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Book of Abstracts

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Francesco Ciccarello
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Giacomo De Palma
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Dario De Santis
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Daniele Dequal
Feasibility of continuous variable QKD from satellite

Donato Farina
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Simone Felicetti
Finite-size phase transitions for quantum metrology

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Extractable work, the role of correlations, and asymptotic freedom in quantum batteries

Jamie Anguita
Accurate Optical Vortex Identification in Turbulence Using a Shack-Hartmann Sensor

Matteo Bina
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Claudio Bonizzoni
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Quantum enhanced estimation of diffusion

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Alessia Castellini
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Local vs global master equation of two coupled qubits: a thorough discussion

Stefano Chessa
Lieb-Robinson bound and applications in Quantum Information

Wayne Jordan Chetcuti
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Dario Ciluffo
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Emanuele Distante
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Alessandra Gatti
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Piergiovanni Magnani
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Giuseppe Magnifico
Real Time Dynamics and Confinement in the Zn Schwinger-Weyl lattice model for 1+1 QED

Nina Megier
Generalized Gaussian non-Markovian unravelings - derivation and applications to quantum information tasks

Milajiguli Rexiti
Adversarial vs cooperative quantum estimation

Jonathan Morgner
Quantum logic in scalable surface-electrode ion traps with microwave driven gates

Farzam Nosrati
Quantumness and memory of an open qubit under classical control

Emilio Onorati
Randomized benchmarking for individual quantum gates

Francesco Pepe
Quantum decay at short, intermediate and long times in a one-dimensional hopping model

Nicolò Piccione
Novel effects from non-dipolar interaction in the bad cavity limit

Domenico Pomarico
Correlated photon emission by two excited atoms in a waveguide

Federico Roccati
Exploring quantumness in a PT-symmetric system

KEYNOTE SPEAKERS

Antonio Acin

ICFO (Spain)

Certification of many-body quantum systems

Abstract:
A ubiquitous question in quantum physics is to certify that a given many-body quantumsystem satisfies an operational property: is this given system in an entangled state? Does it display non-classical correlations? Does it provide a good approximation to the ground state of a relevant Hamiltonian? Does it contain the solution to a classical optimisation problem? In the talk, we first provide a method for device-independent entanglement detection that involves a polynomial number of correlation functions. Second, we move to the computation of ground states of classical spin systems. These systems are relevant because they can encode the solution to classical optimisation problems and are often used to benchmark quantum annealers. We present a method that provides upper and lower bounds to the ground-state energy, so that the error in the approximation is under control. We use it to verify the output of a D-Wave 2000Q device and identify instances where our method provides the exact ground state, while the annealer gives a configuration of higher energy and, more interestingly, other where we certify that the quantum annealer has reached the solution.

Laleh Memarzadeh
Sharif University of Technology (Iran)

Quantum channels and their building blocks

Abstract:
Going beyond unitary and reversible evolution which results from Schroedinger equation, is inevitable for describing dynamics of systems in interaction with their surrounding environment. It turns out that the most general form of evolution is described by the linear maps which are completely positive and trace preserving (CPTP), also known as quantum channels. Regarding the important role of quantum channels, both from fundamental point of view and their application in different areas of quantum information, understanding the structures and properties of quantum channels are of vital role. To get an insight into the characteristics of the CPTP maps, after discussing the possibility of dividing quantum channels in terms of their building blocks, we will focused on the convex structure of the set of CPTP maps and decomposing a given CPTP map in terms of the extreme points of the set. We will discuss the challenges of obtaining the extreme points and demonstrate how considering the covariant properties of the map is helpful in finding a subset of extreme points.

Alessio Serafini
University College London (UK)

Gaussian thermal operations and the limits of algorithmic cooling

Abstract:
We provide a complete characterisation of the set of Gaussian thermal operations (defined as in the resource theory approach to thermodynamics) and discuss certain more or less relevant consequences for the implementation of algorithmic cooling schemes in the Gaussian regime.

Christine Silberhorn
Paderborn University (Germany)

Nonlinear integrated devices for quantum information systems

Abstract:
Recent achievements in the area of integrated quantum optics and quantum information processing have shown impressive progress for the implementation of linear circuits based on monolithic waveguide structures. However, most experiments are based on $\chi(3)$ -media, such as glas, silicon-on insulator or silica-on-silicon. In these platforms the implementation of highly efficient sources, frequency converters and fast active phase shifters and modulators pose severe challenges.
The use of advanced waveguides structures, which harness a $\chi(2)$ –non-linearity, allows for the realization various devices with different functionalities. These include single- and multi-channel sources with extraordinary brightness, quantum frequency conversion with tailored spectral-temporal properties, and complex circuitries comprising degenerate pair generation in orthogonal polarization, linear elements, and active elements such as polarization rotators or an electro-optically controllable time delay. Here we present our latest progress for the implementation of integrated devices based on $\chi(2)$ –media for quantum information and quantum communication systems.

Roberta Zambrini
IFISC (Spain)

Quantum Complex Networks

Abstract:
Quantum complex networks provide descriptions of extended systems where links can range from quantum correlations to physical interactions, particularly relevant in the context of quantum transport or communications. After a personal overview, different topics will be presented in this talk, including their probing, dynamical features, and use in quantum machine learning.

INVITED TALKS

Alessia Allevi
University of Insubria

Homodyne-like detection for quantum information science

Abstract:
We present the implementation of a homodyne-like detection scheme, in which a low-energy local oscillator (LO) and two hybrid photodetectors, which are commercial photon-number-resolving detectors operated at room temperature, are used instead of the traditionally-employed high-energy LO and pin photodiodes. With such a hybrid configuration, we gain direct access to the number of photons measured by each detector separately, but we can also calculate the photon-number difference, which is then processed to retrieve phase-space information about the signal [1]. First of all, we apply the detection scheme to the discrimination between two phase-shifted coherent states affected by either uniform or Gaussian phase noise, performing a proof-of-principle experiment. The performance of the discrimination strategy is quantified in terms of the error probability of discriminating the noisy coherent signals as a function of the characteristic noise parameters. In particular, we demonstrate that in such conditions the homodyne-like scheme is near-optimal, being it endowed with a discrimination error probability that approaches the Helstrom bound, i.e. the minimum error probability allowed by quantum mechanics [2]. Secondly, we report on the tomographic reconstruction of optical states, both classical and quantum. We approach the problem both on the theoretical and the experimental points of view and demonstrate that the pattern function technique, originally developed for optical homodyne tomography, may be also applied to discrete data, even in the case of imperfect quantum efficiency [3].
Our results open new perspectives for quantum-state reconstruction in the mesoscopic regime, and pave the way to the use of PNR-based detection schemes in Quantum Information Science.

[1] A. Allevi et al., Int. J. Quantum Inform. 12, 1461018 (2014)
[2] M. Bina et al., Opt. Express 25, 10685 (2017)
[3] S. Olivares et al., quant-ph/arXiv:1809.00818v1

Tony J. G. Apollaro
University of Malta

n-qubit quantum state transfer

Abstract:
The transfer of quantum information between a sender and a receiver at a distance is a paramount task for many quantum information processing protocols. Whereas the case of the transfer of the quantum information encoded in one qubit has been addressed extensively, the scenario where the information is encoded in many qubits has received less attention. In this talk, a protocol for the transfer of the quantum state of n>1 qubit is addressed [1]. The sender and the receiver are embodied by n spin-1/2 particles, arranged in a one-dimensional XX chain and weakly coupled to the edges of a quantum wire, composed it too of a one-dimensional XX chain . It is shown that, for the transfer to occur with a high fidelity, specific resonance conditions between the energy eigenstates of the systems sender, receiver, and wire have to be met, imposing constraints on the number of particles the quantum wire is made up by. It is also shown how to exploit the same mechanism leading to high-fidelity quantum state transfer in order to generate entanglement between the qubits in the sender and the receiver blocks [2].

[1] Salvatore Lorenzo, Tony J. G. Apollaro, Andrea Trombettoni and Simone Paganelli, 2-qubit quantum state transfer in spin chains and cold atoms with weak links, Int. J. Quantum Inf. Vol. 15, No. 05, 1750037 (2017)
[2] Tony J. G. Apollaro, Guilherme M. A. Almeida, Salvatore Lorenzo, Alessandro Ferraro, Simone Paganelli, Spin chains for two-qubit teleportation, arXiv:1812.11609

Leonardo Banchi
University of Florence

Machine-Learning-Assisted Many-Body Entanglement Measurement

Abstract:
Entanglement not only plays a crucial role in quantum technologies, but is key to our understanding of quantum correlations in many-body systems. However, in an experiment, the only way of measuring entanglement in a generic mixed state is through reconstructive quantum tomography, requiring an exponential number of measurements in the system size. Here, we propose a machine-learning-assisted scheme to measure the entanglement between arbitrary subsystems of size NA and NB, with O(NA+NB) measurements, and without any prior knowledge of the state. The method exploits a neural network to learn the unknown, nonlinear function relating certain measurable moments and the logarithmic negativity. Our procedure will allow entanglement measurements in a wide variety of systems, including strongly interacting many-body systems in both equilibrium and nonequilibrium regimes.

Reference: J. Gray, L. Banchi, A. Bayat, S. Bose, Phys. Rev. Lett. 121, 150503 (2018)

Marco Barbieri
University of Roma Tre

Dynamical quantum phase estimation

Abstract:
Tracking changes in a sample is one of the main purposes of sensing: the variations in its physical properties can be captured by a set of characteristic parameters, whose measurement, possibly close to the ultimate precision limit, is the aim of the experiment.

When quantum light is employed, the limiting factor in the timescale is the detection system: within the current and foreseeable technology, fixed-photon states will only allow tracking dynamics with at best subsecond resolution. Although this might appear too coarse, there exist chemical reactions that accumulate products over fully compatible timescales. Among these, reactions leading to a change in the optical activity of the reactants and the products are particularly intriguing.

Monitoring the dynamics of such processes under realistic circumstances determines another level of complexity, since the samples might be affected by changes other than merely its optical activity. In addition, the quality factor of the probe state itself could be degraded by parasitic processes or setup instabilities as the reaction occurs. These impact the measurement in the form of a nonstationary noise, which, due to its varying size, can not be precompensated, nor precalibrated.

In this respect, a multiparameter approach mitigates these effects, since it provides an estimation of the parameter of interest, along with the quality of the probe that interrogates the sample.

In this talk, we will discuss two experiments that we have carried out on such dynamical cases, both addressing the acidic hydrolysis on sucrose. In the first example, the hydrolysis is catalysed by the presence of HCl, whose concentration dictates the timescale on which the reaction is completed. Further, we extend our investigation to the action of invertase enzyme; in the latter case, the high quality of the probe has allowed us to implement an adaptive scheme to ensure near-optimal measurement conditions at all times.

Angelo Bassi
University of Trieste

Models of spontaneous wave function collapse: an introduction and some recent results

Abstract:
To solve the quantum measurement problem, models of spontaneous wave function collapse (collapse models) propose to modify the Schroedinger equation by including nonlinear and stochastic terms, which describe the collapse of the wave function in space. These spontaneous collapses are rare for microscopic systems, hence their quantum properties are left almost unaltered. At the same time, their effect adds coherently in composite systems, to the point that macroscopic spatial superpositions of macro-objects are rapidly suppressed. Their dynamics thus differs from the standard quantum one. I will briefly review the main features of collapse models. Next I will present an update of the most promising ways of testing them in interferometric and non-interferometric experiments, showing the current lower and upper bounds on their parameters.

Claudia Benedetti
University of Milan

Non-classicality of quantum walks

Abstract:
It is known that classical and quantum walks evolve differently over a given graph. We address the issue of quantifying the difference in the evolution between a continuous-time classical random walk and quantum walk by introducing a definition of non-classicality based on the fidelity between states.
We prove that the optimal initial state for the walker should be a localized one. We describe some universal properties of the non-classicality, give the analytic expressions for the asymptotic regimes and relate it to both the coherence of the quantum walk and the classical fidelity between the probability distributions over the graph.

Paolo Bordone
Univeristy of Modena and Reggio Emilia

Continuous-time quantum walks of a charged particle on planar lattice graphs in the presence of a magnetic field

Abstract:
Quantum walks (QWs) represent a very promising field of research for quantum information, since they offer many interesting possibilities of implementing fast and efficient quantum algorithms for solving various problems in different fields [1,2] . Indeed QWs are able to reproduce the discrete algebra of quantum computers and hence to be exploited to implement quantum computing protocols and algorithms that classical computers cannot execute [2-4]
There are in the literature many works about QWs on arbitrary graphs (understood as mathematical structures, more general than lattice graphs). In the last years analyses of QWs on two-dimensional lattices have been performed, but, to our knowledge, the literature about two-dimensional QWs in the presence of magnetic field is almost absent.
When considering continuous-time quantum walks (CTQWs), as in the present work, the Hamiltonian only involves the kinetic term (which is replaced by the graph Laplacian) and possible potential terms or interactions. Such Hamiltonians do not involve any gradient, since the linear momentum appears only at the second order within the kinetic term, which is simply replaced by the graph Laplacian or by the adjacency matrix. The presence of a vector potential couples the position and the linear momentum, hence we have to find a method which generalizes both the Laplacian and the gradient, since the Hamiltonian describing a CTQWs can be derived from the spatial discretization of the corresponding Hamiltonian in the continuum. To this end we suggest a hybrid method (finite difference formulae from Taylor expansion and conservative finite-difference methods on general grids), which provides a Laplacian analogous to the graph Laplacian and a gradient which involves all the nearest-neighbors of each vertex of the graph. In particular we focus on planar lattice graphs, i.e. graphs possessing a drawing whose embedding in a Euclidean plane forms a regular tiling, a regular tessellation. This can only be achieved with equilateral triangles, squares, and regular hexagons, which yield to triangular, square, and honeycomb lattice graphs, respectively.

1) J. Wang and K. Manouchehri, Physical implementation of quantum walks (Springer, 2013). 2) A. Ambains, Int. J. Quantum Inf. 1, 507 (2003).
3) R. Portugal, Quantum walks and search algorithms (Springer Science & Business Media, 2013).
4) S.E. Venegas-Andraca, Synthesis Lectures on Quantum Computing 1, 1 (2008).

Francesco Buscemi
Nagoya University (Japan)

Statistical aspects of quantum devices: characterization and data-driven inference

Abstract:
In this presentation (either in the form of talk or poster) I would like to present some recent advances that my collaborators and I obtained in the statistical characterization of quantum devices. In particular, this presentation will focus on the topic of quantum majorization, its role in generalized resource theories (including entanglement theory, coherence theory, etc), and its applications to problems of statistical inference. For the latter, our theory leads to the protocol of "data-driven inference," through which it is possible, by invoking a principle of statistical minimality, to infer an unknown quantum device based only on the classical input/output correlations observed in an experiment, thus bypassing some well-known loopholes of conventional tomography.

Filippo Cardano
University of Napoli Federico II

Probing bulk topological phenomena in quantum walks of structured light

Abstract:
Quantum walks (QWs) are intriguing yet simple processes, proving extremely useful for the simulation of exotic phenomena that are typical of condensed matter systems, like topological phases of matter. Different schemes exist that can be used to realize quantum walks in optical systems, but very few allow one to extend the walker space to a two-dimensional lattice. Here we focus our attention on two experiments in which we engineered topological quantum walks in one (1D) and two spatial dimensions (2D), respectively, and detected the associated topology by probing their bulk, instead of looking at the formation of localized edge-states. In 1D, we investigated systems featuring chiral symmetry, whose topology is determined by the winding numbers of the Hamiltonian eigenstates. For these systems, we introduced a novel observable, that is the mean chiral displacement (MCD). If the system initial state is localized at a single lattice site, after a long temporal evolution we found the MCD to converge to a value that is proportional to the winding number. Interestingly, this result is valid for any 1D chiral model and can be generalized to systems with high- dimensional internal degrees of freedom. We experimentally validate these findings in a photonic quantum walk based on helical modes of light. In the second part of the talk we concentrate on the description of a novel setup for the simulation of 2D quantum walks. This platform employs an intrinsically 2D optical degree of freedom: the transverse momentum of a light beam, corresponding to the projection of the wavevector on the plane transverse to the main propagation direction. The quantum walk dynamics is realized by exploiting spin-orbit coupling in liquid crystals polarization gratings, which apply polarization-dependent transverse "kicks" to the photons in the beam. This setup presents different adjustable parameters that can be tuned to explore a variety of quantum walk processes. In particular, we arranged our cells so as to design a QW protocol exhibiting non-trivial topological phases, associated with non-zero values of the Chern of the energy bands, like in topological insulators. By simulating the effect of an external force, we observed the anomalous displacement of the ground state mean position, that is a typical manifestation of the system topological character and it is known to be proportional to the Chern number.

Stefano Carretta
University of Parma

Molecular magnetism: a promising route towards the realization of quantum computers

Abstract:
The terrific advancements in the coherent manipulation of quantum systems and the potential to solve problems with large impact on science, society and economy, make the realization of quantum computers one of the hottest topics of current research. The elementary units of these devices are quantum two-level systems (qubits), which can be realized using a variety of physical objects ranging from trapped ions to superconducting circuits. One promising approach exploits molecular nanomagnets (MNMs), molecules whose magnetic core is embedded in shells of organic ligands. These spin qubits display long coherence times (reaching 1 ms) and elementary single and two-qubits gate have been demonstrated.
Here I review some results on important aspects of the use of MNMs for quantum information: Switchable qubit-qubit interactions, entanglement and quantum error correction. A switchable coupling is needed for an effective implementation of quantum algorithms and here I show how it can be obtained in chains of permanently coupled molecular qubits [1]. Entanglement between molecular qubits had only been experimentally studied rather indirectly by macroscopic techniques or by fitting trial model Hamiltonians to experimental data. In the presentation, I show that four-dimensional inelastic neutron scattering enables us to portray entanglement in weakly coupled molecular qubits and to quantify it [2]. At last, MNMs are typically characterized by a sizeable number of low-energy eigenstates which can be exploited to define qudits (with $d>2$ states) instead of qubits, thus enabling more efficient quantum algorithms. In particular, I will show that nuclear degrees of freedom coupled to electronic ones can be exploited to encode qubits with embedded basic quantum error correction [3,4]. As a comparison, I will show some results [5] we obtained with IBM quantum chips based on superconducting qubits.

[1] Jesus Ferrando-Soria, et al., Nature Communications 7, 11377 (2016).
[2] E. Garlatti, T. Guidi, S. Ansbro, P. Santini, G. Amoretti, J. Ollivier, H. Mutka, G. Timco, I.J. Vitorica-Yrezabal, G.F.S. Whitehead, R.E.P. Winpenny, S. Carretta, Nature Communications 8, 14543 (2017).
[3] R. Hussain, G. Allodi, A. Chiesa, E. Garlatti, D. Mitcov, A. Konstantatos, K. S. Pedersen, R. De Renzi, S. Piligkos and S. Carretta, J. Am. Chem. Soc. 140, 9814 (2018).
[4] M. Atzori, A. Chiesa, E. Morra, M. Chiesa, L. Sorace, S. Carretta and R. Sessoli, Chem. Sci. 9, 6183 (2018).
[5] A. Chiesa, F. Tacchino, M. Grossi, P. Santini, I. Tavernelli, D. Gerace and S. Carretta, Nature Physics (2019).

Filippo Caruso
University of Firenze

Stabilizing Open Quantum Batteries by Sequential Measurements

Abstract:
The concept of an open quantum battery as a non-equilibrium quantum system for energy storage is introduced. In this regard, methods relying on the application of a sequence of projective measurements are used to stabilize the system in its maximum energy state, despite the presence of free energy leakages due to the environmental decoherence. We show that the proposed stabilization scheme obeys a second-law like inequality for the battery entropy production rate, and allows for keeping the energy stored in the system by using the minimum amount of energy. Thermodynamical aspects of sequences of projective measurements in the Zeno regime are finally discussed.

Gonzalo Carvacho
Sapienza University of Rome

Experimental quantum tests of causal structures

Abstract:
The relevance of Bell's theorem in quantum information processing has been demonstrated in several works over the years. Despite their fundamental relevance, however, previous experiments did not consider an ingredient of relevance for quantum networks: the fact that correlations between distant parties are mediated by several, typically independent sources. The first part of the presentation will be devoted to the simplest quantum network, consisting of three spatially separated nodes whose correlations are mediated by two distinct sources. This scenario allows for the emergence of the so-called non-bilocal correlations, incompatible with any local model involving two independent hidden variables. We experimentally witness the emergence of this kind of quantum correlations by violating a Bell-like inequality under the fair-sampling assumption. Our results provide a proof-of-principle experiment of generalizations of Bell's theorem for networks, which could represent a potential resource for quantum communication protocols [1].
Since inferring causal relations from experimental observations is of primal importance in science. The second part will be dedicated to the Instrumental causal structure which is able to provide an essential tool for that aim, as it allow one to estimate causal dependencies even in the presence of unobserved common causes. In view of Bell's theorem, which implies that quantum mechanics is incompatible with our most basic notions of causality, it is of utmost importance to understand whether and how paradigmatic causal tools obtained in a classical setting can be carried over to the quantum realm. We show that quantum effects imply radically different predictions in the instrumental scenario. Among other results, we show that an instrumental test can be violated by entangled quantum states. Furthermore, we demonstrate such violation using a photonic set-up with active feed-forward of information, thus providing an experimental proof of this new form of non-classical behavior. Our findings have fundamental implications in causal inference and may also lead to new applications of quantum technologies [2].

References:

[1] "Experimental violation of local causality in a quantum network", G. Carvacho et al., Nature Communications 8, 14775 (2017).
[2] "Quantum violation of an Instrumental test", R. Chaves et al., Nature Physics 14, 291-296 (2018).

Andrea Crespi
Politecnico di Milano

Generation and manipulation of single-photon states in femtosecond-laser written waveguide circuits

Abstract:
Quantum information and simulation experiments, realized with photons, require a versatile integrated platform, capable of implementing complex interferometric networks with high stability and within a compact footprint. As well, these experiments highly benefit from on-chip generation of single-photon states.
Femtosecond laser waveguide writing is a powerful technology, able to directly inscribe optical circuits in different transparent substrates. Nonlinear interactions of the focused laser pulses with the material indeed allow to obtain a permanent refractive index increase, localized around the focus and at arbitrary depth below the surface, and thus enable to inscribe waveguide circuits with unique three-dimensional freedom.
Here we show how integrated multi-port interferometers, written by femtosecond pulses, can be used for multi-photon interference experiments. Such devices combine high circuital complexity with solid interferometric stability. In addition, metallic resistors are deposited on the surface of the chip and patterned by the same femtosecond laser: local heating by Joule effect enables active thermo-optic phase control inside the waveguide circuit, whose functionality can thus be reconfigured at will in a fraction of a second. We demonstrate that these circuits represent an ideal platform to perform a number of quantum photonics experiments: these include fundamental studies on multi-photon indistinguishability, quantum-enhanced interferometry and quantum simulation tasks.
Furthermore, we report on the development and on the experimental testing of a compact and versatile photon-pair source, operating in the telecom wavelength range. The device consists in a Mach-Zehnder interferometer in which a periodically-poled lithium niobate (PPLN) chip, containing a pair of identical non-linear waveguides, is enclosed inbetween two glass chips containing directional couplers. In fact, the adopted fabrication technology allows to process glass substrates as well as crystalline materials. By employing different versions of the third chip and by acting on an integrated thermo-optic phase-shifter, the source operation can be tuned to produce indistinguishable photon pairs, two-photon NOON states, or even polarization-entangled states.
The reported experiments pave the way to a fully integrated and modular platform for quantum photonics, where chips containing photon sources and linear-optics networks can be assembled in a versatile fashion. The fast-prototyping capabilities of the femtosecond laser microfabrication technology provide further advantages in testing novel circuit layouts with quick production turnaround.

Milena D’Angelo
University of Bari

Advances in Correlation Plenoptic Imaging

Abstract:
Plenoptic Imaging is an imaging modality enabling refocusing of acquired images as well as single-shot 3D imaging; in fact, based on its simplicity and velocity, it is among the most promising 3D imaging techniques currently available. The underlying idea of plenoptic imaging is to retrieve, together with the image, information about the propagation direction of light; this enables both ray tracing, as required for refocusing, and parallele acquisition of multi perspective views, as required for 3D imaging.
In conventional plenoptic cameras, directional information is retrieved by placing a microlens array in front of the camera sensor: the main camera lens reproduces the image of the scene of interest on the microlens array, and each microlens reproduces on the portion of sensor behind it the image of the main camera lens. This enables acquiring the required plenoptic information at the price of: 1) reducing the image resolution well below the diffraction limit; 2) acquiring a reduced amount of different perspectives. Such drawbacks highly limits the effective use of conventional plenoptic devices for practical applications, such as microscopy.
We will introduce Correlation Plenoptic Imaging (CPI), our novel approach for overcoming the above limitations by means of the intrinsic spatio-temporal correlations of both chaotic light sources and entangled photons. In CPI, either coincidences or correlations of intensity fluctuations are measured, pixel by pixel, between two high resolution disjoint sensors: one retrieving the image of the scene of interest, the other one the image of the focusing element. Experimental diffraction-limited plenoptic imaging will be presented, together with the demonstration of a substantial improvement (even by a factor of 40) of the maximum achievable depth of field, for a given image resolution. In addition, the lack of a microlenses substantially increases the available change of perspectives, thus making CPI an effective tool for practical 3D imaging.
More recent experimental advances we shall also discuss include: 1) Correlation Plenoptic Microscopy of 3D samples, as implemented by means of pseudo-thermal light; 2) Sub-shot-noise CPI, with entangled photons from Spontaneous Parametric Down Conversion; 3) A novel CPI scheme enabling a further increase of the maximum available depth of field and change of perspective.
The proposed product and process is covered by two patents and two further patent applications.

Ivo Pietro Degiovanni
INRIM Torino

Genetic Quantum Measurements: Estimating an expectation value by measuring a single photon

Abstract:
In quantum mechanics the measurement procedure, following the Von Neumann scheme, is described as a sequence composed of state preparation, strong interaction (described by a unitary operator), and state detection (typically described with the projective measurements formalism). Genetic Quantum Measurements (GQMs) represent a paradigm shift, since they use genetic-like approach to significantly surpass the performances of the conventional (projector-based) quantum measurement techniques.
GQMs present some analogies, but also relevant differences, with respect to a couple of well-established measurement paradigms, namely sequential measurements [1,2] and protective measurements [3,4]. Specifically, sequential measurements, analogously to GQMs, exploit a sequence of interactions, but without introducing the selective pressure (the selective measurements in GQMs).
The protective measurements concept is somehow analogous to the one of GQMs, since it takes advantage of a continuous protection of the quantum state (quantum-Zeno-like approach) that is connected with an asymptotically infinite sequence of extremely weak interactions. The main concept behind protective measurement is that the estimation of the Observable of Interest is performed by the detection of a SINGLE quantum system. This is possible, from a theoretical point of view, since at each step the interaction is so weak that the probability of losing a photon, through the potential barrier or because of the state-projection, is negligibly small even after an infinite amount of such interaction-protection (projection) steps. GQM approach considers a finite amount of interaction-selection stages and investigates any interaction intensity, in order to optimize the trade-off between single quantum system survival and uncertainty reduction.

References

[1] G. Mitchison, R. Jozsa and S. Popescu Phys. Rev. A **76**, 062105 (2007).
[2] F. Piacentini, M. P. Levi, A. Avella, E. Cohen, R. Lussana, F. Villa, A. Tosi, F. Zappa, M. Gramegna, G. Brida, I. P. Degiovanni, M. Genovese, Phys. Rev. Lett. **117**, 170402 (2016).
[3] Y. Aharonov and L. Vaidman, Phys. Lett. A **178**, 38 (1993).
[4] F. Piacentini, A. Avella, S. Virzì, R. Lussana, F. Villa, A. Tosi, M. Gramegna, G. Brida, E. Cohen, L. Vaidman, I. P. Degiovanni, M. Genovese, Determining the quantum expectation value by measuring a single photon, Nature Physics **13**, 1191(2017).

Elisa Ercolessi
University of Bologna

From one to two dimensions: topological phases in quantum spin ladders

Abstract:
Quantum spin ladders can be analytically studied by means of a generalisation of Haldane's mapping, leading to an effective field theoretical Lagrangian which might contain a topological theta-term. We will examine how this term might induce phase transitions into a topological phase.

Alessandro Ferraro
Queen's University Belfast (UK)

Resource theory of quantum non-Gaussianity and Wigner negativity

Abstract:
In this talk, I will present a resource theory for infinite-dimensional (continuous-variable) quantum systems, grounded on operations routinely available within current technologies. In particular, the set of free operations is convex and includes quadratic transformations and conditional coarse-grained Gaussian measurements. The present theory lends itself to quantify both quantum non-Gaussianity and Wigner negativity as resources, depending on the choice of the free-state set --- i.e., the convex hull of Gaussian states or the states with positive Wigner function, respectively. After showing that the theory admits no maximally resourceful state, a computable resource monotone will be defined --- the Wigner logarithmic negativity. The latter allows to assess the resource content of experimentally relevant states and to find optimal working points of some resource concentration protocols. This framework finds immediate application in continuous-variable quantum computation, where the ability to implement non-Gaussian operations is crucial to obtain universal control.

Giulia Ferrini
Chalmers University (Sweden)

Quantum advantage in Continuous-Variable architectures

Abstract:
In this work we study the computational power of several families of continuous-variable (CV) architectures. These can be composed for instance by non-Gaussian input states, Gaussian transformations such as squeezers or linear optics interferometers, and Gaussian measurements such as homodyne or heterodyne detection. We provide examples of architectures that display computational advantage, i.e. we prove that their output probability distribution cannot be sampled efficiently from a classical computer. We also study under which conditions CV architectures are instead classically efficiently simulatable.

Vittorio Giovannetti
Scuola Normale Superiore, Pisa

Maximum Power Efficiency for Two-Level Quantum Engines

Abstract:
We study how to achieve the ultimate power in the simplest, yet non trivial, model of a thermal machine, namely a two-level quantum system coupled to two thermal baths. We find that, regardless of the microscopic details and of the operating mode of the thermal machine, the maximum power is achieved through an Otto cycle in which the controls are rapidly switched between two extremal values. A closed formula for the maximum power is derived, and the experimental feasibility of the protocol is discussed. Our findings extend the analysis done in the literature on the efficiency at maximum power (EMP) to engines operating at the ultimate performace, which is strongly away from the quasi static regime, and shed new light on the universal role of the EMP. In particular we show that by employing proper energy filters to mediate the system-baths interactions, both the EMP of heat engines and the coefficient of performance at maximum power of refrigerators can approach Carnot's bound with arbitrary accuracy.

Matteo Gregoratti
Politecnico di Milano

Uncertainty relations and information loss

Abstract:
We introduce an information-theoretic formulation of quantum measurement uncertainty relations. When incompatible observables are approximatively jointly measured, we use relative entropy to quantify the information lost in approximation and we prove positive lower bounds for such a loss: there is an unavoidable information loss.
In the case of a finite-dimensional system and for any approximate joint measurement of two target discrete observables, we define the entropic divergence as the maximal total loss of information occurring in the approximation at hand. For fixed target observables, we study the joint measurements minimizing the entropic divergence, and we prove the general properties of its minimum value. Such a minimum is our uncertainty lower bound: the total information lost by replacing the target observables with their optimal approximations, evaluated at the worst possible state.
The bound turns out to be also an entropic incompatibility degree, that is, a good information-theoretic measure of incompatibility: indeed, it vanishes if and only if the target observables are compatible, it is state-independent, and it enjoys all the invariance properties which are desirable for such a measure.
In this context, we point out the difference between general approximate joint measurements and sequential approximate joint measurements; to do this, we introduce a separate index for the tradeoff between the error of the first measurement and the disturbance of the second one.
Finally, the entropic incompatibility degree straightforwardly generalizes to the case of many observables, still maintaining all its relevant properties.
By exploiting the symmetry properties of the target observables, exact values, lower bounds and optimal approximations are evaluated in the case of spin-1/2 components.

Fabrizio Illuminati
University of Salerno

Quantum Resource Theory of Coherence: Criteria, Measures, and Applications

Abstract:
We review the resource theory of quantum coherence. After a short resume of criteria and measures, we discuss the relations between coherence and non-commutativity and the applications to quantum matter and holography.

Salvatore Lorenzo
University of Palermo

Graphs Synchronization through chiral coupling

Abstract:
Dynamical synchronization occurs in various physical, chemical, biological, and mechanical engineering scenarios. Recently, synchronization between quantum systems has received large attention.
Generally, the problem is faced through models with direct coupling between the systems in the presence of collective environments. Here, we investigate synchronisation between N quantum oscillators (nodes), which have generally different frequencies and are chirally coupled in pairs so as to form a network featuring directed links (edges). Chiral interfaces entail light-matter interaction that depends on the propagation direction of light, hence forward and backward propagation are different and in the most extreme case photon emission and absorption become unidirectional. Chiral coupling can be nowadays realised in nanophotonic structures such as waveguides and optical nanofibers, where due to lateral confinement light effectively behaves as a one-dimensional field. Each waveguide enabling the chiral coupling works as a common environment for the two linked nodes, thus mediating a effective direct coupling between them. Nodes are subject to incoherent local pumps, which can be tuned so as to ensure steady-state synchronization. We first consider simple networks, such as two nodes with different frequencies or a three-node ring, and work out the conditions to meet for having synchronisation between all the systems. Next, we investigate larger random networks with the aim to identify "communities", i.e. synchronising sub-networks, and/or occurrence of synchronization between sub-networks connected by few one-way links.

Nicola Malossi
University of Camerino

Interference-based multimode opto-electro-mechanical transducers

Abstract:
As recently demonstrated [T. Bagci, et al., Nature 507, 81 (2013)], an opto-electro-mechanical system formed by a nanomembrane, capacitively coupled to an LC resonator and to an optical interferometer, may be employed for the high{sensitive optical readout of rf signals. Here we show through a proof of principle device how the bandwidth of such kind of transducer can be increased by controlling the interference between the electromechanical interaction pathways of a two{mode mechanical system. The transducer reaches a sensitivity of 10 nV=Hz1/2 over a bandwidth of 5 kHz and a broader band sensitivity of 300 nV=Hz1/2 over a bandwidth of 15 kHz. We discuss strategies for improving the performance of the device, showing that, for the same given sensitivity, a mechanical multi-mode transducer can achieve a bandwidth significantly larger than that of a single-mode one.

Tiago Mendes-Santos
ICTP Trieste

Measuring entanglement in many-body systems via thermodynamics

Abstract:
We present a method to measure the von Neumann entanglement entropy of ground states of quantum many-body systems which does not require access to the system wave function. The technique is based on a direct thermodynamic study of entanglement Hamiltonians, whose functional form is available from field theoretical insights. The method is applicable to classical simulations such as quantum Monte Carlo methods, and to experiments that allow for thermodynamic measurements such as the density of states, accessible via quantum quenches. We benchmark our technique on critical quantum spin chains, and apply it to several two-dimensional quantum magnets, where we are able to unambiguously determine the onset of area law in the entanglement entropy, the number of Goldstone bosons, and to check a recent conjecture on geometric entanglement contribution at critical points described by strongly coupled field theories.

Simone Montangero
University of Padova

Quantum technologies for lattice gauge theories

Abstract:
Gauge theories describe some of the most relevant phenomena encountered in physics, ranging from the Standard Model describing fundamental particles and their interactions to topologically ordered systems.
We briefly introduce the concept of lattice gauge theories and their relevance to high-energy physics, condensed-matter, and classical optimization problems. We then review some recent progresses on quantum and classical tensor network simulations of lattice gauge theories.

Paolo Perinotti
University of Pavia

Higher order quantum theory

Abstract:
Conventional quantum processes are described by quantum circuits, that represent evolutions of states of systems from input to output. Here we will consider computations that describe the transformation of an input circuit to an output circuit, namely computations that describe the transformation of an evolution. As for first-order processes, at this level admissibility conditions are sufficient for the existence of a physical realisation scheme. The construction of a hierarchy of transformations of transformations can proceed arbitrarily far, and in the higher orders one encounters admissible functions that have indefinite causal structures. Still, many of the maps in the hierarchy can be proved to have a sensible physical interpretation. In order to study the hierarchy, we introduce a simple rule for constructing new types of maps from known ones, and show how the tensor product can be rephrased in terms of the new rule. We use the hierarchy of types to introduce a partial order, which allows us to prove properties by induction. We will then use induction proofs to discuss the characterisation of mathematically admissible maps of every level, showing an important result in this direction.

Luca Pezzé
CNR-INO Firenze

Multipartite entanglement in topologiocal quantum systems

Abstract:
We introduce a novel measure of entanglement with a measurable lower bound given by the Fisher information [1] and associated to entanglement-enhanced metrology. We study this lower bound in the ground state of many-body systems [2], focusing in particular to the Kitaev wire [3], an important model showing topological quantum phases. A super-extensive scaling of the Fisher information characterizes non-trivial topological phases and phase transition of this model, showing that multipartite entanglement detected by the Fisher information is an intrinsic property of non-trivial topological phases. Finally, we show that this metrological multipartite entanglement is not affected by local imperfections [4] and low temperature fluctuations [5], paving the way to robust "topological quantum metrology".

[1] A. Smerzi and L. Pezzè, in preparation.
[2] M. Gabrielli, L. Lepori, and L. Pezzè, NJP 21, 033039 (2019)
[3] L. Pezze', M. Gabbrielli, L. Lepori and A. Smerzi, PRL 119, 250401 (2017)
[4] L. Pezzè and L. Lepori, in preparation.
[5] M. Gabbirelli, A. Smerzi and L. Pezzè, SCI. REP 8, 15663 (2018)

Francesco Plastina
University of Calabria

Decoherence in a synthetic fermion environment: from orthogonality catastrophe to Fano physics

Abstract:
We explore the dynamics of a two state impurity embedded in an ultra-cold fermion gas, trapped in an optical lattice. We characterize the Loschmidt echo and the response of the fermions by a numerically exact functional determinant approach and through a diagrammatic perturbation approach. When the gas is in the metal phase, the second-order linked cluster expansion captures well the long-time, power-law behavior of the echo, for which we derive an expression for the critical exponent. As the coupling with the impurity gets stronger, however, the third-order contribution to the linked cluster expansion comes into play, accounting for particle-hole recombination processes, which can suppress the orthogonality catastrophe mechanism when the gas approaches the band insulator regime. In this case, the response of the system is dominated by oscillations of increasing amplitude as the number of particles in the gas tend to completely fill the valence band. These modes may be interpreted as Fano-like resonances yielding a characteristic peak pattern in the work distribution function.

Enrico Prati
CNR Milano

Deep learning for quantum technologies

Abstract:
The diffusion of deep learning algorithms has boosted the research in several fields. The paradigm shift from knowledge-based to representation-based artificial intelligence has opened the chance to apply novel methods to physics. I review quantum computer architectures [1] and I show how to improve quantum computers by exploiting deep reinforcement learning [2]. I present two practical examples of how to steer a qubit by exploiting deep reinforcement learning, namely in the case of spatial coherent transport by adiabatic passage (CTAP) [3] of quantum states [4] as well as STIRAP, and in the field of quantum compiling, managed by using state-of-the.art deep reinforcement learning algorithms. By reverse engineering the neural network, it is possible to achieve better understanding of the physical process itself by identifying those physical quantities more contributing to the process.

[1] D. Rotta, F. Sebastiano, E. Charbon, and E. Prati, Quantum information density scaling and qubit operation time constraints of cmos silicon-based quantum computer architectures, NaturePJ Quantum Information, vol. 3, no. 1, p. 26, 2017.
[2] A. Bonarini, C. Caccia, A. Lazaric, and M. Restelli, Batch reinforcement learning for controlling a mobile wheeled pendulum robot, in IFIP International Conference on Artificial Intelligence in Theory and Practice, pp. 151-160, Springer, 2008.
[3] E. Ferraro, M. D. Michielis, M. Fanciulli, and E. Prati, Coherent tunneling by adiabatic passage of an exchange-only spin qubit in a double quantum dot chain Phys. Rev. B, vol. 91, p. 075435., 2015.
[4] R. Porotti, D. Tamascelli, M. Restelli, and E. Prati, Coherent Transport of Quantum States by Deep Reinforcement Learning, Nature Communications Physics (in press, 2019) - arXiv:submit/2546122 [quant-ph] 20 Jan 2019.

Alessandro Ridolfo
University of Catania

Adiabatic Quantum Operations with Ultra-strongly Coupled Light-Matter Systems.

Abstract:
Since a few years Ultrastrong Coupling (USC) between light and matter has been achieved in a number of solid state systems [1], including devices based on superconductors and semiconductors. In this regime, achieved when the coupling strength of the interaction is comparable to the energies of the uncoupled systems, several intriguing phenomena are expected to manifest, from ground state entanglement to generation of correlated excitations and quantum phase transitions [1]. Such architectures may provide new building blocks for ultrafast quantum state processing. However the demonstration of quantum dynamics in this regime is challenging, experimental evidence of USC being so far limited to spectroscopy. We present two proposals addressing this issue [2,3].
We first discuss a protocol allowing the detection of virtual photon pairs in the entangled eigenstates, a long standing problem in the field. The protocol is based on stimulated Raman adiabatic passage (STIRAP) [4] which achieves coherent amplification of the conversion of virtual to real photons. We tackle critically limitations imposed by present-day hardware, showing that this experiment can succeed using state-of the art flux-based superconducting artificial atoms [2] and in other systems within a suitable photodetection for open quantum systems. If implemented, our protocol would provide a feasible road to benchmark dynamics in real USC structures.
Then, we study the problem of whether USC may help in quantum state processing despite the intrinsic limitation posed by the dynamical Casimir effect (DCE) [5]. We show indeed that adiabatic protocols similar to STIRAP allow to realize an almost perfect population transfer [3], quantum state transfer and entanglement generation among different nodes in a quantum network. In particular we study two artificial atoms ultrastrongly coupled to the same optical mode, acting as a quantum bus. Our protocol is resilient to DCE and to the leakage of the cavity mode, since the cavity itself is ideally never populated during the dynamics, thus acting as a *virtual* quantum bus.

P. Forn-Diaz *et al.*, Rev. Mod. Phys. **91**, 025005 (2019); A. F. Kockum *et al.*, Nat. Rev. Phys. **1**, 19-40 (2019)
G. Falci *et al.*, Fort. Phys. **65**, 1600077 (2017); G. Falci *et al.*, Sci. Rep. **9**, 9249 (2019) ; A. Ridolfo *et al.,* Eur. Phys. J. Special Topics **227**, 2183–2188 (2019)
M. Stramacchia *et al.*, arXiv:1904.04141 (2019)
N. V. Vitanov *et al.,* Rev. Mod. Phys. **89**, 015006 (2017)
G. Benenti *et al.*, Phys. Rev. A **90**, 052313 (2014)

Ivano Ruo-Berchera
INRIM Torino

Quantum enhanced imaging optimized in realistic conditions

Abstract:
Quantum correlations are in principle formidable tools for beating classical capacities of measurement. However, preserving these advantages in practical systems, where experimental imperfections are unavoidable, is a serious challenge to overcome for the future of quantum technologies.
Here, we report our recent results in the optimization of two quantum enhanced imaging protocols such as sub-shot noise imaging and quantum ghost imaging in presence of optical losses and noise.
In the first case, we extend to quantum domain the differential ghost imaging approach elaborated initially for bright thermal light and particularly suitable in the relevant case of faint or sparse objects. Our modified quantum protocol is able to partially compensate for the detrimental effect of losses and detection noise [1]. This represents an important step, as quantum correlations allow low brightness imaging, desirable for reducing the absorption dose. We perform the experiment using SPDC light, on one side validating the theoretical model and on the other showing the applicability of this technique by reconstructing a biological object with 5Î¼m resolution.
In the second case, by using similar optimization procedure in a wide field sub-shot noise imaging experiment [2], we show a sensitivity improvement (up to a factor 2) with respect to the simple protocol used in previous demonstrations [3]. In wide field sub-shot noise imaging there is a trade-off between the resolution and the sensitivity, due to the fact that pixels smaller than the characteristic size of the correlated spatial modes reduces the collection efficiency, deteriorating quantum correlations. In this context, the optimized protocol turns out to significantly improve the resolution without giving up the quantum advantage in the sensitivity.

[1] E. Losero et al. Quantum differential ghost microscopy arXiv:1903.12630v1 [quant-ph], 2019.
[2] E. Losero et al. Unbiased estimation of an optical loss at the ultimate quantum limit with twin-beams. Scient. Rep. 8(1), 7431 (2018).
[3] N. Samantaray , I. Ruo-Berchera, A. Meda, M. Genovese. Realization of the first sub-shot-noise wide field microscope. Light: Science & Applications 6, e17005 (2017).

Tommaso Tufarelli
University of Nottingham

Non-Orthogonal Bases for Quantum Metrology

Abstract:
Many quantum statistical models are most conveniently formulated in terms of non-orthonormal bases. This is the case, for example, when mixtures and superpositions of coherent states are involved. In these instances, we show that the analytical evaluation of the quantum Fisher information may be achieved by avoiding both the diagonalization of the density matrix and the orthogonalization of the basis. As examples of applications, we discuss several estimation problems involving noisy Schroedinger cat states and toy models for sub-wavelength imaging.

Paolo Villoresi
University of Padova

New developments in daylight free-space QKD

Abstract:
The extension to free space channels of the applications of Quantum Key Distribution QKD, as well as other protocols that are based on the exchange of quantum states, have paved the way to expand the spatial scale beyond the terrestrial scale.
A crucial aspect of the success of these free space quantum communications is the rejection of the background. This is realized with the filtering with respect to the spatial direction of the incoming radiation, the spectral filtering and the timing of the detection, in synchronisation with the transmission and taking into account the propagation time.
A step forward in this rejection is the exploitation of the near infrared spectral windows, that enjoy a lower scattering a weaker background intensity.
Free-Space QKD has been demonstrated at 1550 nm using suitable active pointing and single mode injection at the receiver side. This allowed an enhanced contrast with respect to the visibile region. In the talk, the demonstration of QKD exchange with secure key rate in the finite approximation will be presented also occurring in broad daylight.
This result support the development of ground and Space QKD applications and a simplified interplay with the ground secure networks.

CONTRIBUTED TALKS

Francesco Albarelli
University of Warwick (UK)

Evaluating the Holevo Cramér-Rao bound for multi-parameter quantum metrology

Abstract:
It is only with the estimation of multiple parameters simultaneously that the quantum aspects of metrology are fully revealed. This is due to the incompatibility of quantum observables, an essential feature of quantum mechanics. The Holevo Cramér-Rao bound (HCRB), on the weighted sum of the covariance matrix elements of an estimator, is the most fundamental asymptotic quantum bound for the precision of multi-parameter estimation.
However, its evaluation has remained elusive for problems of practical interest. We show that for finite-dimensional systems it can be computed by solving a semidefinite program. We reduce the problem size for rank-deficient states and use it to study two canonical problems in quantum metrology - phase and loss estimation in optical interferometry with fixed total photon number states and estimation of a three-dimensional field with multiple qubits in the presence of dephasing noise. Our novel finding for the former is that in some regimes it is possible to attain the HCRB with single-copy measurements, while optimally estimating the phase. For the latter, we discover a non-trivial interplay between the HCRB and incompatibility, and bring strong numerical evidence that the HCRB can be attained by single-copy projective measurements in the noiseless two-qubit case.

Remigiusz Augusiak
Polish Academy of Sciences (PL)

Self-testing quantum systems of arbitrary local dimension

Abstract:
Imagine we are given a quantum device whose internal working is unknown to us and our task is to verify whether this device operates on the promised quantum state and performs the promised quantum operations on it, without opening this device, and thus destroying it. A way to tackle this problem is self-testing [1]-a device-independent certification method, allowing to make statements about quantum devices only from the statistical data these devices generate. In recent years there has been a wave of results presenting self-testing protocols for various composite quantum systems and measurements. In particular, in [2], using the results of [3], self-testing method for any pure entangled bipartite state was proposed. This method is, however, based on violation of many two-outcome Bell inequalities such as the CHSH [4] or the tilted CHSH [5] ones, and it remains a highly nontrivial problem to propose certification scheme of d-dimensional quantum states based on violation of a single d-outcome Bell inequality that uses genuinely d-outcome measurements. Here we propose a self-testing protocol for the maximally entangled state of arbitrary local dimension and the well-known CGLMP measurements [6], which does not rely on self-testing results for qubit states and exploits the minimal number of measurements on both sites, that is, two. Our result exploits a genuinely d-outcome Bell inequality proposed recently in [7] as a generalization of the well-known CHSH Bell inequality to scenarios involving any number of measurements and outcomes. To this aim, we exploit the sum of squares decomposition of this Bell inequality and show that up to local isometries the state and measurements maximally violating this Bell inequality is the maximally entangled state of two qudits and the CGLMP measurements [6]. We also show that the outcomes of d-outcome measurements made by Alice and Bob are perfectly random and thus our results give rise to a device-independent scheme for randomness expansion from quantum correlations.

[1] D. Mayers, A. Yao, Proc. 39th Ann. Symp. on Foundations of Computer Science (FOCS), 503 (1998).
[2] A. Coladangelo et al., Nat. Comm. 8, 15485 (2017).
[3] T. H. Yang, M. NavascuÃ©s, Phys. Rev. A 87, 050102(R) (2013).
[4] J. F. Clauser et al., Phys. Rev. Lett. 23, 880 (1969). [5] A. AcÃn, S. Massar, S. Pironio, Phys. Rev. Lett. 108, 100402 (2012). [6] D. Collins et al., Phys. Rev. Lett. 88, 040404 (2002).
[7] A. Salavrakos et al., Phys. Rev. Lett. 119, 040402 (2017).

Alessio Belenchia
Queen’s Univeristy Belfast (UK)

Entropy Production in Continuously Measured Quantum Systems

Abstract:
The entropy production rate is a central object in non-equilibrium thermodynamics. Still, we lack definitions of this quantity that are easily manageable and general enough to encompass various experimentally interesting set-ups. In this talk, we characterise the excess entropy produced by a continuously monitored quantum Gaussian system ubiquitous in laboratories due to the observation process. We isolate the entropy production rate using the dynamics of the system in phase space. The end result is a generalised second-law which account for the information acquired by measuring the system.

Bruno Bellomo
Universitè de Franche-Comtè (France)

Energy bounds for entangled states

Abstract:
Energy and entanglement are two fundamental quantities in physics. A question of both fundamental and practical relevance is which are the general local energy bounds for entangled states of an arbitrary discrete bipartite system and which are the states satisfying these bounds.
Here, we address this issue, providing these energy bounds and the corresponding states. Moreover, numerical simulations show that the probability of randomly generating pure states close to these energy bounds finding, in all the considered configurations, is extremely low except for the two-qubit case and highly degenerate cases. This means that given a certain amount of entanglement, there is a very large number of states whose energy costs are much larger than strictly necessary. Then, we show that the bounds found for pure states are valid also for mixed states.
These results can be important for quantum technologies to design energetically more efficient entanglement generation protocols, since they permit to identify the states which would cost less to generate. Finally, we point out formal analogies between the bound states we have found and thermal states.

Matteo Brunelli
University of Cambridge (UK)

Directional amplification in driven-dissipative bosonic chains is topological

Abstract:
Engineered photonic systems featuring topological properties offer novel possibilities for designing light transport. Compared to their electronic counterparts, the most peculiar features of these systems are due to their driven-dissipative nature. Yet their topological properties are usually defined at the level of isolated systems. In this talk I will show that non-reciprocal amplification in translationally invariant open quantum systems has a topological origin. I will consider driven-dissipative bosonic chains where dissipation enters both locally and through a dissipative interaction mediated by an engineered reservoir. For such systems I will show a one-to-one correspondence between a non-trivial topological invariant defined on the spectrum of the dynamical matrix and directional amplification, in which the gain grows exponentially with the number of sites. I will further show how all the relevant information is encapsulated in the scattering matrix, for which it is possible to derive a 'topological phase diagram'. I will finally explain how these results provide a guiding principle for designing new modular directional amplifiers.

Giovanni Chesi
University of Insubria, Como

Quantifying nonclassicality and qualifying photodetectors through autocorrelation functions

Abstract:
Glauber's autocorrelation function [1] is a powerful and versatile tool for the characterization of light statistics and as a matter of fact it is well-known and extensively used in quantum optics. Here we employ the autocorrelation function for both, the characterization of nonclassical states of light and the estimate of the spurious effects due to the detectors [2]. In particular, we investigate the statistical properties of multi-mode twin-beam states in a mesoscopic regime [3] and assess the performance of the new generation of Silicon Photomultipliers, a novel class of photon-number resolving detectors [4]. One of the drawbacks of these devices which is mostly detrimental for the reconstruction of statistics is the optical cross-talk , i.e. the occurrence of events from avalanches triggered by Bremsstrahlung radiation [5]. We show that an estimation of the cross-talk probability, as well as of the mean number of dark-count events, can be provided through a suitable formulation of the autocorrelation function. Last but not least, we highlight the role of the autocorrelation as a function of the photon-number difference in testing nonclassical light [2].

References
[1] R. Glauber, Phys. Rev. 130, 2529-2539 (1963)
[2] G. Chesi et al., Q. Meas. (2019), in press
[3] A. Allevi et al., Sci. Rep. 7, 16787 (2017)
[4] M. Bondani et al., J. Mod. Opt. 56, 226-231 (2009)
[5] F. Nagy et al., Nucl. Inst. and Met. in Phys. Res. A 759, (2014)

Francesco Ciccarello
University of Palermo

Decoherence-free mediated Hamiltonians in waveguide QED

Abstract:
Engineering decoherence-free (DF) mediated Hamiltonians has become an important task for quantum technologies. These are multipartite effective Hamiltonians that arise from second-order, indirect, interactions mediated by a quantum bus that yet does not introduce decoherence.
Recently, it was discovered that DF mediated Hamiltonians with tunable coupling strengths can arise in waveguide-QED setups featuring a collection of systems (such as resonators or qubits) non-locally coupled to a waveguide. Such settings can be implemented for instance with superconductor qubits and MW transmission lines ("giant atoms").
Through a simple collision-model formulation, a general condition for realising a DF mediated Hamiltonian and the form of this are identified. It is shown that the key requisite is having an ordered sequence of elementary system-mediator interactions whose average vanishes due to destructive interference.
We show that longstanding adiabatic elimination methods in quantum optics, on the one hand, and novel waveguide-QED schemes exploiting non-local couplings on the other hand are two particular applications of this general framework.

Valeria Cimini
University of Roma Tre

Tracking enzyme activity with quantum light

Abstract:
One of the most sought application of Quantum Metrology is the implementation of quantum biosensors. The reason behind this is the need of non-invasive probes that may damage or alter the activity of the biological specimen. It is then necessary to look at a trade-off between the amount of modification and the quality of the measurement. The origin and details of the bound on the uncertainty are captured by inspecting the behavior of light at the quantum level. Quantum metrology is the art of identifying how quantum properties need being controlled and measured, and provides clear guidelines on preparing the best possible probe for a given intensity. Using quantum light superior precision is possible.
We applied methods of quantum metrology, using single photon N00N state, to monitor the activity of an enzymatic reaction that leads to a change in optical activity of the products with respect to that of the substrate material. We have employed this technique with a well known biochemistry reaction the hydrolysis of sucrose enabled by invertase. In this reaction, sucrose, a right-handed optically active molecule, is hydrolyzed into fructose and glucose, whose mixture has a left-handed activity.
Quantum light probes are generated by means of two-photon quantum interference, starting with a pair of photons in orthogonal linear polarizations. Since the photons are indistinguishable, in the circular polarizations the behavior is that of a quantum superposition of the two photons being both in the same polarization state. By passing through the sample, the photon pair accumulates an optical phase Ï•, as a consequence of optical activity. This occurs twice as fast as for classical light, hence ensuring superior accuracy. We measure in real time the change of optical activity of a sucrose solution after adding invertase to the sample. We record the kinetics at room temperature with two different invertase concentrations, 10 mg/ml and 20 mg/ml at a sampling rate of 37 s. For each point, the choice of the measurement is optimized with an adaptive scheme to ensure each phase is estimated close to the ultimate precision. In conclusion we also investigated possible effect of laser light on invertase activity, additional reactions were carried out with invertase samples illuminated for 1 h with laser at different frequencies and intensities. Comparison to untreated (i.e. not illuminated) invertase revealed that light exposure is detrimental to enzymatic activity, supporting the development of the quantum metrology approach for non-invasive measurements.

Nicola Dalla Pozza
University of Florence

Smart noisy quantum walks

Abstract:
The formalism of quantum stochastic walks has allowed to effectively investigate the capability of energy and information transport between distant points in very large complex structures. Interestingly, the assistance of external noise in the network evolution has shown an advantage over networks with both pure unitary evolution and classical random walks. The optimal mixing of classical and quantum transport is remarkably universal for a large class of networks. A similarity between quantum stochastic networks and neural networks can be recognized, with nodes of the former which can be organized in input, hidden and output layers as in the latter network framework. From this parallelism it emerges the possibility to investigate the role of classical and quantum machine learning over a quantum system.

Giacomo De Palma
MIT Boston (USA)

New lower bounds to the output entropy of multi-mode quantum Gaussian channels

Abstract:
We prove that quantum thermal Gaussian input states minimize the output entropy of the multi-mode quantum Gaussian attenuators and amplifiers that are entanglement breaking and of the multi-mode quantum Gaussian phase contravariant channels among all the input states with a given entropy. This is the first time that this property is proven for a multi-mode channel without restrictions on the input states. A striking consequence of this result is a new lower bound on the output entropy of all the multi-mode quantum Gaussian attenuators and amplifiers in terms of the input entropy. We apply this bound to determine new upper bounds to the communication rates in two different scenarios. The first is classical communication to two receivers with the quantum degraded Gaussian broadcast channel. The second is the simultaneous classical communication, quantum communication and entanglement generation or the simultaneous public classical communication, private classical communication and quantum key distribution with the Gaussian quantum-limited attenuator.

Dario De Santis
ICFO (Spain)

Equivalence between non-Markovian dynamics and backflows of correlation measures

Abstract:
The study of open quantum systems dynamics is of central interest in quantum mechanics. When the environment that surrounds a quantum system is included in the description of its evolution, we say that the quantum system is open. Therefore, since there are no experimental scenarios where a quantum system is completely isolated, this approach provides a far more realistic description of physical evolutions.
The interaction between an open quantum system and its environment may lead to two different phenomenological regimes. The Markovian regime is characterized by a contractive behavior, where the information encoded in the system is continuously lost and flows into the environment. Instead, in the non-Markovian regime, this flow is not unidirectional and part of the information lost is recovered in one or more time intervals. These phenomena are called backflows of information.
While the phenomenological description of these two regimes can be described clearly, understanding which is the mathematical framework that reproduces them is not obvious. Nonetheless, the description that associates Markovian evolutions with a precise divisibility feature (CP-divisibility) of dynamical maps, namely the superoperators that describe the evolution of open quantum systems, has recently achieved a promising consensus.
Many efforts are directed to test this definition studying the characteristic contractive/non-contractive behavior of different physical quantities when the evolution is Markovian/non-Markovian. Therefore, once we consider a quantity that is contractive under any Markovian evolution, we can study its “non-Markovian witnessing potential”, namely its ability to show backflows when the dynamics is not Markovian. Hence, we look for one-to-one connections between backflows and non-Markovianity. Indeed, only in this case we can consider CP-divisibility a correct mathematical definition for Markovianity.
We focus on the behavior of correlation measures of bipartite systems that evolve under non-Markovian evolutions. Several measures of correlations have already been considered. However, none of them able to witness all non-Markovian dynamics. The main result of this work is a one-to-one relation between backflows of correlation measures and non-Markovianity. Indeed, we introduce a class of correlation measures for bipartite systems that provides backflows if and only if the evolution is not Markovian. In particular, exploiting an enlarged setting that considers wisely chosen ancillary systems, we introduce a class of initial probe states that allows to succeed in this witnessing task. Finally, for almost all non-Markovian dynamics, this measure can be evaluated through semi-definite programming.

This contribution is based on arXiv:1805.00920 (accepted in Phys. Rev. A) and arXiv:1903.12218.

Daniele Dequal
Agenzia Spaziale Italiana

Feasibility of continuous variable QKD from satellite

Abstract:
Satellite communications are considered today as the most promising solution for extending quantum key distribution (QKD) to a global scale. As demonstrated by the Chinese satellite Micius, satellite QKD can be used for the encryption of long-range communication, up to intercontinental distances. The next challenge in this field is the reach of high bandwidth, which are required for real life applications. A possible solution may come from continuous variable (CV) encoding, which could inherit many of the technologies already developed and space-qualified for high speed optical communication in the classical regime. In this work, we focus on the feasibility of CV-QKD from satellite to a ground station. At first, we modeled the channel properties, such as attenuation and induced noise, with a particular emphasis on the fluctuations due to pointing error effects. Then, we estimate the expected key rates under realistic assumptions for the payload and receiving station. The inclusion of finite size effects in the analysis will set a tradeoff between the segmentation of the orbit based on channel transmissivity and the optimal block size for data analysis. The result of the analysis shows the feasibility of satellite CV-QKD for low Earth orbit satellites in a single orbit passage, while for higher orbits finite size effects prevent any communication. This work provides quantitative information about the achievable key rate for satellite CV-QKD in relevant scenarios, highlighting its potential and pointing out critical requirements for its actual implementation.

Donato Farina
Scuola Normale Superiore, Pisa

Quantum bath statistics tagging

Abstract:
Motivated by the recent advances in quantum metrology and by the renewed interest in its application to thermometry, we propose a procedure to discriminate the statistics of a thermal bath using quantum probes and quantum state discrimination.
Since a probe responds differently to the interaction with fermionic and bosonic environmental modes, we can recover information on the nature of a thermal bath by performing a measurement on a system weakly coupled with the environment of interest.
We will also discuss how to achieve the greatest precision in this statistics tagging scheme, by discussing different probes and different initial preparations and by optimizing over the time of exposure of the probe. To give a quantitative description we rely on common figures of merit of quantum metrology, such as the Holevo-Helstrom probability of error and the Quantum Chernoff bound.

Simone Felicetti
Universidad Autónoma de Madrid (Spain)

Finite-size phase transitions for quantum metrology

Abstract:
Metrological quantum advantage is usually defined as the precision that can be achieved in the estimation of a physical parameter, as a function of the number of probe systems. The maximum precision achievable with classical systems scales linearly with the number of probes, while the optimal quantum strategy achieves a quadratic scaling, known as the Heisenberg limit. It is well known that some quantum systems can undergo a critical phase transition in the thermodynamic limit, where the number of constituents becomes macroscopic. In proximity of a quantum phase transition the system susceptibility diverges, apparently leading to a super-Heisenberg scaling of the estimation precision. However the divergence of the susceptibility is counterbalanced by the vanishing energy gap, which makes the estimation protocol slower and slower as the critical point is approached. Once the estimation time is put back in the analysis, the optimal Heisenberg scaling is obtained.
In this contribution, we present metrological protocols which make use of a finite-size quantum phase transition, which has been predicted to take place also for a system composed of a single two-level atom coupled to a single bosonic mode. In this case the thermodynamic limit is replaced by a diverging scaling imposed on a Hamiltonian parameter. Under realistic noise conditions, we compare the metrological performances of standard Ramsey interferometry protocols with two strategies that exploit the finite-size criticality: an adiabatic following and a driven-dissipative setting. In particular, we evaluate analytically the quantum Fisher information, which is a measure of the optimal estimation precision. We focus on the optimal scaling of the quantum Fisher information with respect to the estimation time, both for short- and long-time evolution limits. Finally, we discuss how the proposed protocols could be applied to implement a quantum magnetometer using nowadays atomic and solid-state quantum technologies.

Luca Ferialdi
University of Trieste

Optimal control for feedback cooling in cavityless levitated optomechanics

Abstract:
We consider feedback cooling in a cavityless levitated optomechanics setup, and we investigate the possibility to improve the feedback implementation. We apply optimal control theory to derive the optimal feedback signal both for quadratic (parametric) and linear (electric) feedback. We numerically compare optimal feedback against the typical feedback implementation. In order to do so, we implement a tracking scheme that takes into account the modulation of the laser intensity. We show that such a tracking implementation allows to increase the feedback strength, leading to a faster cooling rate and to a lower temperature.

Manuel Gessner
Ecole Normale Superieure, Paris (France)

Nonlinear Spin Squeezing

Abstract:
The well-known spin squeezing coefficient efficiently quantifies the sensitivity and entanglement of Gaussian states. However, this coefficient is insufficient to characterize the much wider class of highly sensitive non-Gaussian quantum states. In this talk, we present an extension of spin squeezing based on reduced variances of nonlinear observables. An optimization of the measurement observable under experimental constraints further allows us to identify those observables that will yield the highest achievable sensitivity and the strongest criterion for entanglement. Our results can be used to identify optimal quantum-enhanced phase estimation protocols and entanglement witnesses for increasingly complex quantum states.

Paolo Giorda
University of Pavia

State independent uncertainty relations from eigenvalue minimization

Abstract:
One of the very fundamental features of quantum physics is complementarity. The latter manifests itself in a ubiquitous way in all quantum physics and it is at the basis of various phenomena and applications. A fundamental effect of complementarity is preparation uncertainty. The latter was first highlighted by Heisenberg in terms of its famous uncertainty relations, involving “products of variances” of two non-commuting operators. The latest development in this research framework have restated the problem in terms of the “sum of variances”. This formulation of the task of quantifying preparation uncertainty allows on one hand to overcome some of the problems limiting the use of the product version. On the other hand it poses new challenges since the typical desired quantifier i.e., the state independent lower bound for the sum of variances l_b, is extremely difficult to evaluate in the general case i.e., for a set of N generic operators. This is especially true when the operators involved do not share any special relation e.g., symmetries. We show that a general answer to this problem can in fact be provided. By means of a simple, yet powerful, mapping into an eigenvalue problem, we are able to devise a procedure allowing for the estimation of the searched lower bound l_b.In simple cases the method provides the exact value of l_b. When this is not possible, the method allows one: 1) to derive an approximation of l_b from below that itself constitutes a meaningful state independent lower bound; 2) to derive an approximation from above of l_b and the corresponding state that achieves such approximation; 3) the combination of 1) and 2) allows one to estimate the relative error involved of the approximation obtained. 4) the state determined with 2) allows one to identify a possible experimental implementation that approximately realizes the least uncertainty situation. The method is general since it works for sum of variances involving a generic set of N operators. By applying the method to several relevant examples and we show that the approximation obtained is always very satisfactory. Indeed, the relative error with respect to the true known or numerically evaluated lower bound l_b is always, for the presented examples, of the order of few percentage points. While the main general results are stated for bounded operators, by means of a specific example we show that the method introduced can also be applied to unbounded operators.

Giacomo Guarnieri
Trinity College Dublin (Ireland)

Autonomous phonon-induced steady-state coherence in double quantum dot systems

Abstract:
Coherence, being at the root of any interference phenomenon, represents a ubiquitous and central notion in Physics and genuinely marks a departure, together with entanglement, of Quantum Theory from the Classical one. Every realistic quantum system has to be considered as "open" in light of its unavoidable interaction with its surroundings. The resulting reduced non-unitary dynamics takes into account for irreversible processes, such as decoherence and dissipation [1]. Especially the former still withstands among the major obstacles to all the countless applications relying on the maintenance and exploitation of quantum coherence [2], ranging from quantum transport, metrology and state engineering, to even relatively far fields such as quantum thermodynamics and quantum biology. Due to this, lots of efforts have thus been devoted to conceive strategies to fight against the detrimental effects of environmental couplings [3].
In this work [4] we provide sufficient conditions concerning the structure of a system-bath interaction Hamiltonian which allow to generate (rather than just preserve) steady-state coherence (SSC) in the energy eigenbasis of the free system Hamiltonian, without the need of any external coherent driving or measurement procedure.
We prove that such SSC are independent on the initial state of the system, which can thus also be taken as incoherent, and we study their dependence on relevant dynamical parameters.
Finally, we show [5] the implementability of the above SSC generating system-bath interaction in a concrete experimental platform. The latter consists of semiconductor double-quantum-dot (DQD) systems, where the interaction between the two level system, i.e. a charge qubit, and the phonon substrate on which they are situated can be tuned in order to generate SSC.
Remarkably, we conclude by showing how that the latter can be used to induce a displacement of a cavity mode surrounding the system that can be experimentally measured through standard homodyne detection.

REFERENCES

[1] H.-P. Breuer and F. Petruccione, The Theory of Open Quantum Systems (Oxford University Press, 2002)
[2] S. F. Huelga and M. B. Plenio, Contemporary Physics 54, 181 (2013)
[3] A. Streltsov, G. Adesso, and M. B. Plenio, Rev. Mod. Phys. 89, 041003 (2017).
[4] G. Guarnieri, M. Kolar, R. Filip, Phys. Rev. Lett. 121, 070401 (2018)
[5] A. Purkayastha, G. Guarnieri, M. Mitchison, R. Filip, J. Goold, in preparation (2019)

Karen Hovhannisyan
ICTP Trieste

Quantum measurements of work fluctuations

Abstract:
Characterizing the fluctuations of work in coherent quantum systems is notoriously problematic. Aiming to reveal the ultimate source of these problems, we consider isolated systems and require the sheer minimum---the first and second laws of thermodynamics and the quantum-classical correspondence principle must be satisfied by any valid measurement of work. Specifically, the average work must be equal to the difference of initial and final average energies and, moreover, untouched systems must exchange deterministically zero work. Furthermore, the Jarzynski equality must hold for all thermal initial states, encapsulating both the second law and correspondence principle. We prove that neither state-independent nor state-dependent procedures for measuring the fluctuations of work can simultaneously satisfy these conditions, thereby excluding virtually any conceivable work measurement scheme. Our results thus mean that the first and second laws and the correspondence principle essentially eliminate the possibility of describing the fluctuations of quantum work by means of a classical random variable.

Zixin Huang
University of Sheffield (UK)

Boson Sampling Private-Key Quantum Cryptography

Abstract:
We introduce a quantum private-key encryption protocol based on multi-photon interference in linear optics networks. The scheme builds upon Boson Sampling, and we show that it is hard to break, even for a quantum computer. We present an information-theoretic proof of the security of our protocol against an eavesdropper with unlimited (quantum) computational power but time-limited quantum storage. This protocol is shown to be optimal in the sense that it asymptotically encrypts all the information that passes through the interferometer using an exponentially smaller private key. This is the first practical application of Boson Sampling in quantum communication. Our scheme requires only moderate photon numbers and is experimentally feasible with current technology.

Athena Karsa
University of York (UK)

Entanglement-free quantum radar

Abstract:
With the aim to loosen the entanglement requirements of quantum illumination, we study the performance of separable but correlated Gaussian states at the transmitter, combined with an optimal and joint quantum measurement at the receiver. This corresponds to a discord-based type of radar that extends the classical model of noise radar to the quantum realm. We establish that, in the setting of asymmetric hypothesis testing, the use of a separable discordant source is capable of achieving effective signal-to-noise ratios that are comparable to maximally entangled sources under symmetric testing. We also provide new bounds for error probability exponents, allowing comparison of sources with arbitrary quadrature correlations and quantify parameters in terms of those well-known and used in the classical radar equation. Employing Albersheim's equation as a classical benchmark we show that entanglement-free discord-based quantum radar based on separable but correlated Gaussian states has a superior performance at relatively short ranges.

Matteo Lostaglio
ICFO (Spain)

Coherence and asymmetry cannot be broadcast

Abstract:
In the presence of conservation laws, superpositions of eigenstates of the corresponding conserved quantities cannot be generated by quantum dynamics. Thus, any such coherence represents a potentially valuable resource, which can be used, for example, to enhance the precision of quantum metrology or to enable state transitions in quantum thermodynamics. Here we ask if such superpositions, already present in a reference system, can be broadcast to other systems, thereby distributing it indefinitely at the expense of creating correlations. We prove a no-go theorem showing that this is forbidden by quantum mechanics in every finite-dimensional system. In doing so we also answer some open questions in the quantum information literature concerning the sharing of timing information of a clock and the possibility of catalysis in quantum thermodynamics. We also prove that even weaker forms of broadcasting, of which Aberg's `catalytic coherence' is a particular example, can only occur in the presence of infinite-dimensional reference systems. Our results set fundamental limits to the creation and manipulation of quantum coherence and shed light on the possibilities and limitations of quantum reference frames to act catalytically without being degraded.

Joint work with M. P. Mueller. To appear in PRL. ArXiv:1812.08214

Luca Mancino
Queen's University Belfast (UK)

Non-equilibrium quantum thermometry

Abstract:
The strategies aiming at buoying up measurement accuracies through quantum peculiarities have been one of the purposes of quantum thermodynamics, where an accurate control of the temperature is highly demanding. New efforts have been addressed to perform such measurements at even smaller scales, in which the systems to be probed might be sensitive to external disturbances. In order to overcome this sought-after requirement, the implementation of temperature measurements by means of single-particle systems has been strikingly considered. On the one hand, the isolation of a single element simplifies the way the probe interacts with the reference system, on the other it shifts the focus on its internal energy levels and, in the case of quantum systems, on the coherence among them. In conventional thermometry, in which the probe is expected to thermalize with the reference sample, the Einstein Theory of Fluctuations establishes a neat correspondence between the thermal susceptibility of the system and the external perturbations imposed by the sample. Equilibrium measurements, however, cease to be ideal when dealing with unstable reference systems demanding for non-equilibrium schemes working far from thermalisation. In this case, we have demonstrated that the conditions dictated by Einsteinâ€™s theory lose their validity on behalf of more general inequalities allowing to bridge information and thermodynamic aspects. Our results endorse non-equilibrium quantum thermometry works best, and shed light on the role of quantum coherence and correlations in the remit of quantum thermodynamics. We have pinpointed the origin of this behaviour looking at the dynamics of the probes onto Riemannian manifolds, introducing geometrical figures of merit able to assess the speed of thermalisation, and the energy dissipation for both classical and quantum preparations of the probes. These considerations allow us to introduce geometric upper and lower bounds on the irreversible entropy production, and to give insights on the entropy required to lose the knowledge of the initial state of the thermometer, thus underpinning the intrinsic duality between information and thermodynamics.

Antonio Mandarino
University of Gdansk (Poland)

Quantum thermal analogues of electronic devices

Abstract:
We address the study and design of the thermal quantum analogues of electronic devices. In particular, one needs a system composed of two or three qubits to build a thermal diode or a thermal transistor, respectively. The qubits are strongly interacting among them and in addition each of them is plugged to a separate and independent reservoir that acts as thermostat, i.e. its own temperature remains fixed and it is not affected by the interaction with the system supposed small in comparison with it. By means of a dissipative equation we study the steady-states currents exchanged by the system and the heath bath in function of an incoherent control parameter, such as the temperature of one of the thermostats, this allow to compute the rectification and the amplification of the currents in diode case and transistor case respectively. We discuss thoroughly some experimentally implementable setups like a spin chain or single molecule magnets. Our analysis suggests that a proper engineering of molecular nanomagnetic systems, whose effective interactions well approximate the considered ones, can be the best candidate to build such described devices. in addition, aiming at a feasible realization, different regime of validity and robustness are considered, and nevertheless experimental limitations are discussed.

Stefano Marcantoni
University of Trieste

Fluctuation Relation and Quantum Detailed Balance in open quantum systems

Abstract:
I will show that, for open quantum systems undergoing thermalizing dynamics, quantum detailed balance implies the validity of a quantum fluctuation relation (where only forward-time dynamics is considered). However, the converse is not necessarily true; indeed, there are cases of thermalizing dynamics which feature the quantum fluctuation relation without satisfying quantum detailed balance.

Matthias Mueller
Institute of Quantum Control, Juelich (Germany)

Quantum Sensing via Coherent and Dissipative Control

Abstract:
The dynamics of quantum systems are unavoidably influenced by their environment and in turn observing a quantum system (probe) can allow one to measure its environment: Dynamical decoupling sequences as an extension of the Ramsey interference measurement allow to spectrally resolve a noise field coupled to the probe [1]. Here, we report also on dissipative manipulations of the probe leading to so-called Stochastic Quantum Zeno (SQZ) phenomena that can be seen as an extension of the Rabi measurement. Recently, we could detect time correlations in the noise through an ergodicity breaking in SQZ dynamics [2], and the concept was experimentally demonstrated with a BEC on a chip [3]. We present a robust method to reconstruct an unknown spectrum from measurements of the survival probability of the SQZ dynamics.

[1] C. L. Degen, F. Reinhard, and P. Cappellaro, Rev. Mod. Phys. 89, 035002 (2017).
[2] M.M. Mueller, S. Gherardini, and F. Caruso, Sci. Rep. 6, 38650 (2016).
[3] S. Gherardini, C. Lovecchio, M.M. MÃ¼ller, P. Lombardi, F. Caruso, and F.S. Cataliotti, Quantum Science and Technology 2 (1), 015007 (2017).
[4] M.M. Mueller, S. Gherardini, A. Smerzi, and F. Caruso, Phys. Rev. A 94, 042322 (2016).
[5] M.M. Mueller, S. Gherardini, and F. Caruso, Scientific Reports 8, 14278 (2018).

Alessandro Seri
ICFO (Spain)

Quantum Storage of Frequency-Multiplexed Heralded Single Photons

Abstract:
Quantum Storage of Frequency-Multiplexed Heralded Single Photons Quantum memories for light are important devices in quantum information science, in particular for applications such as quantum networks and quantum repeaters [1]. It has been predicted that multimode quantum memories able to store independently multiple modes would greatly help the scaling of quantum networks by decreasing the entanglement generation time between remote quantum nodes [1]. Current research focuses mostly on time multiplexing in rare-earth doped crystals and in spatial multiplexing in atomic gases. Beyond these demonstrations, rare-earth doped crystals, thanks to their large inhomogeneous broadening, represent a unique quantum system which could also add another degree of freedom for multiplexing, the storage of multiple frequency modes [2].
We report on the first demonstration of quantum storage of a frequency-multiplexed heralded single photon into a laser-written waveguide integrated in a Pr-doped crystal . The great advantage of using a confined waveguide for this task is that the power required to prepare the quantum memory is strongly reduced due to the increased light-matter interaction in the waveguide [3]. This enables simultaneous preparation of several memories at different frequencies, with a moderate laser power. The memory protocol used is the atomic frequency comb (AFC). The frequency-multiplexed photon pair is created in a cavity-enhanced spontaneous parametric downconversion (CSPDC) source [3], with one photon in resonance with a transition of Pr and the other at telecom wavelength. We show that we can store the main part of the spectrum of the multiplexed photon (about 15 modes). The intrinsic temporal multimodality of the AFC protocol, for a storage time of 3.5 mus, allows us to store about 9 temporal modes, resulting in more than 130 stored modes. The measured cross-correlation and heralded autocorrelation of the stored photons violate the classical bound.
Our results show that integrated laser written waveguides can be used as powerful light-matter interaction platforms with both time and frequency multiplexing capabilities. The unique 3 dimensional fabrication capability of this technique also hold promises for implementing large memory arrays in one crystal. The ability to combine several multiplexing capabilities in one system would open the door to the realization of massively multiplexed quantum memories.

[1] N. Sangouard et al, Rev. Mod. Phys. 83, 33 (2011)
[2] N. Sinclair et al, Phys. Rev. Lett. 113, 053603 (2014)
[3] A. Seri et al, Optica 5, 934 (2018)

Nathan Shammah
RIKEN (Japan)

Quantum Information Science with QuTiP, the Quantum Toolbox in Python

Abstract:
I address the emergence of open-source software for numerical studies in quantum physics research [1,2]. QuTiP, the Quantum Toolbox in Python, (www.qutip.org) [3] is at the centre of a lively community of users, as well as an ecosystem of satellite libraries interested in modeling open quantum systems. I will show the main features of QuTiP's latest release (4.4, July 2019) and development version. They include efficient, flexible methods to study stochastic dynamics and to simulate noise in quantum information processing implemented in real devices. I will also show how we numerically studied cooperative effects in driven-dissipative many-body quantum systems out of equilibrium, such as superradiance [4], spin squeezing [5], and transport-assisted ground-state luminescence [6] by exploiting permutational symmetry to exponentially reduce the computational resources required to model Lindblad dynamics.

[1] NS and Shahnawaz Ahmed, *The rise of open source in quantum physics research*, *Nature* Physics's Blog,
http://blogs.nature.com/onyourwavelength/2019/01/09/the-rise-of-open-source-in-quantum-physics-research/
[2] NS, *interactive notebooks,* https://github.com/nathanshammah/interactive-notebooks
[3] J. Robert Johansson, Paul D. Nation, and Franco Nori, *QuTiP: An open-source Python framework for the dynamics of open quantum systems*, Comp. Phys. Comm. **183**, 1760 (2012); *ibid.* **184**, 1234 (2013).
[4] NS, Neill Lambert, Franco Nori, and Simone De Liberato, *Superradiance with local phase-breaking effects*, Phys. Rev. A **96,** 023863 (2017). https://arxiv.org/abs/1704.07066
[5] NS, Shahnawaz Ahmed, Neill Lambert, Simone De Liberato, and Franco Nori,
Open quantum systems with local and collective incoherent processes: Efficient numerical simulation using permutational invariance, Phys. Rev. A **98**, 063815 (2018). https://arxiv.org/abs/1805.05129
[6] Mauro Cirio, NS, Neill Lambert, Simone De Liberato, and Franco Nori, *Multielectron ground state electroluminescence*, Phys. Rev. Lett. 122, 190403 (2019) https://arxiv.org/abs/1811.08682

Andrea Smirne
University of Ulm (Germany)

Nonperturbative approach to general open quantum system dynamics

Abstract:
The understanding of the interaction of a quantum system with the surrounding environment is of crucial importance for modern physics, both from a theoretical and from a practical point of view. One of the main obstacles towards a fully satisfactory description of the dynamics of open quantum systems is certainly the characterization of non-Markovian dynamics, in which the memory effects due to the interaction with the environment cannot be neglected. While there are analytical, as well as numerical approaches which deal with specific models, or, in the best cases, with certain classes of models, the complexity of the treatment of quantum non-Markovian evolutions remains mostly intact, due to the high number of degrees of freedom of the possibly structured environment which affect the open-system dynamics.
Here, I will present a general nonperturbative approach to non-Markovian dynamics, which consists in dividing the influence of the environment on the open system into a non-Markovian core, which encloses all the memory effects during the evolution, and a further Markovian component, representing the unidirectional leakage of information out of the non-Markovian core. The method is built on an equivalence theorem, recently derived in [1], which proves that a Gaussian bosonic environment evolving unitarily can be replaced by a Gaussian bosonic environment undergoing a Lindblad dynamics without changing the reduced dynamics of the open system interacting with it, if the first moments and the two-time correlation functions of the original and the auxiliary baths are the same at all times. Starting from this result, a systematic procedure can be developed [2] to formulate auxiliary effective environments consisting of few bosonic degrees of freedom, typically a network of damped interacting harmonic oscillators, in this way reducing dramatically the complexity of the model under study. On the one hand, this allows for the evaluation of general, possibly highly non-Markovian evolutions by applying efficiently standard numerical techniques to simpler Lindbladian open-system dynamics. On the other hand, it sets the ground for the systematic design of quantum simulators reproducing in a certified way the dynamics of quantum systems subject to complex environments.

[1] D. Tamascelli, A. Smirne, S.F. Huelga, and M.B. Plenio, Nonperturbative Treatment of non-Markovian Dynamics of Open Quantum Systems, Phys. Rev. Lett. 120, 030402 (2018).
[2] F. Mascherpa, A. Smirne, D. Tamascelli, P. Fernandez Acebal, S. Donadi S.F. Huelga, and M.B. Plenio, Optimized auxiliary oscillators for the simulation of general open quantum systems, arXiv:1904.04822

POSTER PRESENTATIONS

Gian Marcello Andolina
Scuola Normale Superiore, Pisa

Extractable work, the role of correlations, and asymptotic freedom in quantum batteries

Jamie Anguita
Universidad de los Andes (Chile)

Accurate Optical Vortex Identification in Turbulence Using a Shack-Hartmann Sensor

Matteo Bina
Applied Materials Italia

Engineering Solid-State Qubits Structures for High-Temperature Silicon Quantum Computing Through Multi-Scale Simulations

Claudio Bonizzoni
University of Modena and Reggio Emilia

Coherent manipulation of molecular spin ensembles by microwave pulse sequences

Dominic Branford
University of Warwick (UK)

Quantum enhanced estimation of diffusion

Lorenzo Buffoni
University of Florence

Reinforcement learning on a quantum maze

Alessia Castellini
University of Palermo

Indistinguishability-enabled coherence for quantum metrology

Marco Cattaneo
IFISC - Universitat de les Illes Balears (Spain)

Local vs global master equation of two coupled qubits: a thorough discussion

Stefano Chessa
Scuola Normale Superiore, Pisa

Lieb-Robinson bound and applications in Quantum Information

Wayne Jordan Chetcuti
University of Malta (Malta)

Charging a Many-Body Quantum Battery

Dario Ciluffo
University of Palermo

Long-time photo-count Quantum Corrrelation in WQED systems

Emanuele Distante
MPG Garching (Germany)

Time Entanglement between a Photon and a Spin Wave in a Multimode Solid-state Quantum Memory

Alessandra Gatti
University of Insubria, Como

Engineering multipartite entanglement in nonlinear photonic crystals

Marco Fanizza
Scuola Normale Superiore, Pisa

Local and global estimation of quantum state overlap

Kianvash Farzad
Scuola Normale Superiore, Pisa

Optimal Quantum Subtracting Machine

Simone Felicetti
Universidad Autónoma de Madrid (Spain)

Non-Hermitian Hamiltonians in Molecular Cavity QED

Louis Garbe
Universitè Paris Diderot (France)

Metrological quantum advantage with finite-size phase transition

Francesco Garrisi
University of Pavia

Self-pumped emission of heralded single photons from a silicon microring resonator

Stefano Gherardini
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Non-Markovianity of quantum evolutions and multi-time statistics

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Quantum metrology with squeezed states

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Detecting ultrastrong coupling by nonequilibrium photon distributions

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Quantumness and memory of an open qubit under classical control

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Randomized benchmarking for individual quantum gates

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Correlated photon emission by two excited atoms in a waveguide

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Exploring quantumness in a PT-symmetric system

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Multi-mode squeezing distribution in waveguide arrays

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Is ESIC stronger than Realignment criterion?

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Trainable Artificial Neuron Efficiently Implemented on NISQ Quantum Computers

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Twins Percolation for Qubit Losses in Topological Color Codes

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Optimal Gaussian Metrology for Generic Multimode Interferometric Circuit

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Integrated entangling quantum logic gate in a scalable surface-electrode ion trap