning machines

Luca Innocenti

UNIPA

Quantum reservoir computers (QRC) and quantum extreme learning machines (QELM) aim to efficiently post-process the outcome of fixed — generally uncalibrated — quantum devices to solve tasks such as the estimation of the properties of quantum states. The characterisation of their potential and limitations, which is currently lacking, will enable the full deployment of such approaches to problems of system identification, device performance optimization, and state or process reconstruction. We present a framework to model QRCs and QELMs, showing that they can be concisely described via single effective measurements, and provide an explicit characterisation of the information exactly retrievable with such protocols. We furthermore find a close analogy between the training process of QELMs and that of reconstructing the effective measurement characterising the given device. Our analysis paves the way to a more thorough understanding of the capabilities and limitations of both QELMs and QRCs, and has the potential to become a powerful measurement paradigm for quantum state estimation that is more resilient to noise and imperfections.

Machine Learning-Assisted Read out of Molecular Spin Qubits

Claudio Bonizzoni

Dipartimento di Scienze Fisiche, Informatiche e Matematiche (FIM) - Università di Modena e Reggio Emilia

We have recently implemented Storage/Retrieval protocols [NPJQuantInf6,68(2020)] and dispersive readout [AdvQuantTech2100039(2021)] on molecular spin qubits embedded into planar superconducting microwave resonators [AdvPhysX3,1435305(2018)]. Along this line, we present our results on the use of machine learning to assist the readout of the spin echo signal of an Oxovanadyl (VO(TPP)) molecular spin ensemble at low temperature. We first revisit our Storage/Retrieval protocol using trains of 4 input pulses, which allows us to codify up to 16 binary numbers. We first show that an Artificial Neural Network can be used to correctly recognize the output echoes from the raw measured traces without any prior information on their number or positions. Further post selection by means of a Clustering method allows us to successfully infer the initial input bit sequence. We then consider the phase of the Hahn echo signal, showing that it is possible to use an Artificial Neural Network to correctly infer the initial input phase from raw measured data. Our approach is found to detect the effect of additional single-pulse phase control, holding potential to assist single-qubit gate operations.

Learning Feedback Control Strategies for Quantum Metrology

Marco Genoni

Università degli Studi di Milano

In this talk I will discuss the usefulness of reinforcement learning techniques (RL) for enhancing the performance in a quantum metrology protocol. In particular we consider the problem of frequency estimation for a single bosonic field evolving under a squeezing Hamiltonian and continuously monitored via homodyne detection. In the first part of the talk I will introduce continuously monitored quantum systems along with the mathematical formalism needed to describe them and the corresponding quantum Cramer-Rao bound that sets the ultimate precision in parameter estimation. Then I will (very) briefly discuss the concept of RL and in particular how to exploit these techniques for our particular metrological problem. Finally I will present our results: we show that the feedback control determined by the neural network greatly surpasses in the long-time limit the performances of both the “no-control” strategy and the standard “open-loop control” strategy, which we considered as benchmarks. We indeed observe how the devised strategy is able to optimize the nontrivial estimation problem by preparing a large fraction of trajectories corresponding to more sensitive quantum conditional states.

Quantum Asymmetry and Noisy Multimode Interferometry

Francesco Albarelli

Università di Milano

DOI:10.1103/PhysRevLett.128.240504 Quantum asymmetry is a physical resource that coincides with the amount of coherence between the eigenspaces of a generator responsible for phase encoding in interferometric experiments. We highlight an apparently counterintuitive behavior that the asymmetry may increase as a result of a decrease of coherence inside a degenerate subspace. We intuitively explain and illustrate the phenomena by performing a three-mode single-photon interferometric experiment, where one arm carries the signal and two noisy reference arms have fluctuating phases. We show that the source of the observed sensitivity improvement is the reduction of correlations between these fluctuations and comment on the impact of the effect when moving from the single-photon quantum level to the classical regime. Finally, we also establish the analogy of the effect in the case of entanglement resource theory.

An Adversarial Learning Approach to Quantum Noise Sensing

Paolo Braccia

Università degli Studi di Firenze

One of the recent breakthroughs of Machine Learning (ML) has been Generative Adversarial Networks (GANs). By exploiting results from Nash's Game Theory, these learning models can generate fake data with the same distribution of some target ones. In the spirit of early-day Quantum ML (QML), a direct ”quantization” of this learning paradigm, dubbed Q-GANs, has been proposed, where the agents competing in the adversarial game are quantum and can be modeled by Parametrized Quantum Circuits (PQCs). We show how to solve typical issues that arise when the quantum states involved in QGANs training are mixed, and equipped with that piece of knowledge we move on to deploy SuperQGANs, a framework for learning quantum Super Operators in an adversarial fashion. Particularly, we show a proof of concept of how this new paradigm could be used to sense noise affecting real quantum hardware, by modeling the noise as a Pauli channel and learning the associated error-rates. We show numerical evidence of the success of our method, even in the case of spatially and temporally correlated noise.

Wednesday 14

Quantum cryptography beyond quantum key distribution

Erika Andersson

Heriot-Watt University

Quantum key distribution is probably both the most well-known and the most investigated application in quantum communication. However, there's more to communication than sending secret messages. This talk will give an overview of some other things that "quantum" enables us to do, such as quantum fingerprinting and quantum coin flipping. We will also discuss multiparty computation, which "quantum" only enables us to do partly (still better than ”classical”, but not perfectly). This is where two or more parties do not trust each other, but want to compute something together, without revealing any more than necessary about their individual input data. Examples include determining the outcome of an election, or determining which bid is the highest, among a number of secret bids. If we limit the quantum memory adversaries can use, perfect quantum multiparty computation is impossible. Otherwise, cheating probabilities are still lower than for classical protocols.

A new ultracold ytterbium experiment with single-atom control

Francesco Scazza

Università degli Studi di Trieste

A fundamental goal in quantum science and technology is the control and preservation of coherence in large qubit ensembles. Neutral atoms stored in optical traps offer a platform with large potential for flexibility and scalability, as witnessed by recent experimental progress enabled by precise motional and configurational control obtained using tailored optical potentials. While most efforts in neutral atom quantum information experiments have been focused on alkali atoms, alkaline-earth-like atoms provide new capabilities for realizing and probing pristine quantum systems, featuring extremely robust nuclear and electronic excited states. Here, I will report on the ongoing development of a new experimental apparatus in Trieste, aiming to achieve single-atom control in ultracold ytterbium ensembles. I will outline our main research directions, targeting important questions at the interface between quantum many-body physics, open quantum systems and quantum information science.

Orientational melting in planar ion crystals.

Lucia Duca

LENS / INRiM

The crystallization behavior of a finite number of long-range interacting particles is of fundamental interest for a wide variety of physical systems, from nanoparticle to atomic and molecular physics. Nevertheless, our understanding of mesoscopic systems is limited by the fact that there is no universal description of their collective properties which are highly particle number-dependent. I will report on our studies of melting of a planar trapped ion crystal which, notably, is also the first trapped ion experiment in Italy. The geometry of our trap electrodes makes it possible to continuously change the structure of the crystal from a 1D string to a 2D crystal by changing a DC voltage. When the confining potential is made isotropic, the ions undergo a structural transition from a Coulomb crystal to a rotor, in which the particles are no longer localized in space, but are rather delocalized along circular trajectories. Interestingly, for sufficiently large numbers of ions two or more concentric rings are populated, and the rings can exhibit independent dynamics, controllable by pinned impurities.

Towards hole-spin qubits in planar Si pMOSFETs

Filippo Troiani

Centro S3, CNR-Istituto di Nanoscienze, I-41125 Modena, Italy

Hole spins in Si and Ge quantum dots represent a viable route towards the implementation of electrically controlled qubits. In particular, the qubit implementation based on pMOSFETs offers great potentialities in terms of integration with the control electronics and long-term scalability. Moreover, the future down scaling of these devices will possibly improve the performance of both the classical (control) and quantum components of such monolithically integrated circuits. Here we develop and use a multi-scale approach to simulate hole-spin qubits in a down scaled version of a commercial Si pMOSFET [1]. Our simulations show the formation of well-defined hole quantum dots within the Si channel, the possibility of a general electrical control (with Rabi frequencies of the order of 100 MHz), and the presence of sweet spots (where the qubit sensitivity to electrical noise is possibly suppressed). In all these respects, a crucial role is played by the channel geometry, and specifically by its aspect ratio, for which we identify an optimal range of parameter values. [1] L. Bellentani et al., Phys. Rev. Applied 16, 054034 (2021).

Restoration of the non-Hermitian bulk-boundary correspondence via topological amplification

Matteo Brunelli

University of Basel

Non-Hermitian lattices display a unique kind of energy gap and extreme sensitivity to boundary conditions [1]. Within the current description of NH topological phases, any NH Hamiltonian featuring a point gap in the spectrum is regarded as topologically nontrivial. This, in turn, leads to the breakdown of the bulk-boundary correspondence for NH systems, since under open boundary conditions the separation between edges and bulk is lost—the so-called NH skin effect. In this presentation, I show how to restore the bulk-boundary correspondence for the most paradigmatic class of NH lattice models, namely single-band models with no symmetry.

Topological matter from topological light: Hermitian and non-Hermitian scenarios.

Federico Roccati

University of Luxembourg

Topology and quantum optics are two fields whose interplay can give rise to new physics [1]. Fractional decay in a topological continuum and topological dependent atom-atom interactions mediated by topological light are just few examples of a pletora of unconventional phenomena [2]. In parallel to this, non-Hermitian Hamiltonians, often used to describe nanophotonic platforms [3], have been shown to possess topological properties with no Hermitian counterpart [4]. In this talk I will present the relation between the Hermitian (or non-Hermitian) topology of a photonic lattice and the topological nature of the atom-atom Hamiltonian mediated by such lattice [5]. [1] https://www.benasque.org/2021tmqo/, [2] M. Bello, G. Platero, J. I. Cirac, A. González-Tudela. Sci. Adv. 2019, [3] F. Roccati, S. Lorenzo, G. Calajò, G. M. Palma, A. Carollo, F. Ciccarello. Optica 2022,[4] E. J. Bergholtz, J. C. Budich, F. K. Kunst. Rev. Mod. Phys. 2021,[5] F. Roccati et al., in preparation

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Topologically frustrated systems

Salvatore Marco Giampaolo

Ruđer Bos⍰ković Institute, Zagreb, Croatia

I summarize our main findings on topologically frustrated one-dimensional spin models. Topological frustration arises when we consider periodic boundary conditions in a system with short-range antiferromagnetic interactions consisting of an odd number of spins. Despite its simplicity, which paves the way for the possibility of using fully analytical methods, this kind of frustration gives rise to an entirely new phenomenology. Among the different results obtained, I will focus on three of them, that provide a clear picture of the richness of such models. The three properties that I will discuss are the Loschmidt-echo and its peculiar chaotic properties, the extra contribution to Magic inherent in the geometry of topologically frustrated states, and the peculiar spatial dependence of magnetization in such systems.

Coherence and Majorana qubits in Josephson circuits featuring pi-periodic elements

Luca Chirolli

Istituto Nanoscienze Pisa

A Josephson junction based on a π-periodic energy-phase relation has emerged as a novel element that can provide augmented freedom in engineering of superconducting circuits. In ordinary Josephson circuits, the dependence of the energy spectrum on the offset charges on different islands is 2e periodic through the Aharonov-Casher effect and resembles a crystal band structure. The employment of cos(2φ) Josephson junctions enables tailoring of the Josephson potential and designing spectra featuring multiplets of flat bands, providing us with noise-insensitive energy levels. Furthermore, the suppression of individual Cooper pair tunneling in π-periodic Josephson junctions results in parity-protected superconducting qubits. We propose to couple such a qubit to a Majorana qubit based on Majorana zero energy modes. By properly driving the system we can obtain a SWAP gate between the superconducting qubit and the Majorana qubit and employ the latter as a topologically protected memory. The system enables fast gates and long-lived quantum memories, a key requirement for high fidelity quantum information processing in a noisy quantum computing environment.

Imaging stars with quantum error correction

Zixin Huang

Macquarie University

The development of high-resolution, large-baseline optical interferometers would revolutionize astronomical imaging. However, classical techniques are hindered by physical limitations including loss, noise, and the fact that the received light is generally quantum in nature. We show how to overcome these issues using quantum communication techniques. We present a general framework for using quantum error correction codes for protecting and imaging starlight received at distant telescope sites. In our scheme, the quantum state of light is coherently captured into a non-radiative atomic state via Stimulated Raman Adiabatic Passage, which is then imprinted into a quantum error correction code. The code protects the signal during subsequent potentially noisy operations necessary to extract the image parameters. We show that even a small quantum error correction code can offer significant protection against noise. For large codes, we find noise thresholds below which the information can be preserved. Our scheme represents an application for near-term quantum devices that can increase imaging resolution beyond what is feasible using classical techniques. arXiv:2204.06044

Distributed quantum sensing

Marco Malitesta

QSTAR, INO-CNR & University of Naples ”Federico II”

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

Remote quantum sensing: quantum illumination and quantum doppler radar/lidar

Roberto Di Candia

Aalto University

Remote quantum sensing has recently gained interest from the scientific community due to its potential capability in achieving a quantum advantage in radar-like scenarios. In the quest of creating a concept working with state-of-the-art technology, we discuss the feasibility of two such protocols in the optical and microwave regime. We give the reasons that the quantum illumination protocol fails in reaching a quantum advantage from a practical point of view. At the same time, we recognize that other protocols, such as velocity estimation with a quantum doppler radar/lidar, can achieve a substantial quantum advantage with respect to a coherent state used as a classical benchmark. We show that our quantum doppler radar/lidar is robust to the use of amplifiers, reaching large SNR values without spreading the signal on an unfeasibly large bandwidth, as needed in the quantum illumination protocol. Finally, we discuss the role of losses and not-optimal measurements setup in the performance of both protocols.

Quantum noise limits and squeezed-light enhancement of optical magnetometry

Vito Giovanni Lucivero

ICFO-The Institute of photonic sciences

Optically-pumped magnetometers (OPMs), in which an atomic ensemble is optically pumped and the spin precession is optically detected, are among the most sensitive devices to measure low-frequency magnetic fields. As in other atomic quantum sensors, the achievable sensitivity of OPMs is limited by three contributions of quantum noise: photon shot noise, atomic projection noise, and quantum backaction, the latter due to the effective field produced by ac-Stark shift. Here we first describe a pulsed scalar magnetic gradiometer [1] that achieves state-of-the-art differential sensitivity of 14 fT/√Hz over a broad dynamic range, including Earth's field magnitude. We discuss the theoretical Cramer-Rao lower bound, in the presence of non-white spin noise and atomic diffusion, and we compare it against the experimental standard deviation of the estimated frequency difference. Secondly, we describe the quantum enhancement of an OPM by polarization squeezing of the probe beam [2]. We report an improvement in high-frequency sensitivity and measurement bandwidth with no loss of sensitivity in any region of the frequency spectrum, a direct demonstration of the evasion of measurement backaction.

[1] V. G. Lucivero et al. "Femtotesla nearly-quantum-noise-limited pulsed gradiometer at Earth-scale fields", Phys. Rev. Applied 18, L021001 (2022) [2] C. Troullinou et al. "Squeezed-light enhancement and backaction evasion in a high-sensitivity optically pumped magnetometer", Phys. Rev. Lett. 127, 193601 (2021)

Thursday 15

Quantum optics using atomic arrays

Darrick Chang

ICFO

Our conventional theories of the quantum interactions between light and atomic media tend to treat the atoms as a smooth macroscopic medium, ignoring the possibility that the dynamics might depend strongly on microscopic configurations and disorder. Within classical optics, however, it is well-known that the details of spatial configurations of scatterers — and the associated multiple scattering and interference of light — can give rise to important new phenomena and control, ranging from Anderson localization to photonic crystals and phased array antennas. We discuss our recent efforts to advance a theory of quantum multiple scattering of light. We also show how multiple scattering can be harnessed as a powerful resource, including the possibility to realize polynomially or exponentially better error scalings for applications such as quantum memories of light and photon-photon gates, as a function of system resources.

Exploiting the photonic nonlinearity of free-space subwavelength arrays of atoms

Cosimo Rusconi

Max Planck Institute for Quantum Optics

In this talk I will discuss subwavelength atomic arrays - order arrays of atoms where the interatomic distance is smaller than wavelength of the relevant atomic transition - as a novel platform for light matter interaction at the quantum level. Ordered ensembles of atoms exhibit distinctive features from their disordered counterpart. In particular, while collective modes in disordered ensembles efficiently couple to light but show a linear optical response, collective subradiant excitations of subwavelength arrays are endowed with an intrinsic nonlinearity. Such nonlinearity has both a coherent and a dissipative component: two excitations propagating in the array scatter off each other leading to formation of correlations and to emission into free-space modes. We show how to take advantage of such nonlinearity to coherently prepare a single excitation in a subradiant (dark) collective state of a one-dimensional array as well as to perform an entangling operation on dark states of parallel arrays. We discuss the main source of errors represented by disorder introduced by atomic center-of-mass fluctuations, and we propose a practical way to mitigate its effects.

Finite-size and multimerization effects in an array of emitters coupled to a waveguide

Francesco Pepe

Università di Bari - INFN Bari

We present the features of a system of two-level quantum emitters, coupled to a single transverse mode of a closed waveguide, in which photon wavenumbers and frequencies are discretized, and characterize the states in which one excitation is steadily shared between the field and the emitters. We quantify finite-size effects in the field-emitter interactions and identify a family of dressed bound states that represent the forerunners of bound states in the continuum. For these states, we discuss possible applications in the field of quantum information. We conclude by showing that, in the limit of infinite-length waveguide, we find the occurrence of multimerized bound states for multi-emitter arrays.

Quantum optics of giant atoms in engineered photonics baths

Luca Leonforte

Università degli Studi di Palermo

Giant atoms are an emerging paradigm of quantum optics, which can exhibit unprecedented effects thanks to their multiple, non-local coupling to a photonic waveguide/ lattice. Here, their behavior is for the first time settled within a general theory based on the Green's function. This encompasses within a comprehensive framework effects such as decoherence-free Hamiltonians in a waveguide and emergence of atom-photon bound states (BSs) in structured lattices. As a relevant application, we predict that in the photonic SSH model, in contrast to normal atoms (local coupling), occurrence of zero-mode bound states is generally not guaranteed. This is shown to depend on the positions and phases of the coupling points inside the photonic lattice unit cell. [1] L. Leonforte, D. Valenti, B. Spagnolo, A. Carollo, F. Ciccarello, Nanophotonics 10, 4251 (2021), [2] L Leonforte, D. Valenti, B. Spagnolo, A. Carollo, F. Ciccarello, to appear on arXiv (2022)

Fingerprint and universal Markovian closure of structured bosonic environments.

Dario Tamascelli

Università degli Studi di Milano

We exploit the properties of chain mapping transformations of bosonic environments to identify a finite collection of modes able to capture the characteristic features, or fingerprint, of the environment. Moreover we show that the countable infinity of modes composing the (featureless) residual bath modes can be replaced by a universal Markovian closure, namely a small collection of damped modes undergoing a Lindblad-type dynamics whose parametrization is independent of the spectral density under consideration. We discuss the computational speed-up provided by such universal closure and present some relevant applications.

Statistical time-domain characterization of non-periodic optical clocks

Dario Cilluffo

Institut für Theoretische Physik und IQST, Albert-Einstein-Allee 11, Universität Ulm, D-89081 Ulm, Germany

Measuring time means counting the occurrence of periodic phenomena. Over the past centuries a major effort was put to make stable and precise oscillators to be used as clock regulators. In this work we consider a different class of clocks based on stochastic clicking processes. We provide a rigorous statistical framework to study the performances of such devices and apply our results to a single coherently driven two-level atom under photodetection as an extreme example of non-periodic clock. Quantum Jump MonteCarlo simulations and photon counting waiting time distribution will provide independent checks on the main results.

Gibbs state preparation on a quantum computer

Jacopo Settino

Università della Calabria

An important task in quantum state preparation is the production of finite-temperate thermal states of a given Hamiltonian, on a quantum computer. The reason being that Gibbs states (also known as thermal states) can be used for quantum simulation, quantum machine learning, quantum optimization , and studying open quantum systems. In particular, combinatorial optimization problems , semidefinite programming , and training quantum Boltzmann machines, can be tackled by sampling from well-prepared Gibbs states.

Digital qubit readout with a flux-switchable superconducting circuit

Luigi Di Palma

Università degli Studi di Napoli Federico II

Digital qubit readout with a flux-switchable superconducting circuit

L. Di Palma 1, A. Miano 2, P. Mastrovito 1, M. Arzeo 3, H. G. Ahmad 1, D. Massarotti 4,5, D. Montemurro 1, G. P. Pepe1, F. Tafuri1,6 and O. A. Mukhanov 3

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

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

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

[1] J. M. C. J. M. Gambetta and M. Steffen, "Superconducting quantum bits", NPJ Quantum Inf 2, 1 (2017). [2] H. G. Ahmad et al., "Hybrid ferromagnetic transmon qubit: Circuit design, feasibility, and detection protocols for magnetic fluctuations" Phys. Rev. B, 2022 [3] O. Mukhanov et al., "Scalable Quantum Computing Infrastructure Based on Superconducting Electronics" IEEE International Electron Devices Meeting

(IEDM), 2019, [4] R. McDermott et al., “Quantum–classical interface based on single flux quantum digital logic”, Quantum Science and technology 3 (2018). [5] Di Palma et al., “Discriminating the phase of a weak coherent tone with a flux-switchable superconducting circuit”, in prep.

Genuine multipartite entanglement as an identifier of exotic quantum phases

Sudipto Singha Roy

1. INO-CNR BEC Center and Department of Physics, University of Trento, Via Sommarive 14, I-38123 Trento, Italy, 2. INFN-TIFPA, Trento Institute for Fundamental Physics and Applications, Trento, Italy

Quantum entanglement is a fascinating concept of quantum theory and is considered to be one of the key features in recent developments in quantum technologies. Apart from the fundamental importance, characterization of quantum entanglement in a, quantum many-body system often helps us assess the suitability of the considered model as a resource for quantum information processing tasks. However, quantification of quantum entanglement in complex quantum many-body systems is a challenging task. In particular, characterization of genuine multipartite entanglement requires full knowledge of entanglement distribution in all possible bipartitions of the system. In this work, we consider one such quantum many-body model, namely, the one-dimensional Bose-Hubbard model comprising both nearest-neighbor (t_N) and next-nearest neighbor hoppings (T_{NN}) and examine how the interplay of onsite interaction (U) and hopping results in different quantum phases in the model. The model is considered to be a prototype of the physical system consisting of ultracold bosonic atoms in optical lattices. We then analyze the, behavior of genuine multipartite entanglement in the system and make a comparative study with bipartite entanglement and other relevant order parameters. We observe genuine multipartite entanglement has a very rich behavior throughout the considered parameter regime and helps us in identifying most of the phase boundaries. ,Reference:, In preparation: Leon Carl, Sudipto Singha Roy, and Philipp Hauke, ”Genuine multipartite entanglement as an identifier of exotic quantum phases”. ,Funding: We acknowledge support by the ERC Starting Grant StrEnQTh (project ID 804305), Provincia Autonoma di Trento, and by Q@TN, the joint lab between University of Trento, FBK-Fondazione Bruno Kessler, INFN-National Institute for Nuclear Physics and CNR-National Research Council.

Unveiling Quantum Entanglement in Many-Body Systems from Partial Information

Flavio Baccari

Max Planck Institute of Quantum Optics

Quantum entanglement is commonly assumed to be a central resource for quantum computing and quantum simulation. Nonetheless, the capability to detect it in many-body systems is severely limited by the absence of sufficiently scalable and flexible certification tools. This issue is particularly critical in situations where the structure of entanglement is a priori unknown, and where one cannot rely on existing entanglement witnesses. I will present a scheme in which the knowledge of the mean value of arbitrary observables can be used to probe multipartite entanglement in a scalable, certified, and systematic manner. Specifically, we rely on positive semidefinite conditions, independent of partial-transposition-based criteria, necessarily obeyed if the data can be reproduced by a separable state. The violation of any of these conditions yields a specific entanglement witness, tailored to the data of interest, revealing the salient features of the data which are impossible to reproduce without entanglement. I will show how this approach allows to probe theoretical many-body states of several hundreds of qubits relevant to existing experiments: a single-particle quench in a one-dimensional XX chain; a many-body quench in a two-dimensional XX model with 1/r3 interactions; and thermal equilibrium states of Heisenberg and transverse-field Ising chains. In all cases, these investigations have led us to discover new entanglement witnesses, some of which could be characterized analytically, generalizing existing results in the literature. The presentation will be based on the results in [PRX Quantum 3 (1), 010342].

Quantum and classical complexity methods in quantum communication network optimization

Valentina Brosco

Institute for Complex Systems and Physics Department University of Rome La Sapienza, Rome, Italy

Complex quantum communication infrastructures where a large number of users share entanglement and information offer a natural test-bed for quantum network theory. The rate and security of quantum communications between users placed at arbitrary points of a quantum communication network indeed depends on the structure of the network, on its extension and on the nature of the communication channels. In this talk we present a theoretical framework to understand how the properties of the underlying network influence the performances of quantum communications and we illustrate a potential strategy of network optimization. Our approach intertwines classical network approaches, complexity theory and quantum information. Specifically, by suitably defining a weight associated to each network's link, we construct optimal quantum communication channels through the network by balancing the quantum security and the quantum communication rate. The optimal network is then constructed as the network of the optimal channels and its performances are evaluated by studying the scaling of average properties as functions of the number of node and network's extension.

Underwater Quantum Communication with mesoscopic twin-beam states of light

Alessia Allevi

Department of Science and High Technology, University of Insubria, Como (Italy)

Quantum resources can improve the security of information transmission between two parties. So far, Quantum Communication protocols have been implemented at the single-photon level by means of entangled states. In contrast to this domain, in the mesoscopic one the optical pulses contain sizeable numbers of photons, thus resulting more robust against any kind of external degradation. In a recent work of ours, we have demonstrated that the transmission of one arm of a twin-beam (TWB) state through a lossy and noisy channel does not prevent the observation of nonclassical correlations between the two parties. Based on these successful results, here we consider a more realistic scenario, in which a portion of TWB is sent through water-filled tubes, while the other one undergoes free-space propagation. We investigate the role played by the length of the tubes, the number of optical elements, and the divergence of the beams through the different media. We demonstrate that, by properly acting on the light beams, we can still observe nonclassical correlations at moderate distances. The experimental implementations involve two classes of commercial photon-number-resolving detectors.

Photonic quantum implementations of causal structures

Emanuele Polino

Sapienza università di Roma

General physical scenarios can be studied under the light shed by the causal framework where cause-effect relationships between variables are encoded in constraints on the observable correlations. This framework is a powerful tool fruitfully employed in different scientific disciplines, from medicine to physics. However, when quantum systems are employed and connected according to a causal structure, the classical causal constraints imposed by the considered scenario can be violated, giving rise to the so-called quantum nonlocality. This is the strongest evidence of the departure between classical and quantum physics. We present several photonic quantum implementations of different causal structures. We start from the standard bipartite Bell scenario where violations of causal inequalities are optimized without any assumption on the system and the measurement devices. Then, we present the experimental study of new forms of quantum causal influences in a relaxed scenario by means of interventions, a fundamental tool in the causality framework. Finally, we describe the nonlocal correlations obtained in complex networks with independent sources where new forms of nonlocality arise.

Structured light: a tool for quantum information and ultra-sensitive measurements

Vincenzo D'Ambrosio

Università degli studi di Napoli ”Federico II”

Vectorial modes of light, a type of structured light where the polarization varies across the beam profile, are a useful tool in quantum information since they provide large alphabets, rich entanglement structures and enhanced resilience to noise. In quantum communication, for instance, vectorial modes enable rotational invariant protocols, therefore overcoming the requirement of a shared reference frame between users. Moreover, structured light can be a resource for enhanced sensing purposes as for instance in the “photonic gears” technique. This quantum inspired scheme enables a boost of sensitivity in mechanical displacements measurement thanks to a bidirectional mapping between the polarization state and a properly tailored vectorial mode of a paraxial light beam. By exploiting this technique, we recently measured, in ordinary ambient conditions, the relative shift between two objects with a resolution of 400 pm. Thanks to a single-optical-path scheme, photonic gears are intrinsically stable and could be implemented as a compact sensor, using cost effective integrated optics.

High-speed integrated source-device-independent quantum random number generator for space applications

Marco Avesani

Università di Padova

Random numbers are a fundamental building block for many different applications. Classical generators, based on algorithms or classical systems, are predictable since they are based on deterministic processes, while Quantum random number generators (QRNG) exploit the intrinsic randomness of quantum mechanics to generate genuine randomness. However, practical QRNG are usually trusting their devices and their security can be compromised in case of imperfections or malicious external actions.Moreover, typical QRNG are complex and bulky devices, which cannot be fitted in mobile devices or are not suitable for space payloads.In this work we address the problems of security, speed and compactness with a single integrated device.In particular, we describe a source-device-independent protocol based on generic POVM.This allows us to certify the randomness without any assumption on the source.We implement it on a custom-designed silicon photonics chip of 5.6 x 2.5 mm.The silicon PIC integrates a full shot-noise-limited heterodyne detector, which allows to implement the QRNG protocol.Thanks to the performances of the devices we were able to certify 10.075 bits of entropy for measurement, for a record-breaking generation rate of 20.150 Gbps, including finite size effects.

Spin-orbit photonics for optical simulations of quantum walks

Filippo Cardano

Università degli Studi di Napoli Federico II

Engineering synthetic quantum evolutions in artificial systems has proved a powerful resource in various applications. An interesting example is provided by quantum walks (QWs), introduced back in the 90's to describe a peculiar discrete-time motion of quantum particles on a lattice. Variants of QWs have been widely used for quantum simulation/computation, to model transport phenomena and to engineer topological phases of matter. Here I will report on our approach to the experimental implementation of QWs based on spin-orbit photonics. After associating walker positions with optical modes carrying quantized transverse momentum, we emulate the unitary QW evolution by coupling these via the diffractive action of periodic spin-orbit metasurfaces. These are liquid-crystal based birefringent optical elements, engineered to have a space-dependent orientation of the optic axis. After illustrating the working principle of this platform, I will present the results of a recent experiments on the implementation of QWs in their long-time limit. Eventually, I will discuss some prospects of these research activities.

Non-Markovian dynamics and measurement induced entanglement criticality

Giuliano Chiriacò

ICTP

In recent years,there has been growing interest towards phase transitions induced by the interaction of a quantum system with its environment.These phase transitions arise from the competition between the unitarity of the system Hamiltonian and the decoherence action of the environment,and can occur at the level of symmetry breaking (such as paramagnetic to ferromagnetic transitions) or at the level of the scaling law of the entanglement of the system.The latter transition has been studied in many settings,in an effort to understand under what conditions the information stored in a quantum system is robust against the action of the environment.However,all of the studies so far have focused on Markovian environments,thus neglecting the memory effects present in realistic baths.In this talk,I will present results on the study of entanglement transitions in comparison to symmetry breaking transitions driven by the same dissipative mechanism.I will also discuss recent studies on how to study the dynamics of non-Markovian systems at the level of quantum trajectories and the effect that the interaction with a non-Markovian environment has on the entanglement transition.

Quantum Generalized Hydrodynamics

Stefano Scopa

SISSA

Understanding the nonequilibrium dynamics of many-body quantum systems is typically a very hard task, due the exponential increase of the Hilbert space dimension with the number of the system's components. Though, in the case of quantum integrable models, a large-scale description of the nonequilibrium dynamics is attained by means of an Euler hydrodynamic theory characterized by the presence of infinitely many conservation laws, dubbed Generalized Hydrodynamics (GHD). However, although GHD is able to predict the outcome of some experimental measures with great accuracy, such hydrodynamic viewpoint on the dynamics leads to a loss of large-scale quantum fluctuations and, consequently, to vanishing equal-time correlations. In order to capture these missing quantum effects, we incorporate an effective field theory description of leading quantum fluctuations over the evolving semi-classical background established by GHD. The resulting theory, called Quantum Generalized Hydrodynamics, gives asymptotically exact results for the dynamics of entanglement and of equal-time correlations which are not accessible by other standard methods at the current state of the art.

Natural gauge defermionization of lattice models

Pietro Silvi

Dipartimento di Fisica e Astronomia, Università di Padova

Numerical and quantum simulations of fermionic lattice models require a qubit encoding. Here I show that, by simply upgrading the fermion parity to a gauge symmetry, we naturally obtain an encoding with non-scaling complexity in the system size.

Friday 16

The p-adic qubits

Vincenzo Parisi

Camerino

Within the framework of quantum mechanics over (a quadratic extension of) the non- Archimedean field of p-adic numbers Qp, we provide a general definition of a quantum state relying on an algebraic approach and on a suitable p-adic model of probability theory. As in the standard complex case, a distinguished class of physical states are related to a notion of a trace for a bounded operator, and one can define a suitable class of trace class operators in the non-Archimedean setting. Eventually, we will particularize our discussion to two-dimensional systems, thus obtaining a p-adic model of the qubit.

Geometric Event-Based Relativistic Quantum Mechanics

Lorenzo Maccone

Universita’ di Pavia

We propose a special relativistic framework for quantum mechanics. It is based on introducing a Hilbert space for events. Events are taken as primitive notions (as customary in relativity), whereas quantum systems (e.g. fields and particles) are emergent in the form of joint probability amplitudes for position and time of events. Textbook relativistic quantum mechanics and quantum field theory can be recovered by dividing the event Hilbert spaces into space and time (a foliation) and then conditioning the event states onto the time part. Our theory satisfies the full Poincare’ symmetry as a ‘geometric’ unitary transformation, and possesses observables for space (location of an event) and time (position in time of an event).

Incompatibility of observables, channels and instruments in information theories

Alessandro Tosini

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Every theory of information, including classical and quantum, can be studied in the framework of operational probabilistic theories—where the notion of test generalizes that of quantum instrument, namely a collection of quantum operations summing to a channel, and simple rules are given for the composition of tests in parallel and in sequence. Here we study the notion of compatibility for tests an operational probabilistic theory. Following the quantum literature, we first introduce the notion of strong compatibility, and then we illustrate its ultimate relaxation, that we deem weak compatibility. It is shown that the two notions coincide in the case of observation tests—which are the counterpart of quantum POVMs—while there exist weakly compatible channels that are not strongly compatible. We prove necessary and sufficient conditions for a theory to exhibit incompatible tests. We show that a theory admits of incompatible tests if and only if some information cannot be extracted without disturbance.

Multi-parameter digital quantum estimation

Giovanni Chesi

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Global quantum estimation strategies allow to extract information on a phase or a set of phases encoded on a quantum state without any prior knowledge about them. As far as we know, unlike the local estimation case, a general model encompassing all of the global strategies does not exist yet. We show that Holevo's estimation theory provides a good candidate, i.e. a model that allows to retrieve both parallel and sequential strategies. Moreover, it yields a framework for multiparameter global estimation, since the model can be straightforwardly generalized for the estimation of more than one phase. In particular, we focus on the case of double-parameter estimation and explore the advantages of multiparameter estimation with respect to multiple single-parameter estimations in terms of mutual information.

Quantized-gravity and “gravitzed”-quantum, testing spin-statistics and quantum collapse in the cosmic silence

Kristian Piscicchia

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The VIP experiment, at the Laboratori Nazionali del Gran Sasso of INFN, is exploring Quantum Mechanics (QM) foundations, investigating models of dynamical wave function collapse and performing high sensitivity tests of the Pauli Exclusion Principle (PEP) for electrons.Motivated by the awareness that space-time fluctuations would induce decoherence in quantum systems, the idea to ”gravitize” QM aroused growing interest in the last decades.We will report the strong experimental constrains on the gravity-related collapse models developed by Diosi and Penrose, obtained by searching for an unavoidable effect of the collapse mechanism, namely a faint radiation emission by charged particles.The development of non-Markovian and dissipative versions of the models, and their impact on the spontaneous radiation will be outlined.Recently emerged that PEP violation may be induced by space-time non-commutativity,a class of universality for several models of Quantum Gravity.X-ray surveys, searching for atomic transitions prohibited by the PEP, represent stunning candidates to test Quantum Gravity, at unexpectedly high energy scales.The results of exploratory studies will be presented.

Certification and quantification of non-classicality through causal inference

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Quantum technologies have promised to bring advances in several fields. However, to correctly exploit them, we need to certify the quantum operation of a given device. Device-independent protocols tackle this problem, requiring minimal assumptions and relying on quantum causal inequality violations (e.g. Bell tests). Unfortunately, on one hand, such testable constraints are not always available, and, on the other, for practical purposes, we also need to quantify non-classicality, e.g. to evaluate the randomness that is extractable from quantum random numbers generators. Here, we present two methods to address these issues and their implementation on a photonic platform. First, we show how the amount of causal influence among variables (measured through direct interventions on the apparatus) allows to distinguish classical and non-classical features within a given process, even if no standard quantum inequality violations are possible. Then, we design an optimizer over the set of behaviors allowed by quantum mechanics, based on an artificial neural network. This tool extends currently used methods, being able to deal with non-linear objective functions and optimization constraints.

Collapse dynamics are diffusive

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Testing the limits of validity of the superposition principle is of crucial importance in the foundations of quantum mechanics and the development of quantum technologies. A way to quantify possible breakdowns of the superposition principle is given by collapse models. These models modify quantum mechanics by introducing a nonlinear interaction with a classical noise that induces collapse in space. The natural way of testing collapse models is through interferometric experiments of systems with large masses, which is challenging. For this reason, non-interferometric experiments were considered. These exploit the fact that the noise responsible for the collapse induces a diffusion in momentum, in principle detectable even in localized systems by performing high precision position measurements. We first give a summary of the bounds on collapse models from non-interferometric experiments. Then we show how the diffusion in momentum is not just a property of collapse models but it is a universal feature of any dynamics inducing collapse in space. This implies that non-interferometric experiments test the quantum superposition principle in a stronger sense than one might suppose.

Optimal interferometry and Bell-nonclassicality with a single photon state

Antonio Mandarino

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Bell nonclassicality of a single photon superposition in two modes, often referred to as ’nonlocality of a single photon’, is one of the most striking nonclassical phenomena discussed in the context of foundations of quantum physics. We reconsider the all-optical weak homodyne-measurement based experimental schemes aimed at revealing Bell nonclassicality (‘nonlocality’) of a single photon. We focus on the schemes put forward by Tan, Walls and Collett (TWC, 1991) and Hardy (1994). There are consequential differences between TWC and Hardy setups: (i) The initial state of Hardy is a superposition of a single photon excitation with vacuum in one of the input modes of a 50-50 beamsplitter. In the TWC case, there is no vacuum component. (ii) In the final measurements of Hardy’s proposal the local settings are specified by the presence or absence of a local oscillator field (on/off). Eventually, we show that the TWC experiment can be described by a local hidden variable model, hence the claimed nonclassicality is apparent. The nonclassicality proof proposed by Hardy remains impeccable. We investigate which feature of Hardy’s approach is crucial to disclose the nonclassicality. Nowadays, photon-number resolving weak-field homodyne measurements allow the realization of emblematic gedankenexperiments revealing correlations of optical fields. Here we show how to robustly violate local realism within the weak-field homodyne measurement scheme for any superposition of one photon with vacuum. Our modification of the previously proposed setups involves tunable beamsplitters at the measurement stations, and the local oscillator fields significantly varying between the settings, optimally being on or off. We find a condition for optimal measurement settings for the maximal violation of the Clauser-Horne inequality with weak-field homodyne

detection, which states that the reflectivity of the local beam-splitter must be equal to the strength of the local oscillator field. We show that this condition holds not only for the vacuum-one-photon qubit input state but also for the superposition of a photon pair with vacuum, which suggests its generality as a property of weak-field homodyne detection with photon-number resolution. Our findings suggest a possible path to employ such scenarios in device-independent quantum protocols. T. Das, M. Karczewski, A. Mandarino, M. Markiewicz, B. Woloncewicz and M. Ż1ukowski, Wave-particle complementarity: detecting violation of local realism with photon-number resolving weak-field homodyne measurements, New J. Phys. 24 033017 (2022), T. Das, M. Karczewski, A. Mandarino, M. Markiewicz, B. Woloncewicz and M. Ż1ukowski, Remarks about Bell-nonclassicality of a single photon, Phys. Lett. A 435 128031 (2022), T. Das, M. Karczewski, A. Mandarino, M. Markiewicz, B. Woloncewicz and M. Ż1ukowski, Can single photon excitation of two spatially separated modes lead to a violation of Bell inequality via weak-field homodyne measurements? New J. Phys. 23 073042 (2021), T. Das, M. Karczewski, A. Mandarino, M. Markiewicz, and M. Ż1ukowski, Optimal interferometry for Bell-nonclassicality by a vacuum-one-photon qubit, arXiv:2109.10170

Gate fidelities in arrays of noisy flip-flop qubits

Marco De Michielis

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A Flip-Flop Qubit (FFQ) is defined on a mixture of nuclear and bonded electron spin states of a 31P atom in a spin-free 28Si substrate [1]. High-fidelity one-qubit operations are implemented by exploiting electric dipole spin resonance [2] and two-qubit ones could be created by using electric dipole interaction. The long-range dipole-dipole interaction between FFQs can relax the stringent fabrication requirements for spin-based qubits, particularly on the lateral positioning of gates/donors thus easing the fabrication specs from some tens of nm to few hundreds of nm range. Parallel gating is a central ingredient for quantum computation, but gate parallelism is limited by unwanted inter-qubit interactions. Those interactions reduce gate fidelities thus parallel one-qubit and two-qubit gates performances are simulated in FFQ-arrays embedded in a realistic noisy environment [3]. Such results are presented, also providing additional insights for system scaling-up towards a silicon-based quantum processor. [1] G. Tosi et al., Nat Commun. 6 8(1):450, 2017, [2] R. Savytskyy et al., arXiv:2202.04438v1, [3] D. Rei, E. Ferraro and M. De Michielis, Adv. Quantum Technol., 5: 2100133, 2022

Energy-efficient entanglement generation and readout in a spin-photon interface

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Spin photon interfaces (SPI) are devices where a spin is strongly coupled to a one dimensional atom. They are essential building blocks for quantum technologies. In particular, they can be used to generate cluster states of photons needed to implement measurement based quantum computing. So far, SPIs have been probed by using coherent pulses or single photons as input light. Here we study the potential of a purely quantum resource, i.e. quantum superpositions of zero and single photon states, which have recently been shown to be within experimental reach. Based on an exact resolution of the light-matter dynamical equations, we show that such quantum superpositions are more energy efficient than coherent pulses, generating more spin-light entanglement with the same input energy. We show that this energetic quantum advantage is transferred at the classical level, quantum superpositions giving rise to more precise spin readouts than coherent pulses of the same energy. Estimations with realistic numbers taken from semiconducting devices (quantum dots) show that these effects can be observed with state-of-the-art SPIs.

Coherent Quantum Control of an Insulator-to-Metal Mott Transition

Claudio Giannetti

Università Cattolica del Sacro Cuore

Managing light-matter interaction on timescales faster than the loss of electronic coherence is key for achieving the full quantum control of final products in solid-solid transformations. In this work, we demonstrate coherent electronic control of the photoinduced insulator-to-metal transition in the prototypical Mott insulator V2O3. Selective excitation of a specific interband transition with two phase-locked light pulses manipulates the orbital occupation of the correlated bands in a way that depends on the coherent evolution of the photoinduced superposition of states. Comparison between experimental results and numerical solutions of the optical Bloch equations provides an electronic coherence time on the order of 5 fs. Temperature dependent experiments suggest that the electronic coherence time is enhanced in the vicinity of the insulator-to-metal transition critical temperature, thus highlighting the role of fluctuations in determining the electronic coherence. These results open new routes to selectively switch functionalities of quantum materials and store quantum information in solid-solid transformations.

Cavity protection for intersubband polaritons in strong magnetic field

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We analyse the effect of a perpendicular homogeneous magnetic field on an optical intersubband transitions coupled to a cavity. It turns out that the magnetic field changes the shape of the intersubband optical density, strongly affecting the resulting polaritonic emission linewidth. In the strong coupling regime and when the magnetic field reaches the Hall regime for the confined electrons the polaritonic linewidth can be reduced by several order of magnidutes. This effect may pave the way for the full implementation of an infrared laser with intersubband transitions and opens to more fundamental studies regarding the interplay between quantum Hall physics and cavity light-matter interactions.

Here we summarize recent theoretical studies on the dynamical Casimir effects (DCEs) in optomechanical systems.

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We studied the DCE using a fully quantum-mechanical description and without linearizing the dynamics. We have shown that the resonant generation of photons from the vacuum is determined by a ladder of mirror-field vacuum Rabi splitting. We find that vacuum emission can originate from the free evolution of an initial pure mechanical excited state, in analogy with the spontaneous emission from excited atoms. We also show that the DCE can also be driven by incoherent mechanical pumping. We then applied this framework to study the interaction of two mechanical oscillators mediated by the exchange of virtual photon pairs. Specifically, we demonstrated that mechanical quantum excitations can be coherently transferred among spatially separated mechanical oscillators, through a dissipationless quantum bus, due to the exchange of virtual photon pairs. This system can also operate as a mechanical parametric downconverter.

Cavity optomechanics with levitated nanosphere: Quantum signatures in hybrid light-mechanical states and advances in two-dimensional cooling

Andrea Ranfagni

LENS, Unifi

Optically levitated nanospheres in high-finesse cavities offer a unique platform for the study of macroscopic quantum mechanics in all three spatial dimensions and the achievement of quantum coherent control of their motion, with applications ranging from quantum foundations and information processing to directional quantum sensing. We report on cavity-optomechanical experiments in which the motion of a nanosphere levitated in high vacuum is strongly coupled to a single cavity mode by coherent scattering of the tweezer photons. The two-dimensional motion on the plane orthogonal to the tweezer axis and the optical cavity mode define an optomechanical system with three degrees of freedom. In the quantum-coherent strong-coupling regime, i.e. when the optomechanical coupling exceeds the total decoherence rate, we observe the formation of hybrid light-mechanical states with a peculiar vectorial nature. Such states give rise to polaritonic dispersion relations characterized by two avoided crossings at different frequencies, unambiguous signature of the strong three-body interactions. For appropriate frequencies and polarization of the tweezer beam, the motion of the particle is strongly cooled in the plane orthogonal to the tweezer axis. We demonstrate a regime in which the fully 2D dynamics of the nanoparticle exhibits strong non-classical properties, and we introduce an indicator that quantifies how close the system is to a minimum uncertainty state. These findings pave the way to novel protocols for the transfer of quantum information between photonic and phononic components and represent an important step towards the demonstration of optomechanical entangled states at room temperature.

Two-membrane cavity optomechanics and Quantum Technologies

Paolo Piergentili

Università di Camerino; INFN Sezione di Perugia;

The linear and non-linear dynamics of an optomechanical system made of a two-membrane ethalon in a high-finesse Fabry-Pérot cavity is presented. This two-membrane setup has the capacity to enhance the single-photon optomechanical coupling, and in the linearized interaction regime to cool simultaneously two mechanical oscillators. The experimental characterization of the optical, mechanical, and especially optomechanical properties of a two-membrane sandwich within an optical cavity will be presented. In the non-linear regime, a truthful detection of membrane displacements much above the usual linear sensing limited by the cavity linewidth is presented. The non-linear dynamics of the mechanical oscillator provides a novel procedure for the determination of the single-photon optomechanical coupling rate, that is the optomechanical interaction strength of the system. In the second part of the talk, we will illustrate the QUANTum Experimental Platform (QUANTEP) INFN project, which aims at the development and implementation of a complete Silicon Photonics Integrated platform for Quantum Computation with linear optics circuits, focusing on its recent achievements.

Quantum-jump trajectories from non-linear rate operators: continuous measurements and non-Markovianity

Andrea Smirne

Università degli Studi di Milano

Stochastic methods with quantum jumps are routinely used to describe open quantum system dynamics, both for the advantage they provide from a computational point of view, and for their insight into fundamental topics, such as the role of measurements in quantum mechanics and the description of non-Markovian memory effects. In this talk, I will present a recently introduced quantum-jump approach [1], named rate operator quantum jumps (ROQJ), whose quantum-jump trajectories are defined in terms of state-dependent, non-linear rate operators. I will first show that ROQJ is associated with a systematic continuous-measurement scheme for a wide and physically relevant class of dynamics, including a set of master equations with negative decay rates, where the standard Monte Carlo wave function (MCWF) approach [2] to quantum jumps does not apply. I will then discuss how ROQJ can be extended to deal with general non-Markovian evolutions, going beyond the current non-Markovian generalizations of MCWF [3] and helping clarify the different types of memory effects within the context of quantum jumps. Finally, I will show that different quantum-jump pictures can be formulated by exploiting the freedom in how to assign the terms of the underlying master equation to the deterministic and jump parts of the trajectories, which can result in a significant simplification of the corresponding stochastic description [4]. [1] A. Smirne, M. Caiaffa, and J. Piilo, Phys. Rev. Lett. 124, 190402 (2020) [2] J. Dalibard, Y. Castin, and K. Mølmer, Phys. Rev. Lett. 68, 580 (1992) [3] J. Piilo, S. Maniscalco, K. Härkönen, and K.A. Suominen, Phys. Rev. Lett. 100,180402 (2008) [4] D. Chruściński, K. Luoma, J. Piilo, A. Smirne, arXiv:2009.11312v2 (2021)

Quantum transfer of interacting qubits

Tony Apollaro

University of Malta

The transfer of quantum information between different locations is key to many quantum information processing tasks. Whereas, the transfer of a single qubit state has been extensively investigated, the transfer of a many-body system configuration has insofar remained elusive. We address the problem of transferring the state of n interacting qubits. Both the exponentially increasing Hilbert space dimension, and the presence of interactions significantly scale-up the complexity of achieving high-fidelity transfer. By employing tools from random matrix theory and using the formalism of quantum dynamical maps, we derive a general expression for the average and the variance of the fidelity of an arbitrary quantum state transfer protocol for n interacting qubits. Finally, by adopting a weak-coupling scheme in a spin chain, we obtain the explicit conditions for high-fidelity transfer of 3 and 4 interacting qubits. https://doi.org/10.48550/arXiv.2205.01579

Exact solution for the quantum and private capacities of bosonic dephasing channels

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The capacities of noisy quantum channels capture the ultimate rates of information transmission across quantum communication lines, and the quantum capacity plays a key role in determining the overhead of fault-tolerant quantum computation platforms. In the case of bosonic systems, central to many applications, no closed formulas for these capacities were known for bosonic dephasing channels, a key class of non-Gaussian channels modelling, e.g., noise affecting superconducting circuits or fiber-optic communication channels. Here we provide the first exact calculation of the quantum, private, two-way assisted quantum, and secret-key agreement capacities of all bosonic dephasing channels. We prove that that they are equal to the relative entropy of the distribution underlying the channel to the uniform distribution. Our result solves a problem that has been open for over a decade, having been posed originally by [Jiang & Chen, Quantum and Nonlinear Optics 244, 2010].

Posters

Analysis of spin-squeezing generation in cavity-coupled atomic ensembles with continuous measurements

Andrea Caprotti

INRiM

Spin-squeezed states have metrological relevance, as their intrinsic quantum noise is reduced with respect to the standard quantum limit of spin-coherent states, thus enabling quantum-enhanced atomic clocks. We study the generation of conditional spin squeezing in ensembles of three-level atoms coupled to a near-resonant cavity through continuous Quantum-Non Demolition measurements, starting with fully numerical simulations of the system dynamics. In particular, we consider the dependence of squeezing on various system parameters, including the coupling strength between atoms and cavity, photon decay and pumping rate, and number of atoms. We then analyse a series of approximations that simplify the computation of the trajectories' dynamics. In particular, we have determined the regime in which we can adiabatically remove the cavity, reducing the system to just the atomic degrees of freedom. Having characterised this "bad cavity regime", we are able to determine the optimal super-classical scaling for the squeezing parameter with the total spin. We also discuss the different degrees of squeezing reachable with or without continuous feedback in a continuous measurement protocol.

Non-locality breaks the relations between measures of quantum objectivity

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Università di Palermo

We show the existence of two different aspects of quantum objectivity,"redundancy" and "consensus". Though used as synonyms in this context, we prove that they quantify different features of the emergence of classicality from quantum mechanics.We show that the two main frameworks to measure quantum objectivity, namely spectrum broadcast structure and quantum Darwinism, naturally emerge from these two notions.Furthermore, by analyzing explicit examples of non-local states, we highlight the potentially stark difference between the degrees of redundancy and consensus.In particular, this causes a break in the hierarchical relations between spectrum broadcast structure and quantum Darwinism. Our framework provides a new perspective to interpret known and future results in the context of quantum objectivity, which paves the way for a deeper understanding of the emergence of classicality from the quantum realm.

Probing the quantum Fisher information of passive states

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The quantum Fisher information (QFI) is a measure of the metrological enhancement obtained from quantum correlations. As such, it provides a bridge between quantum metrology and the study of entanglement. Recent works have leveraged this connection to use the QFI as a scalable tool for certifying the presence of multipartite entanglement in quantum many-body systems. However, in general, it remains a challenge to calculate and measure the QFI for both theory and experiment and this limits its usage for entanglement detection. In this talk, we discuss a protocol for extracting the QFI of thermal states and how it can be extended to a much broader class of equilibrium states. More specifically, we study so-called passive states and how virtual temperatures can be used to obtain the QFI with the help of linear response theory. Numerical results showcase our generalized protocol for a specific model. Our work broadens the scope of applicability of the QFI and opens interesting questions regarding possible extensions to different entanglement measures.

Thermodynamics of Reduced State of the Field

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Recent years have seen the flourishing of research devoted to quantum effects on mesoscopic and macroscopic scales. In this context, in Entropy 2019, 21, 705, a formalism aiming at describing macroscopic quantum fields, dubbed Reduced State of the Field (RSF), was envisaged. While, in the original work, a proper notion of entropy for macroscopic fields, together with their dynamical equations, was derived, here, we expand thermodynamic analysis of the RSF, discussing the notion of heat, solving dynamical equations in various regimes of interest, and showing the thermodynamic implications of these solutions.

Quantum Approximation Optimization Algorithm with Quantum Natural Gradient optimizer

Federico Dell'Anna

University of Bologna

Variational Quantum Algorithms (VQA) are powerful tools in the Noisy Intermediate-Scale Quantum (NISQ) era. They are based on the encoding the problem into a cost function depending on some trainable parameters. This is the case of the Quantum Approximation Optimization Algorithm (QAOA), a parameterized ansatz for a quantum state obtained by repeated applications of time evolution operators of two non-commuting Hamiltonians, complemented by a classical optimization procedure.

In this work we consider a Quantum Natural Gradient Descent method to optimize the parameters of the variational wave function prepared by the quantum circuit. This iterative procedure selects the best direction in the parameter space exploiting the quantum information coming from the real part of the Quantum Geometric Tensor (QGT), that is the well-known Fubini-Study metric tensor.

We calculate the latter on states evolved with QAOA ansatz and we show how this routine outperforms other classical methods finding the ground states with fewer steps. This method is applied to some interesting problems related to combinatorial optimization on graphs, simple molecules in quantum chemistry and spin systems.

Measuring Fano quantum coherence in a hot Rubidium atomic vapor under incoherent light. An experimental proposal

Ludovica Donati

European Laboratory for Non-linear Spectroscopy (LENS), University of Florence

Quantum interference is a quantum process whose effects range from changing optical properties of media to enhancing energy transport in light-harvesting complexes or information transfer in quantum networks. It can arise through the application of coherent as well as incoherent processes. Solar cells could see improvements exploiting quantum interference between internal states. Previous works have theoretically demonstrated that a V-type three-level system driven by incoherent light, as a minimal model of a photocell, can experience quantum interference between the transitions from the excited states to a ground state. The phenomenon leads to a mitigation of radiative recombination and thus to an increase in photocurrent that can be extracted from the cell. We propose an experiment realizing a V-type three-level system in the hyperfine structure of hot Rb atoms driven by an incoherent field. The aim is the observation of quantum beats in the fluorescence spectrum that proves the presence of interference and provides us new insight about quantum coherence terms originated by non-coherent excitation. This shall find application in future novel high-efficiency solar cells.

Quantumness and speedup limit of a qubit under transition frequency modulation

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Controlling and maintaining quantum properties of an open quantum system along its evolution is essential for both fundamental and technological aims. We assess the capability of a frequency-modulated qubit embedded in a leaky cavity to exhibit enhancement of its dynamical quantum features. The qubit transition frequency is sinusoidally modulated by an external driving field. We show that a properly optimized quantum witness effectively identifies quantum coherence protection due to frequency modulation while a standard quantum witness fails. We also find an evolution speedup of the qubit through proper manipulation of the modulation parameters of the driving field. Importantly, by introducing a new figure of merit Rg, we discover that the relation between Quantum Speed Limit Time (QSLT) and non-Markovianity depends on the system initial state, which generalizes previous connections between these two dynamical features. The frequency-modulated qubit model thus manifests insightful dynamical properties with potential utilization against decoherence.

Quantum-enhanced imaging for large baseline telescopes

Marta Maria Marchese

University of Sheffield

In this work, we use quantum metrology tools to enhance the imaging resolution of large baseline telescopes. These apparatuses, through interferometric measurements, constitute systems for imaging with large aperture size, resulting in a high resolving power. A major challenge is represented by the dissipation encounter in the transmission, which increases with distances and significantly limits the baseline. The use of a quantum network can overcome some of the limits. The introduction of a higher number of photons to perform more interferometric measurements leads to a better imaging resolution. However, the more photons are used the more dissipation will affect the system. In this work we investigate the interplay between these two factors in an imaging apparatus consisting of two faraway telescopes and a set of entangled photons emitted from central sources. The coherent star photon will be interfered at both telescopes' sites with the entangled photons and then measured. We study the resolution to find the optimal trade-off between the number of entangled photons and the loss effects to extend the baseline beyond the current limits.

Engineering nonlinear boson-boson interactions

Hannah McAleese

Queen’s University Belfast

The use of continuous-variable states has led to significant progress in the fields of quantum communication,quantum computing and quantum state engineering.In particular,encoding a qubit in a superposition of two opposite-phase coherent states has proved useful for quantum teleportation protocols,schemes for universal quantum computing and more.Difficulties arise,however,when it comes to generating entangled coherent states and there is a need to achieve effective interaction Hamiltonians which we can tune to produce nonclassical states of this form.In this work,we present a protocol to engineer nonlinear boson-boson interactions using mediating spin systems.We make use of the result that nonlinear spin-boson interactions can be simulated using linear spin-boson couplings by adding spin rotations and making a suitable transformation[1].Taking two spin-boson systems and allowing the spins to interact,we aim to manipulate the system’s dynamics in order to obtain certain interactions between the bosonic modes.We first focus on producing a cross-Kerr interaction which allows for the creation of entangled coherent states.We find that this is indeed possible by acting on both spins with local operations halfway through the evolution.Our simulations show that the entanglement dynamics of the bosons matches that of our target interaction as long as the spin-spin coupling is sufficiently strong.However,the amount of entanglement we can gain is restricted by the need to work in the Lamb-Dicke regime

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Probing confinement in a Z2 lattice gauge theory on a quantum computer

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Digital quantum simulators provide a table-top platform for addressing salient questions in particle and condensed-matter physics. A particularly rewarding target is given by lattice gauge theories (LGTs). Their constituents, e.g., charged matter and electric gauge field, are governed by local gauge constraints, which are highly challenging to engineer and lead to intriguing yet not fully understood features such as confinement. We simulate confinement dynamics in a Z2 LGT on a superconducting quantum chip. The charge-gauge-field interaction is synthesized by only 6 native two-qubit gates, enabling simulation of up to 25 Trotter steps. We observe how tuning a term coupling only to the electric field confines the charges, manifesting the tight bond that the local gauge constraint generates between both. Moreover, we study a different mechanism, where a modification of the gauge constraint from Z2 to U(1) symmetry freezes the system dynamics. Our work showcases the restriction that the underlying gauge constraint imposes on the dynamics of a LGT, illustrates how gauge constraints can be modified and protected, and paves the way for studying other models with many-body interactions.

Quantum pattern recognition on a quantum channel discrimination experimental sensing

Carmine Napoli

Istituto Nazionale di Ricerca Metrologica

The use of quantum states of light, such as entanglement and squeezing, allows surpassing the limitation of conventional measurement increasing the amount of information extracted from an object under investigation. Here I will present the realization of the experimental sensing protocols in the framework of quantum hypothesis testing and channel discrimination focusing in three different tasks: quantum reading, quantum conformance test and quantum pattern recognition. The quantum hypothesis test is considered in the case of the parameter under investigation as an optical loss determined by the transmission properties of the object. The quantum enhancement in the estimation of the loss parameter distributed in a 2-D object leads to full field sub-shot-noise imaging. Here we have considered the general multi-cell scenario, where the information can be stored in complex patterns, rather in each single cell of a memory or individual pixel of an image. The quantum enhanced readout of the cells is expected to produce a more efficient classification of the patterns. In this experiment we have considered the problem of handwritten digit classification with supervised learning algorithms.

Spatial indistinguishability-based thermal machine enabling quantum entanglement and cooling processes

Farzam Nosrati

University of Palermo & INRS (Quebec)

Indistinguishability has a remarkable role when it comes to the understanding of identical quantum entities. Usually, this genuinely quantum property arises from the unaddressability of particles of the same kind when wavefunctions become spatially overlapping. Indistinguishability of identical quantum subsystems is an exploitable resource for quantum information processing, including teleportation, quantum estimation, entanglement distribution between nodes of a quantum network Here we show how an equilibrium thermal state, composed of two identical qubits, can be manipulated by adjusting the spatial indistinguishability (SI) of the qubits. Via this fundamental mechanism, we develop a SI-based quantum machine which produces robust quantum resources, such as entanglement and coherence, at any temperature. We also demonstrate that this thermal machine can act as a refrigerator by harnessing SI. These results open new pathways for SI-fueled quantum thermodynamic processes.

Entanglement Witnessing for Lattice Gauge Theories

Veronica Panizza

Università degli Studi di Trento

LGTs are at the core of fundamental physics and, recently, substantial theoretical and experimental efforts have gone into simulating LGTs using quantum technologies., In the quantum realm, entanglement plays a crucial role and its detection can be efficiently performed using entanglement witnesses., Yet, entanglement witnessing in LGTs is extremely challenging due to the gauge constraints, that severely limit the operators that can be employed to detect quantum correlations., In this work, we develop the theoretical framework of entanglement witnessing in lattice gauge theories and, by way of illustration, consider bipartite entanglement witnesses in a U(1) LGT (with and without fermionic matter)., Our framework, which avoids the costly measurements required, e.g., by full-tomography,opens the way to future theoretical and experimental studies of entanglement in an important class of many-body models.

Cascaded optomechanical systems

Claudio Pellitteri

Università degli studi di Palermo

In optomechanical systems, light modes interact with massive mechanical oscillators, leading to quantum technologies applications. Depending on the configuration of the system, the optomechanical interaction can be used to drive or cool the mechanical mode near to its ground state , generating squeezing or create entanglement between optical and mechanical modes. A natural extension consists into consider not only one optical and one mechanical, but more modes. One way to do that is to consider a scheme in which the cavity modes are coupled to a unidirectional waveguide, resulting, in this way, placed in a cascaded configuration. This induce a non-reciprocal interaction at first glance between the cavities and indirectly between the mechanical oscillators. In the weak coupling regime the cavity field modes can be adiabatically eliminated resulting in an effective coupling between te two mechanical oscillators. This framework can be used to investigate the dynamics of the system and the possibility of engineering a temperature gradient.

Characterization of Kinetic Degrees of Freedom as a Control for Implementing Time-Dependent Hamiltonians

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In many situations, the kinetic degree of freedom of moving particles is used to implement time-dependent Hamiltonians on internal degrees of freedom. The supposedly implemented (time-dependent, i.e., non-autonomous) dynamics is exact only in the ideal case of an infinitely massive point-like particle. Here, we compute the correction to the dynamics of the internal degrees of freedom due to the small yet finite spatial extension of the moving particle by using a fully quantum description. Looking at the dynamics from a thermodynamics perspective and using a generalized definition of work, we define the efficiency of the energy transfer between kinetic and internal degrees of freedom and use it to quantify the quality of the time-dependent Hamiltonian implementation. The analytical expression of both the correction to the dynamics and the quality of the time-dependent Hamiltonian implementation turn out to be proportional to the square of the spatial extension of the moving particle wavepacket.

Efficient optimisation for the implementation of QAOA on NISQ devices: a Bayesian approach

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Quantum Approximate Optimization Algorithm (QAOA) is a variational hybrid quantum-classical algorithm often considered as a benchmark to test the validity of quantum computers. It relies on the estimation of the energy on a variational state prepared via a quantum circuit, depending on parameters fixed via classical optimisation techniques. While many theoretical results prove the efficiency of this algorithm there are two main problems to deal with: the presence of barren plateaus in the optimization landscape, the need to take into consideration the limits of the NISQ era devices. In this work we propose a Bayesian optimization, a global approach that makes use of a probabilistic model to sample in an efficient way the evaluation of objective function, so that to make predictions about the landscape of the energy we are trying to minimize. We apply it to typical combinatorial problems on graph and show it converges to a minimum with a very a limited number of calls to the circuit with respect to standard global optimization routines. We are also able to prove that it is resistant against noise.

Noisy quantum batteries: optimizing the output ergotropy

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Energy-storing devices which use quantum effects (quantum batteries) are expected to provide an advantage in terms of charging power with respect to their classical counterparts. However another crucial feature that needs to be assessed is the ability of quantum batteries to store energy through a period of time withstanding self-discharging and noise. In this work we characterize the best way to store a total energy E in an array of n (two-level) noisy quantum batteries, with the aim of retrieving the maximum possible energy after the batteries have undergone some environmental noise. We consider several kinds of detrimental noise: energy decay and thermalization (generalized amplitude damping channels), loss of coherence (dephasing channels) and depolarization. We consider both the case in which the allowed number of quantum batteries n is restrained to a fixed fraction of the initial energy E to store in the batteries, and the case in which we are allowed to use an unlimited number of quantum batteries (E/n tending to infinity). For some noise channels (most notably, the generalized amplitude damping channel) storing the energy in a large number of batteries is the best way to prevent the degradation of extractable work due to the use of quantum coherence in energy allocation. However, this is not the case for all the kinds of models: we find some quantum channels for which the ergotropy is best preserved by keeping a finite ratio E/n. This result shows that quantum resources, apart from providing an advantage in the charging power of quantum batteries, can also be helpful in preventing their degradation by environmental noise.

Non-equilibrium quantum thermodynamics of a particle trapped in a controllable time-varying potential

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Many advanced quantum techniques feature non-Gaussian dynamics, and the ability to manipulate the system in that domain is the next-stage in many experiments. One example of meaningful non-Gaussian dynamics is that of a double-well potential. Here we study the dynamics of a levitated nanoparticle undergoing the transition from an harmonic potential to a double-well in a realistic setting, subjecting to both thermalisation and localisation. We characterise the dynamics of the nanoparticle from a thermodynamic point-of-view, investigating the dynamics with the Wehrl entropy production and its rates. Furthermore, we investigate coupling regimes where the the quantum effect and thermal effect are of the same magnitude, and look at suitable squeezing of the initial state that provides the maximum coherence. The effects and the competitions of the unitary and the dissipative parts onto the system are demonstrated. We quantify the requirements to relate our results to a bonafide experiment with the presence of the environment, and discuss the experimental interpretations of our results in the end.

Spin phase-space approach to the study of the effect of coherence on the entropy production rate

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Recent studies have pointed out the intrinsic dependence of figures of merit of thermodynamic relevance – such as work, heat and entropy production – on the amount of quantum coherences that is made available to a system. However, whether coherences hinder or enhance the value taken by such quantifiers of thermodynamic performance is yet to be ascertained. We show that, when considering entropy production generated in a process taking a finite-size bipartite quantum system out of equilibrium through local non-unitary channels, no general hierarchy exists between the entropy production and degree of quantum coherence in the state of the system. A direct correspondence between such quantities can be retrieved when considering specific forms of open-system dynamics applied to suitably chosen initial states. Our results call for a systematic study of the role of genuine quantum features in the non-equilibrium thermodynamics of quantum processes.

Criticality and compatibility in multi-parameter quantum metrology.

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Many-body systems near a quantum phase transition (QPT) exhibit several properties which makes them appealing for metrological purposes. Indeed, it is now well established that the divergences of the quantum Fisher information (QFI) observed near a QPT can be used to increase the precision in the estimation of a parameter. Meanwhile, when it comes to the simultaneous estimation of multiple parameters, the benefits of criticality are much harder to analyze due to possible incompatibilities arising from the Heisenberg uncertainty. This involves the use of quite convoluted quantities, as the Holevo-Cramer-Rao bound, which are generally difficult to evaluate. Here we study the quantumness (R), a scalar index, which provides an asymptotic bound on the compatibility of a metrological scheme. The advantage of this approach is that R can be easily evaluated once the QFI and the mean Uhlmann curvature are known. Moreover, a scaling analysis of R reveals that many-body criticalities generally improve the compatibility in a multi-parameter framework. We also evaluate R in different representative systems, such as Ising chain and XY chain, in which we find this positive criticality effects.

Time Dependent Markovian Master equation beyond the adiabatic limit

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We develop a Master equation in the Born-Markov approximation for arbitrary driven systems coupled, to an environment. Our approach is formulated on a combination of coarse-graining in time and, weak coupling limit for the system-environment interaction and it also requires a secular approximation., We prove that our derivation is fundamentally based, on the adiabatic time-evolution operator, although it can efficiently describe strongly driven systems, and, thus it can be seen as a natural extension of the famous Adiabatic Markovian Master equation., Our result is applied to the paradigmatic cases of a qubit subject to linear and periodic driving, moreover, the solutions are benchmarked with numerical simulations by using Tensor Networks.

Relativistic Quantum Thermometery by moving qubit system

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Unipa's phd student

We investigate quantum thermometry through a quantum probe interacting with a static thermal bath in a relativistic scenario. We study the effects of different couplings of the probe to the heat bath. In particular, we focus on low-temperature regime and examine how the velocity of the probe affects the temperature estimation. Moreover, the possible deviation of quantum thermometry, originating from the Lamb shift of the energy levels, is analyzed. Our work opens new horizons for detailed investigation of relativistic effects to enhance quantum thermometry.

Direct measurements of multipartite spatial indistinguishability

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The direct measurement of the spatial indistinguishability of identical particles as a quantum resource is of practical importance when complete information of the system state is unknown. We provide an experimentally-friendly scheme for measuring the amount of spatial indistinguishability in many-particle systems. Our scheme can be used to witness the structure of spatial overlap among the identical particles of the system without state tomography. In this sense, the measurement procedure is somewhat similar to

a Bell non-locality test. The procedure is based on photon counting by using photon number resolving detectors (PNRD). Spatial indistinguishability is obtained as a function of photon-counting via combinations of local and nonlocal joint probabilities. We first develop our method for two and three identical particles, then generalizing it to the case of N identical particles in M sites, with 2 ≤ M ≤ N. We finally show how tuned multipartite spatial indistinguishability can be directly related to the generation of multipartite entanglement

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Observable Signatures of Quantum Charge-Field Interactions

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Different facets of the quantum nature of the electromagnetic field have been investigated starting from the observation of Lamb shift in 1947. Currently, the experimental realisation of sophisticated optomechanical systems has furnished a suitable platform for further investigations on the vacuum fluctuations of the electromagnetic field. We find that moments of appropriately chosen observables of one or two charged particles could potentially indicate the presence of a background quantum electromagnetic field in the vacuum state. We also document the changes in these moments due to the specific nature of the initial state. To further understand and identify clear signatures of the vacuum fluctuations, we also consider three different scenarios: a free charged particle, a single charged particle in a harmonic trap and two charged particles each in a harmonic trap coupled through the Coulomb force. Considering the fact that there has been recent interest in observable signatures of quantum nature of gravity, our investigation could provide a possible stepping stone for similar investigations in that context too.

Indistinguishability-based direct measurement of the exchange phase of identical quantum particles

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The symmetrization postulate in quantum mechanics, leads to the appearance of, an exchange phase dictating the symmetry of identical, particle global states under particle swapping. Many indirect measurements of such a, fundamental phase have been reported so far, while a direct observation has been only recently, carried out for photons. We introduce, a general scheme capable to directly measure, the exchange phase of any type of particles, (bosons, fermions, anyons), exploiting spatial indistinguishability within the operational framework of spatially localized operations, and classical communication. An experimental, implementation has been performed in an all-optical platform, providing a direct measurement of the real bosonic exchange, phase of photons and a proof-of-principle measurement of different simulated exchange phases., Our results confirm the symmetrization tenet and, provide a tool to explore it in various scenarios: with this regard, an experimental implementation in double quantum dots is being designed to achieve the first direct measurement of the fermionic exchange phase.

Quantum Fisher Information as tool for detecting topological phases

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Quantum Fisher Information (QFI) is known to provide a valuable tool for measuring the Multipartite Entanglement (ME) in one-dimensional models, which can give valuable information about the existence of topological phases. In this work we consider two paradigmatic models: the Kitaev chain, a toy model of a topological superconductor, and the Bilinear-Biquadratic model, a general SU(2)-invariant spin-1 chain. The former is also generalized to include a long-range coupling, which decays as function of the distance between sites with a power law. We show that the scaling of the QFI of strictly non-local observables can be used for characterizing the phase diagrams and, in particular, for detecting topological phases, where it scales maximally. Numerical results obtained with the DMRG algorithm, are tested against known results of the Bilinear-Biquadratic model and a new analytical calculation of the QFI for the Kitaev chain, showing the emergence of a a new kind of topological phase in the strongly long- range regime.

Support Vector Machine Classification of Entangled States

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Quantum entanglement is one of the main features that distinguish a classical from a quantum state. This distinction has real application, as quantum entanglement is the basic resource for quantum computation advantage. Although the importance of detecting an entangled state is clear to the community, we still miss a universal recipe for entanglement classification, with analytical results obtained for low dimensional system (2 qubits or 1 qubit and 1 qutrit) and some special cases of higher dimensional system. Classification tasks have been solved with high precision by machine learning algorithms. In particular, we are interested in the support vector machine (SVM), which separates two regions of the space by an optimal hyperplane/hypersurface. In this work we develop an algorithm to use SVM classifiers to divide separable and entangled states. We apply this technique to two-qubit and three-qubit system, showing the power of this protocol. Finally, we relate the separating hyperplane to an operational procedure we can implement on a quantum computer, making use of copies of the input state.

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