IQIS 2016
Italian Quantum Information Science Conference

SAPIENZA
UNIVERSITÀ DI ROMA

IQIS 2016

9th Italian Quantum Information Science Conference

Rome, 20-23 September 2016

ABSTRACT BOOK

Table of contents

Young IQIS satellite event invited talks

Networking for Nerds

Alaina G. Levine

Quantum Success Solutions – Tucson, Arizona

It's elementary- networking is an absolute necessity in any career, and especially in science and engineering, and math. In fact, networking is not only critical to advancing your own career, but also to advancing scholarship itself. But what exactly is "networking"? It's more than just saying hello at a conference! Learn how to appropriately promote yourself and build a network. Discover how to "work a room", start conversations with people you have never met before, and obtain information that can set you on a path to career victory. Specific communications techniques that can help you be more confident in your networking will be discussed, as will the importance of and use of social networks.

Skill Bill

Antigone Marino

Institute of Applied Sciences and Intelligent Systems, Physics Department, University of Naples Federico II, Via Cinthia Monte S. Angelo, 80126 Naples, Italy

Nowadays, the job market is more and more selective. The possibility to have a good position becomes difficult in academia as well as industry. The technical skills are the first ingredient for a successful career, but often the competition with the others is played on other skills, which are more related to the character of the person. This does not mean owning them or not. A good training action will widen the spectrum of these skills as well as technical ones.

In scientific research skills such as networking, teamwork, decision-making and communication are the turbo needed to better optimize the work. We will review the most important of them, trying to focus on how today these are indispensable to the curriculum of a young researcher.

Invited talks

Invited talk

Multipartite steering of Gaussian states: monogamy constraints and cryptographical applications

Gerardo Adesso

School of Mathematical Sciences, The University of Nottingham, UK

We investigate EPR steerability of multimode Gaussian states by Gaussian measurements. On the one hand, we establish a monogamy--like constraint, preventing joint steerability of a single mode by Gaussian measurements on multiple group of modes; this follows by proving a strong subadditivity inequality for the log-determinant of covariance matrices [1]. On the other hand, we show that a recently introduced quantifier of Gaussian steering [2] obeys a Coffman-Kundu-Wootters--type monogamy inequality for arbitrary multimode Gaussian states. In the case of pure Gaussian states of three modes, we find that the residual steering emerging from such an inequality admits an operational interpretation, related to the key rate of a semi-device-independent implementation of quantum secret sharing, taking into account potential dishonesty of some of the parties [3]. A novel security analysis for the latter protocol is provided [4].

References

[1] G. Adesso and R. Simon, arXiv:1601.03226 (2016)
[2] I. Kogias, A. R. Lee, S. Ragy, G. Adesso, Phys. Rev. Lett. 114, 060403 (2015)
[3] Y. Xiang et al., arXiv:1603.08173 (2016)
[4] I. Kogias et al., arXiv:1603.03224 (2016)

Recent advancement in many-body quantum simulations

Simone Montangero

Ulm University and Center for Integrated Quantum Science and Technology (IQST), Germany

We review some recent advancements we have obtained in tensor network algorithms and their application to the study of correlated matter. We present novel approaches to study abelian and non abelian lattice gauge theories, open many-body quantum systems and systems with long range interactions or periodic boundary conditions. These novel approaches allowed us to obtain results on a variety of phenomena hardly accessible before, such as the Kibble Zurek mechanism in Wigner crystals, the out-of-equilibrium dynamics of the Schwinger model and the phase diagram of the disordered Bose-Hubbard model.

References

[1] E. Rico, T. Pichler, M. Dalmonte, P. Zoller, and S. Montangero, Phys. Rev. Lett. 112, 201601 (2014).
[2] A. H. Werner, D. Jaschke, P. Silvi, M. Kliesch, T. Calarco, J. Eisert, and S. Montangero, Phys. Rev. Lett. 116, 237201 (2016).
[3] P. Silvi, G. Morigi, T. Calarco, and S. Montangero, Phys. Rev. Lett. 116, 225701 (2016).
[4] T. Pichler, M. Dalmonte, E. Rico, P. Zoller, and S. Montangero, Phys. Rev. X 6, 11023 (2016).
[5] M. Gerster, M. Rizzi, F. Tschirsich, P. Silvi, R. Fazio, and S. Montangero, New J. Phys. 18, 15015 (2016).

Quantum control of two-qubit gates via dynamical decoupling filtering of 1/f noise

A. D'Arrigo (1), G. Falci (1,2,3), E. Paladino (1,2,3)
Dipartimento di Fisica e Astronomia, Università di Catania, Via Santa Sofia 64, 95123 Catania, Italy
CNR-IMM UOS Catania (Università), Consiglio Nazionale delle Ricerche, Via Santa Sofia 64, 95123 Catania, Italy
Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Via Santa Sofia 64, 95123 Catania, Italy

Entanglement is a fragile resource easily degraded by hardware-intrinsic noise sources. In solid-state nanocircuits, noise with 1/f power spectrum [1] represents the major obstacle toward reaching high-fidelity thresholds compatible with fault-tolerance and error correction. The design of quantum control of 1/f noise became a key requirement in the newly perspective of hybrid distributed architectures made of natural/artificial atoms and photons. In this presentation I will review our recent works on entanglement protection of 1/f noise via dynamical decoupling during both universal two-qubit gates and distribution through noisy communication channels.

I will present the integration of dynamical decoupling into a universal two-qubit gate in the presence of 1/f noise acting locally on each of the qubits forming the entangling gate. Both the case of pure dephasing and of depolarizing noise will be addressed investigating the gate efficiency under periodic, Carr-Purcell, and Uhrig dynamical decoupling sequences. For depolarizing noise with current noise figures in superconducting qubits, two-qubit gate errors $\sim 10^{-6}$, meeting the requirements for fault-tolerant quantum computation, can be achieved. The Carr-Purcell-Meiboom-Gill sequence turns out to be the most efficient procedure, stable for 1/f noise with UV-cutoff up to gigahertz [2]. For local pure dephasing, dynamical control allows for quantum sensing of 1/f noise. We find an analytic expression of entanglement fidelity in terms of noise filter functions allowing to single out the sequence-specific capability to bypass cumulants of the underlying non Gaussian processes.

Finally I will report two all-optical experiments demonstrating that purely local control also allows for on-demand entanglement restoration during distribution through noisy communication channels in the presence of non-Markovian dynamics [3]. The restored entanglement being a manifestation of ‘‘hidden’’ quantum correlations resumed by the local control [4].

References

[1] E. Paladino, Y. Galperin, G. Falci, and B. Altshuler, Rev. Mod. Phys. 86, 361 (2014).
[2] A. D'Arrigo, G. Falci and E. Paladino, Phys. Rev. A 94, 022303 (2016).
[3] A. Orieux, A. D’Arrigo, G. Ferranti, R. Lo Franco, G. Benenti, E. Paladino, G. Falci, F. Sciarrino and P. Mataloni Sci. Rep. 5, 8575 (2015).
[4] A. D'Arrigo, R. Lo Franco, G. Benenti, E. Paladino and G. Falci Annals of Physics 350, 211 (2014).

Quantum non-Markovianity induced by Anderson localization

Salvatore Lorenzo (1)

Federico Lombardo , Francesco Ciccarello and G. Massimo Palma(2)

(1) Quantum Technology Lab, Dipartimento di Fisica, Universita` degli Studi di Milano, 20133 Milano, Italy
(2) Dipartimento di Fisica e Chimica, Universita` degli Studi di Palermo, via Archirafi 36, I-90123 Palermo, Italy

As discovered by P. W. Anderson, excitations do not propagate freely in a disordered lattice, but, due to destructive interference, they localise. As a consequence when an atom interacts with a disordered lattice one indeed observes, a non-trivial excitation exchange between atom and lattice. Such non-trivial atomic dynamics will in general be characterised also by a non-trivial quantum information backflow, a clear signature of non-Markovian dynamics. To investigate the above scenario we consider a quantum emitter, or atom, weakly coupled to a uniform coupled-cavity array (CCA). If initially excited, in the absence of disorder, the emitter undergoes a Markovian spontaneous emission by releasing all its excitation into the CCA (initially in its vacuum state). By introducing static disorder in the CCA the field normal modes become Anderson- localized, giving rise to a non-Markovian atomic dynamics. We show the existence of a functional relationship between a rigorous measure of quantum non-Markovianity and the CCA localization. We furthermore show that the average non-Markovianity of the atomic dynamics is well-described by a phenomenological model in which the atom is coupled, at the same time, to a single mode and to a standard - Markovian dissipative bath.

From the first loophole-free Bell test to a quantum Internet

Ronald Hanson

QuTech and Kavli Institute of Nanoscience, Delft University of Technology

The realization of a highly connected network of qubit registers is a central challenge for quantum information processing and long-distance quantum communication. Diamond spins associated with NV centers are promising building blocks for such a network as they combine a coherent optical interface [1] (similar to that of trapped atomic qubits) with a local register of robust and well-controlled nuclear spin qubits [2].

Here we introduce the field of quantum networks and present an overview of the latest progress, including the first loophole-free violation of Bell's inequalities [3,4] and the realization of a robust quantum network memory with nuclear spin qubits using decoherence-protected subspaces [5].

References

[1] W. Pfaff et al., Science 345, 532 (2014).
[2] J. Cramer et al., Nature Comm. 7, 11526 (2016).
[3] B. Hensen et al., Nature 526, 682 (2015).
[4] B. Hensen et al., Scientific Reports 6, 30289 (2016).
[5] A. Reiserer et al., Phys. Rev. X 6, 021040 (2016).

Cut-and-paste restoration of entanglement-breaking channels

Antonella De Pasquale

Scuola Normale Superiore di Pisa, Italy

Quantum correlations represent a key ingredient for efficient quantum commnication between two or more parties. Physical communication lines are formally modelled as completely positive, tracepreserving maps, taking into account unavoidable sources of disturbance. Several protocols, based on local operations and classical communcation, aim to amplify and partially restore the correlations surived in the transmission process. In this context entanglement-breaking channels, mapping every bipartite state into a separable one, are considered useless for quantum communication objectives, as they get rid of all quantum correlations. In this work we overthrow this statement. We prove both theoretically and experimentally, that is possible to transmit quantum correlations having at disposal ONLY entanglement-breaking maps. We dub the theoretical mechanism underpinning this phenomenon CUT-AND-PASTE, as it consists in cutting and reshuffling the subparts of entanglement-breaking channels. We have successfully tested this mechamism in a quantum optics experiment, by monitoring the trasmission of singlephoton polarization states.

Noise-assisted quantum coherence - a case study with Gaussian states

Vittorio Illuminati

University of Salerno, Italy

We study monotones and measures of quantum coherence for Gaussian states of continuous-variable systems. In particular, we investigate a peculiar phenomenon of noise-assisted coherence and discuss its physical origin and operational meaning.

Invited talk

Quantum entanglement in curved spaces

Stefano Mancini

In the theory of quantum fields in curved spacetime, matter creation is associated with conformal symmetry breaking of the underling geometry, where the created pairs of particles and anti-particles with opposite momenta are entangled. We shall consider in this contribution three physical entities responsible for conformal symmetry breaking, namely mass of particles associated with the field, coupling between field and spacetime curvature, small gravitational disturbance (anisotropy). We then characterize entanglement generated from the vacuum state by the expansion of the universe. Given the relation between entanglement entropy and cosmological parameters we show how it is possible to extract information regarding the underlying geometry from the detected entanglement.

Quantum estimation: from foundations to quantum technology

Matteo G A Paris

Dipartimento di Fisica - Universita` di Milano

The quantum technology lab @ UniMI is a theoretical and experimental facility for the quantum characterization of states and operations. This talk contains a summary of the recent results obtained at QTL, which range from foundamental aspects at the interface between gravity and quantum mechanics to experimental implementation of quantum information protocols with both discrete and continuos variables.

Invited talk

Time-invariant entanglement and sudden death of non-locality

Sabrina Maniscalco

Turku Centre for Quantum Physics, Department of Physics and Astronomy, University of Turku

We investigate both theoretically and experimentally the dynamics of entanglement and non-locality for two qubits immersed in a global pure dephasing environment. We demonstrate the existence of a class of states for which entanglement is forever frozen during the dynamics, even if the state of the system does evolve at the same time non-local correlations, quantified by the violation of the Clauser-Horne-Shimony-Holt (CHSH)inequality, either undergo sudden death or are trapped during the dynamics.

Cold atomic gases and quantum simulation

Jean Dalibard

Collège de France et Laboratoire Kastler Brossel

Calculate or simulate? Predicting the evolution of a multi-component system is a challenge that can be solved by two different means: A direct mathematical analysis, or the comparison with a device that simulates its behaviour. Following the seminal proposal by Feynman [1], the second approach is now explored on a large scale to investigate some properties of quantum matter, from condensed matter physics and quantum chemistry, up to neutron stars and high energy physics [2-4]. In this talk I will briefly discuss the implementation of this quantum simulation program with cold gases of neutral atoms [5]. Through a few examples I will discuss the requirements needed for analog quantum simulation, present some recent achievements, and outline some of the main challenges of this vast research field.

References

[1] R.P. Feynman, Int. J. Theor. Phys. **21**, 467 (1982); See also S. Lloyd, Science **273,** 1076 (1996)
[2] J. I. Cirac and P. Zoller, Nature Phys. **8**, 264 (2012)
[3] P. Hauke, F. M. Cucchietti, L. Tagliacozzo, I. Deutsch and M. Lewenstein, Rep. Prog. Phys. **75**, 082401 (2012)
[4] I. M. Georgescu, S. Ashhab and Franco Nori, Rev. Mod. Phys. **86** , 153 (2014)
[5] I. Bloch, J. Dalibard, and S. Nascimbene, Nat. Phys. **8**, 267 (2012)

Manipulating the shape of ultrashort single photons

L. S. Costanzo (1,2), A. S. Coelho (3), D. Pellegrino (2), M. S. Mendes (4), L. Acioli (4), K. N. Cassemiro (4), D. Felinto (4), A. Zavatta (1,2), and M. Bellini (1,2)

(1) Istituto Nazionale di Ottica - CNR, Florence, Italy; (2) LENS and University of Firenze, Italy; (3) Instituto Camillo Filho, PI, Brazil; (4) Universidade Federal de Pernambuco, Brazil

We present recent results on the manipulation of the spectrotemporal shape of ultrashort single-photon wavepackets. These results were made possible by the development of sophisticated experimental tools that merge techniques from quantum and ultrafast optics [1]. In particular, we present the first experimental demonstration of the formation of zero-area single-photon pulses [2,3] obtained by propagating ultrashort heralded single photons through hot resonant rubidium atoms. Due to the huge bandwidth mismatch, almost no absorption takes place, so that single, heavily deformed, photons with a clearly negative Wigner function are still present at the exit of the cell. In addition to their fundamental interest, zero-area single photons may open exciting perspectives for novel quantum technologies, where ultrashort single photons can encode quantum information in their spectrotemporal shape and efficiently couple with atoms for its storage and manipulation [4].

References

[1] C. Polycarpou, et al., Phys. Rev. Lett. 109, 053602 (2012)
[2] L. S. Costanzo, et al., Phys. Rev. Lett. 116, 023602 (2016)
[3] M. D. Crisp, Phys. Rev. A 1, 1604 (1970)
[4] Sh. Petrosyan and Y. Malakyan, Phys. Rev. A 88, 063817 (2013)

Quantum metrology & sensing with twin beams: from sub shot noise imaging to quantum holometer

I. Ruo-Berchera, N. Samantaray, A. Meda, F. Scafirimuto, and **M. Genovese**

INRIM

In this talk, I will present the use of photon number correlations in twin beam in quantum imaging [1].

In particular I will mention two experiments addressed to beating sub shot noise limit [1a] and identifying an object in a preponderant background [1b] and I will summarize recent ideas for application to interferometry [1c].

Then I will describe in detail the realization of a sub-shot-noise (SSN) microscope providing imaging of the absorption profile of a sample with signal-to-noise ratio (SNR) exceeding the one of classical techniques at equal light intensity. The microscope operates in single-shot and wide-field regime (no scanning is required), thus it is suitable for dynamic imaging.

It is based on the non-classical and spatially multi mode correlations of squeezed vacuum, naturally generated by a traveling wave parametric amplifier. The noise of the image formed by the probe beam interacting with the sample is locally reduced by subtracting the correlated noise pattern measured on the other beam (reference) [2]. Moreover, the comparison with the reference beam provides the absolute value of the absorption, giving the possibility of quantitative analysis of the properties related to it. This differential imaging approach is indeed commonly used in UV-visible spectroscopy.

We have studied in detail the existing trade-off between spatial resolution and the noise reduction for this system, which comes from the finite size of the correlation area in the far field [2], the detection efficiency, as well as from other minor effect due to experimental imperfections. At present the SSN microscope has a noise reduction of 20% below the shot noise for each resolution cell (pixel) of 5mm in a matrix of about 8000 pixels. This is sufficient for wide-field imaging of complex structures. Increasing the spatial scale of the details, the noise reduction improves accordingly, e.g. for resolution of 25μm is 62% below shot noise and for 50 μm is 72% on average below shot noise level. At this scale, for example, it doubles the SNR of the classical differential technique for the same illumination level, or equivalently allows maintaining the same SNR reducing either the exposure time or the illumination level of four times. At the same time it provides an average improvement with respect to classical direct imaging (obtained by a single, shot noise limited beam) of more than 30% in terms of SNR.

A important point is that all the gained information at any spatial scale, i.e. at different level of detail, can be obtained by a posteriori elaboration of the same single shot taken at full resolution and eventually combined together.

We show the results on test samples, like ultra-thin metallic depositions on glass slide. These performances are far beyond the one reported in previous proofs of principle of SSN imaging [1] (where the resolution was 480mm and the average noise reduction was limited to about 50% of the shot noise, not sufficient to provide a real advantage (on average) on the direct shot-noise image. Phase contrast quantum enhanced microscopy has been also demonstrated in Ref. [3], with maximum resolution of 45 μm and the need of spatial scanning of the sample, not suitable for dynamic imaging.

We believe that this technique has the potentiality for a wide-spread use in absorption microscopy. The spatial resolution can be improved up to the 1 μm and the range of applicability, can be extended engineering highly non-classical bright squeezed vacuum sources in pulsed regime [2, 4].

References

1"Real applications of quantum imaging", M.Genovese, Journal of Optics, 18 (2016) 073002
1a. G. Brida, M. Genovese & I. Ruo Berchera, ”Experimental realization of sub-shot-noise quantum imaging,” Nature Photonics
1b E.Lopaeva, I.Ruo Berchera, I.Degiovanni, S.Olivares, G. Brida, M. Genovese Phys. Rev. Lett. 110, 153603 (2013)
1c "Quantum light in coupled interferometers for quantum gravity tests"; I. Ruo Berchera, I. P. Degiovanni, S. Olivares, M.Genovese; Phys. Rev. Lett. 110, 213601 (2013)
2. E. Brambilla, L. Caspani, O. Jedrkiewicz, L. A. Lugiato, and A. Gatti, ”High-sensitivity imaging with multi-mode twin beams”, Phys. Rev. A 77, 053807 (2008).
4, 227 (2010); G. Brida, M. Genovese, A. Meda, & I. Ruo Berchera, ”Experimental quantum imaging exploiting multimode spatial correlation of twin beams,” Phys. Rev. A 83, 033811 (2011).
3. T. Ono, R. Okamoto, S. Takeuchi, ”An entanglement-enhanced microscope”, Nature Communications 4, 2426 (2013).
4. T. Sh. Iskhakov, V. C. Usenko, U. L. Andersen, R. Filip, M. V. Chekhova, and G. Leuchs ”Heralded source of bright multimode mesoscopic sub-Poissonian light ”, Optics Letters 41, 2149-2152 (2016).

Quantum simulation in femtosecond-laser-written photonic circuits

Roberto Osellame

Istituto di Fotonica e Nanotecnologie (IFN) – CNR, Piazza L. da Vinci 32, 20133 Milano, Italy

The use of integrated optics in quantum optics experiments has introduced dramatic improvements in terms of stability and scalability of the set-up. In particular, femtosecond laser direct writing (FLDW) of photonic circuits enabled the manipulation of polarization encoded single photons and their use for advances quantum simulations in glass chips. As a further significant advantage, FLDW enabled the realization of 3D photonic circuits, introducing an additional dimension with respect to standard planar circuits. The unique 3D capabilities of this technology enabled the experimental investigation of the role of particle statistics in quantum phenomena as Anderson localization and Fano resonances, as well as photonic simulations of perfect state transfer protocols and on-chip manipulation of hyper-entangled states.

Practical challenges in quantum key distribution

E. Diamanti

CNRS, Telecom ParisTech

Quantum key distribution (QKD) promises unconditional security in data communication and is currently being deployed in commercial applications. Nonetheless, before QKD can be widely adopted, it faces a number of important challenges such as secret key rate, distance, size, cost and practical security. In this tutorial, we survey those key challenges and the approaches that are currently being taken to address them.

References

E. Diamanti, H.-K. Lo, B. Qi, Z. Yuan, npj Quantum Information (2016), quant-ph arXiv:1606.05853

Invited talk

Quantum optics with solid-state artificial atoms

Pascale Senellart

Centre for Nanoscience and Nanotechnology – C2N – CNRS UMR9001, Site de Marcoussis, Route de Nozay, 91460 Marcoussis, France
Physics Department, Ecole Polytechnique, F-91128 Palaiseau, France

Today, optical quantum protocols are limited by the low brightness of heralded single-photon sources based on frequency conversion and the probabilistic nature of linear two-photon gates. Deterministic sources and gates can be obtained based on natural or artificial atoms such as semiconductor quantum dots (QDs). To obtain efficient devices, an ideal atom–photon interface is required, where the QD interacts with only one mode of the optical field and is isolated from decoherence. This is challenging considering the randomness of QDs position and shape, and the sources of decoherence (phonons, charges) of the solid-state environment.

We have developed a near-optimal QD-photon interface. We have developed a technology to deterministically couple a single QD to a microcavity [1]. By adding an electrical control [2], the charge noise is minimized and the QD state is shown to be almost decoherence free. The QD-cavity devices present a record cooperativity of 12: the incident photons interact with the QD with probability 0.95, which radiates back in the cavity mode with probability 0.96. In such devices, the QD state can be coherently manipulated with a π-pulse obtained for only 3.8 incident photons [3].

Based on such structures, bright solid-state single-photon sources are reproducibly fabricated: the single photon purity is above 98% and the indistinguishability of successively emitted photons exceeds 98%. The brightness of the source exceeds by a factor 20 the one of parametric down-conversion sources with similar properties [4]. We also demonstrate the generation of long streams of photons that can contain more than 200 photons being more than 87% indistinguishable [5].

Finally, we have made progresses toward the development of deterministic optical gates. We report on devices performing as a nonlinear switch at the single-photon level that can convert a coherent pulse into a highly non-classical light wavepacket [6].

References

[1] A. Dousse et al. , Phys. Rev. Lett. 101, 267404 (2008)
[2] A. Nowak et al., Nature Communications 5, 3240 (2014)
[3] V. Giesz et al., Nature Communications 7, 11986 (2016)
[4] N. Somaschi, et al. Nature Photonics 10, 340 (2016).
[5] J. Loredo et al, Optica 3, 433 (2016)
[6] L. De Santis et al, arXiv:1607.05977

Invited talk

Quantum boundary conditions

Paolo Facchi

Dipartimento di Fisica, Università di Bari, I-70126 Bari, Italy
INFN, Sezione di Bari, I-70126 Bari, Italy

We discuss the quantum dynamics of a free particle in a bounded domain of physical space, bringing out both the analogies and the differences with the corresponding classical motion. In particular, we will consider the case of varying domains and/or boundary conditions, that can be viewed as a model of spacetime topology change. We will explicitly show how geometric terms yielding non-trivial Berry phases naturally arise, and, in the case of rapidly changing boundary conditions, we will exhibit a dynamical composition law ruling the superposition of different topologies. Possible experimental implementations are analyzed.

References

[1] M. Asorey, et al., J. Phys. A **46**, 102001 (2013);
[2] S. Di Martino, P. Facchi, Int. J. Geom. Meth. Mod. Phys. **12,** 1560003 (2015);
[3] P. Facchi, et al., Annals of Physics **372,** 201 (2016).

The ultimate rates of quantum communications

Stefano Pirandola

York Centre for Quantum Technologies

"Quantum communications promises reliable transmission of quantum information, efficient distribution of entanglement and generation of completely secure keys. For all these tasks there is a crucial question to answer: What are their optimal rates without quantum repeaters? Our work solves this basic question for two remote parties connected by a quantum channel in the most relevant practical scenarios, without imposing any restriction on their classical communication, which can be unlimited and two-way. To achieve our results, we first extend the notion of relative entropy of entanglement from quantum states to channels, proving a general upper bound for all the two-way assisted capacities. Then, we design a novel technique, dubbed "teleportation stretching", which reduces the most general adaptive protocols for quantum or private communication to a simple block form. In this way, we can simplify our upper bound to a single-letter expression for many fundamental channels, establishing exact formulas for the two-way assisted capacities of bosonic lossy channels, quantum-limited amplifiers, dephasing and erasure channels in arbitrary dimension. In particular, we determine the fundamental rate-loss scaling which affects any quantum optical communication, e.g., for long-distance quantum key distribution. By setting these limits, we also establish the most general and correct benchmarks for testing the performance of quantum repeaters."

Quantum Computing

Matthias Troyer

ETH Zurich (Switzerland)

With small-scale quantum computers on the horizons and first demonstration devices accessible it is timely to think about applications of quantum computers. In this tutorial I will give an introduction to quantum computing from a high performance computing point of view and discuss the steps needed to develop a quantum algorithm with quantum speedup into an application program that outperforms any classical computer. I will discuss which application areas are very promising and which ones are more speculative.

Quantum Interference with an Orbiting Correspondent

G. Vallone[1], D. Dequal[1], M. Tomasin[1], F. Vedovato[1] M. Schiavon[1], V. Luceri[2], G. Bianco[3] and P. Villoresi[1*],

- , Padova, Italy,
2e-GEOS spa, Matera, Italy,
3MLRO, Matera Laser Ranging Observatory, Agenzia Spaziale Italiana, Matera, Italy.
4Presenting author, paolo.villoresi@dei.unipd.it

Space Quantum Communications are considered as a novel arena for both providing the way to realize tests on the interplay of Quantum Physics and Gravity on very long scale and for terminals in relative motion as well as to provide a network of secure communications on planetary scale.

In the perspective to extend the realm of Quantum Communications toward larger distances, we would like to present the extension of the single photons exchange, initially demonstrated for Low Earth Orbit orbits to a source in Medium Earth Orbit, with a slant distance from the satellite to the station of over 7000 km.

Moreover, we would like to report on the experiment using the temporal modes of light as the physical degree of freedom used for the encoding of the qubit. This represent an evolution with respect to the polarization of the photon, used in the first demonstration of QC in Space.

References

1. D. Rideout et al., Fundamental quantum optics experiments conceivable with satellites reaching relativistic distances and velocities, Classical and Quantum Gravity 29, 224011 (2012).
R. Hughes and J. Nordholt, Refining Quantum Cryptography, Science 333, 1584 (2011).
P. Villoresi et al., Experimental verification of the feasibility of a quantum channel between space and Earth, New J. Phys. 10, 033038 (2008).
G. Vallone et al, Experimental Satellite Quantum Communications, Phys. Rev. Lett. 115, 040502 (2015).
D. Dequal et al. Experimental single photon exchange along a space link of 7000 km, Phys. Rev. A 93, 010301(R) (2016).
G. Vallone et al. Quantum interference along satellite-ground channels, Phys. Rev. Letters.

Young IQIS satellite event contributed talks

An Integrated Optical Memory based on Laser Written Waveguides

A. Seri (1), G. Corrielli (2), M. Mazzera (1), R. Osellame (2), H. de Riedmatten (1, 3)

(1) ICFO-Institut de Ciencies Fotoniques, Spain; (2) Istituto di Fotonica e Nanotecnologie (IFN), Italia; (3) ICREA-Instituci´o Catalana de Recerca i Estudis Avan, Spain

The efficient and reversible mapping of quantum states of light into collective excitations of atomic ensembles r epresents one of the most promising routes towards the realization of quantum memories. Rare earth doped crystals, in particular, offer long lived spin states and are naturally suitable for miniaturization and integration, e.g. in form of waveguides, of several quantum memories onto a single substrate, facilitating the scalability and, thanks to the tight confinement of light, leading to a strong enhancement of the light matter interaction. Pr3+: Y2SiO5 crystals are currently one of the best systems for quantum memory applications, in fact they exhibited very efficient storage of weak coherent states [1] as well as the longest storage time ever demonstrated in any system, in the regime of 1 minute, for classical images [2]. Moreover in this material, the first solid state spin-wave quantum memory has been recently demonstrated [3]. Despite this, only one approach for integration has been reported so far [4], but the weak coupling within the ions and the incoming light, occurring through the evanescent field, limited the implementation of optical pumping schemes necessary for the memory preparation.

We propose a new platform for integrated optical memory based on laser written waveguide. We fabricate single mode channel waveguide in Pr3+:Y2SiO5 with a technique called femtosecond laser micromachining [5]. We demonstrate that the waveguide inscription does not affect the coherence properties of the material and that the light confinement in the waveguide increases the interaction with the active ions by a factor 6. Finally, we perform storage and on-demand retrieval experiments with bright light pulses using the atomic frequency comb (AFC) protocol [6], demonstrating the first implementation of an integrated on-demand spin wave optical memory. This opens new perspectives for integrated quantum memories.

References

1. M. P. Hedges et al., Nature 465, 1052 (2010)
2. G. Heinze et al., Phys. Rev. Lett. 111, 033601 (2013)
3. M. Gündoğan et al., Phys. Rev. Lett. 114, 230502 (2015)
4. S. Marzban et al., Phys. Rev. Lett. 115, 013601 (2015)
5. F. Chen et al., Laser Photonics Rev. 8, 251 (2014)
6. G. Corrielli, A. Seri et al., arxiv 1512.09288 (2015)

Photonic Simulation of Entanglement Growth After a Spin Chain Quench

I. Pitsios(1)(2), L. Banchi (3), A. S. Rab (4), M. Bentivegna (4), D. Caprara (4), A. Crespi (1)(2), N. Spagnolo (4), S. Bose (3), P. Mataloni (4), R. Osellame (1)(2), F. Sciarrino (4)

(1) Istituto di Fotonica e Nanotecnologie - Consiglio Nazionale delle Ricerche (IFN-CNR), Italy
(2) Dipartimento di Fisica - Politecnico di Milano, Italy
(3) Department of Physics and Astronomy, University College London, United Kingdom
(4) Dipartimento di Fisica - Sapienza Università di Roma, Italy

The possibility of using photonic networks to investigate various physical phenomena, by implementing arbitrary unitary transformations, allows us to simulate many processes which are extremely difficult to investigate directly in they natural occurrences. An example of such complex physical processes is the transport of a quantum state in a spin chain [1], and the formation of “rainbow states”, which is the generation of multiple entangled states between spin chain sites symmetric to the centre [2], effect of entanglement growth in many-body systems due a sudden change in the Hamiltonian of system, known as quantum quench.
Investigating this phenomena finds its importance in the capability of quantum simulator to capture the extensive growth of entanglement in a many-body systems, seen in many areas of physics and hard, if not impossible, to achieve with classical computers.

In this work we simulate the quantum state transport (QST) in a 1D spin chain by the means of a quantum walk, possible due the fact that Jordan Wigner transformations can be used to map spin excitations into non-interacting fermions. This is achieved in a 5 waveguide integrated photonic device micro machined with femtosecond laser writing technology, and the possibility of simulating fermionic statistics in a photonic quantum network with entangled photons in an anti-symmetric state [3].

The simultaneous generation of multiple entangled states between symmetric waveguides pairs, resulting from the quantum state transport of a Néel state in the first device, was studied with a second femtosecond laser written device with thermally reconfigurable phase shifter [4]. This allowed the measurement of coherence between the waveguides and estimate the entanglement fraction of the systems, resulting in values of 0.66 ± 0.03 and 0.74 ± 0.03, verifying the generation of entanglement.

References

[1] M. Christandl et. al. A Perfect State Transfer in Quantum Spin Networks Phys. Rev. Lett. 92 187902 (2004)
[2] G. Ramirez et. al. Entanglement over the rainbow J. Stat. Mech. P06002 (2015)
[3] L. Sansoni et. al. Two-particle bosonic-fermionic quantum walk via integrated photonics Phys. Rev. Lett. 108 010502 (2012)
[4] F. Flamini et. al. Thermally reconfigurable quantum photonic circuits at telecom wavelength by femtosecond laser micro-machining. Light: Science & Applications. 4, e354 (2015)
[5] C. H. Bennett et. al. Mixed-state entanglement and quantum error correction. Phys. Rev. A 54, 3824 (1996)

A quantum Fredkin gate

R.B. Patel (1), J. Ho (1), F. Ferreyrol (1,2), T.C. Ralph (3) and G.J. Pryde (1)

(1) CQC2T (Centre for Quantum Computation and Communication Technology) and Centre for Quantum Dynamics, Griffith University, QLD, Australia; (2) Laboratoire Photonique, Numerique et Nanosciences, Institut d'Optique, CNRS and Université de Bordeaux, France; (3) CQC2T and School of Mathematics and Physics, University of Queensland, Australia

One of the greatest challenges in modern science is the realisation of quantum computers which, as their scale increases, will allow enhanced performance of tasks across many areas of quantum information processing. Quantum logic gates play a vital role in realising these applications by carrying out the elementary operations on the qubits; a key aim is minimising the resources needed to build these gates into useful circuits. While the salient features of a quantum computer have been shown in proof-of-principle experiments, e.g., single- and two-qubit gates, difficulties in scaling quantum systems to encode and manipulate multiple qubits has hindered demonstrations of more complex operations. This is exemplified by the classical Fredkin (or controlled-SWAP) gate [1] for which, despite many theoretical proposals [2,3] relying on concatenating multiple two-qubit gates, a quantum analogue has yet to be realised.

Here, by directly adding control to a two-qubit SWAP unitary [4], we use photonic qubit logic to report the first experimental demonstration of a quantum Fredkin gate [5]. Our scheme uses linear optics and improves on the overall probability of success by an order of magnitude over previous proposals [2,3]. This optical approach allows us to add control an arbitrary black-box unitary which is otherwise forbidden in the standard circuit model [6]. Additionally, the action of our gate exhibits quantum coherence allowing the generation of the highest fidelity three-photon GHZ states to date.

The quantum Fredkin gate has many applications in quantum computing, quantum measurements [7] and cryptography [8,9]. Using our scheme, we apply the Fredkin gate to the task of direct measurements of the purity and state overlap of a quantum system [7] without recourse to quantum state tomography.

References

1. Fredkin, E. and Toffoli, T., Int'l J. of Theo. Phys. 21, 219-253 (1982)
2. Fiurášek, J., Phys. Rev. A. 78, 032317 (2008)
3. Gong, Y.X., Guo, G.C. & Ralph, T.C., Phys. Rev. A. 78, 012305 (2008)
4. Zhou, X. Q., et al., Nature Comm. 2, 413 (2011)
5. Patel, R.B., Ho, J., Ferreyrol, F., Ralph, T.C. & Pryde, G.J., Sci. Adv. 2(3), e1501531 (2016)
6. Araújo, M., Feix, A., Costa, F. & Brukner, V., New J. Phys. 16, 093026 (2014)
7. Ekert, A., et al., Phys. Rev. Lett. 88, 217901
8. Buhrman, H., Cleve, R., Watrous, J. & de Wolf, R., Phys. Rev. Lett. 87, 167902 (2001)
9. Gottesman, D. & Chuang, I., "Quantum digital signatures" arXiv:quant-ph/010532 (2001)

Reversing Quantum Dynamics on an Atom-Chip

C. Lovecchio (1), F. Caruso (1,2,3), S. Montangero (4) , T. Calarco (4) , F. S. Cataliotti (1,2,3)

(1) LENS - Università di Firenze, Italy; (2) Dipartimento di Fisica ed Astronomia Università di Firenze, Italy; (3) QSTAR, Firenze, Italy; (4) Institut fur Quanteninformationsverarbeitung, Universitat Ulm, Germany

Reversing the dynamics of a quantum system to bring the system back in its initial state, is usually unfeasible in the laboratory, essentially because time in nature goes always forward. In our work we theoretically and experimentally drive forth and back through several paths in the five-level Hilbert space of a Rubidium atom in the ground state. We achieve such an objective applying optimal control strategies to a Bose-Einstein condensate on an atom-chip via a frequency modulated RF field. We prove that backward dynamical evolution does not correspond to simply inverting the time arrow of the driving field as this neglects the free evolution component of the dynamics. Besides the relevance for the foundations of quantum mechanics, these results are important steps forward in the manipulation of quantum dynamics that is crucial for several physical implementations and very promisingly powerful quantum technologies.

Multi-user quantum key distribution with a semi-conductor source of entangled photon pairs

C. Autebert (1), J. Trapateau (2), A. Orieux (2), A. Lemaître (3), C. Gomez-Carbonell (3), E. Diamanti (2), I. Zaquine (2), and S. Ducci (1)

(1) MPQ, Paris, France ; (2) LTCI, Paris, France ; (3) LPN, Marcoussis, France

Quantum cryptography with entangled photon pairs can be more powerful than protocols based on single photons or weak coherent pulses: they can tolerate higher losses and thus allow the distribution of quantum secret keys (QKD) over longer distances [1], and they also open the way towards device-independent quantum cryptography [2]. However, in order to enable a wide use of entangled photon pairs in future quantum telecommunication systems, further developments are needed to demonstrate high performance sources that can be easily fabricated and integrated into Telecom fiber networks.

Here we present a source consisting of an aluminium gallium arsenide waveguide generating photon pairs in the Telecom band by type II spontaneous parametric down-conversion [3]. Such a device has already been proven to work under electrical pumping [4]. Thanks to the very small birefringence of the guided modes, the pairs are directly generated in a polarization-entangled Bell

state, without the need for any post-compensation. Moreover, as the photons are emitted over a large bandwidth (about 100 nm) with a joint spectrum that exhibits frequency anticorrelation, the same source can be used to simultaneously distribute keys among multiple pairs of users by using

standard Telecom wavelength demultiplexers [5]. Here, we experimentally show the distribution of quantum secret keys with the BBM92 QKD protocol [6] between four different pairs of users with a commercial 100 GHz demultiplexer (0.8 nm channel width and spacing). Under CW pumping conditions, using free-running InGaAs single-photon detectors, we achieve a secret key rate of 0.21

bits/s and a qubit error rate (QBER) of 6.9% over 50 km of standard optical fiber.

Our results, obtained with a robust and simple experimental set-up, open the way towards the implementation of practical device-independent quantum communication protocols.

References

[1] X. F. Ma et al., Phys. Rev. A 76, 012307 (2007).
[2] S. Pironio et al., New J. Phys. 11, 045021 (2009).
[3] F. Boitier et al., Phys. Rev. Lett. 112, 183901 (2014).
[4] C. Autebert et al., Optica 3, 143-146 (2016).
[5] J. Trapateau et al., J. Appl. Phys. 118, 143106 (2015).
[6] C. H. Bennett et al., Phys. Rev. Lett. 68, 557-559 (1992).

Entanglement transfer via a large-S magnetic channel

D. Nuzzi (1, 2), A. Cuccoli (1, 2), R. Vaia(3, 2), P. Verrucchi (3, 1, 2)

(1)Dipartimento di Fisica e Astronomia, Università di Firenze, via G. Sansone 1, I-50019 Sesto Fiorentino (FI), Italy; (2) Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, via G. Sansone 1, I-50019 Sesto Fiorentino (FI), Italy; (3) Istituto dei Sistemi Complessi, Consiglio Nazionale delle Ricerche, via Madonna del Piano 10, I-50019 Sesto Fiorentino (FI), Italy

Creating and transferring entanglement are fundamental tools in performing quantum actions. These tasks are usually accomplished by purely quantum channels, for instance spin-1/2 chains, which are very effective, but need a high level of protection against external disturbance. We here follow the idea of using large-S 1-d systems as robust channels for entanglement transfer: spin-S chains do indeed possess stable traveling excitation and are known to be capable of transmitting classical information [1], which makes them suitable candidates for our purpose. Being a full quantum description of a many-body large-S system interacting with some qubits not feasible, ad hoc approximations are needed in order to describe the interaction of purely quantum objects (qubits) with a quasi-classical macroscopic system (spin-S chain) still retaining enough of the system quantum nature to account for entanglement generation and transmission.

In this talk, I will analyze the case of a magnetic system, constituted by large-S (S>1/2) spin objects, as entanglement mediator. In particular, I will introduce a semi-classical approximation scheme, based on single-spin coherent states, which enables to account for the dynamics of a system made by two distant (and not directly interacting) qubits and a large number of interacting spin-S, at least numerically. Finally, I will apply this scheme to an Heisenberg spin-S chain, showing that, choosing the chain initial state close to a localized classical dynamical configuration (soliton), the entanglement established between the first qubit and the chain can be transferred along the spin-S system through to the second qubit finally leading to an entangled state of the two distant qubits.

References

1. A. Cuccoli, D. Nuzzi, R. Vaia e P. Verrucchi, “Getting through to a qubit by magnetic solitons”, New J. Phys. 17, 083053 (2015)

Quantum information processing in phase space: A modular variables approach

A. Ketterer (1), A. Keller (2), S. P. Walborn (3), T. Coudreau (1), P. Milman (1)

(1) Laboratoire Matériaux et Phénomènes Quantique, Université Paris Diderot, France; (2) Institut de Sciences Moléculaires d'Orsay, Université Paris-Sud, Orsay, France; (3) Instituto de Física, Universidade Federal do Rio de Janeiro Brazil

Binary quantum information can be fault tolerantly encoded in states defined in infinite dimensional Hilbert spaces [1]. Such states define a logical basis, and permit a perfect equivalence between continuous and discrete universal operations. The drawback of this encoding is that the corresponding logical states are unphysical, meaning infinitely localized in phase space. In this talk I apply the modular variables formalism to show that, in a number of protocols relevant for quantum information and for the realization of fundamental tests of quantum mechanics, it is possible to loosen the requirements on the encoded subspace without jeopardizing neither their usefulness nor their successful implementation [2]. Such protocols involve measurements of appropriately chosen modular observables that permit the readout of encoded discrete quantum information from the corresponding logical states. To demonstrate the applicability of our framework we show how to violate a Bell inequality in terms of continuous variables states expressed in the modular variables basis [3].

References

[1] D. Gottesman, A. Kitaev and J. Preskill, Phys. Rev. A 64, 012310 (2001).
[2] A. Ketterer, A. Keller, S. P. Walborn, T. Coudreau and P. Milman, arXiv:1512.02957 (2015).
[3] A. Ketterer, A. Keller, T. Coudreau and P. Milman, Phys. Rev. A 91, 012106 (2015).

Practical quantum metrology in noisy environments

R. Nichols, T. R. Bromley, L. A. Correa, G. Adesso

University of Nottingham

The problem of estimating an unknown phase using two-level probes in the presence of depolarizing noise and using finite resources is investigated. In particular, we introduce a simple model in which the phase-imprinting operation on the probes is realized by a unitary transformation with a randomly sampled generator. We set a general lower bound to the optimal phase sensitivity under this type of noise. In a sequential estimation protocol, this is shown to grow quadratically with the number of applications of the phase-imprinting operation, then attain a maximum, and eventually decay to zero. We express the optimum number of applications, i.e. at this maximum, in terms of accessible geometric properties of the noise and illustrate its usefulness as a practical guideline for the optimization of the estimation protocol. The use of entangled probes in parallel to improve the phase sensitivity is also considered. We find that multi-probe entanglement generally offers no practical advantage over single-probe coherence if the interrogation of the probes at the output is restricted to separable measurements.

References

R. Nichols et al. arXiv:1604.00532v2 (2016)

Source-device-independent Ultra-fast Quantum Random Number Generation

D. G. Marangon, G. Vallone, P. Villoresi

University of Padova, Dept. Engineering of Information

We present a novel protocol [1] for the fast and secure generation of random numbers. We exploited the quantum fluctuations of electromagnetic quadratures which have been already used in the past for continuous variable quantum random number generation (CV-QRNG). However, the numbers generated by this method are more secure with respect to those obtained by previous CV-QRNGs. Indeed, we devised a protocol which eliminates any possible “side-information” on the generated numbers. If the random numbers are used for instance for Quantum Cryptography such improvement is of main relevance: side information can be exploited by an eavesdropper to predict the outcomes of the generator and the whole security of a quantum key distribution protocol could be compromised. With our protocol, this backdoor is closed while the generation rate is kept large.

At present time, ultimate randomness is reachable only by using device independent protocols of randomness expansion or amplification: however, such protocols are highly demanding from an experimental point of view, since they require a loophole-free violation of a Bell inequality. On the other hand, other typical QRNGs are always defined in a full-trusted scenario, in which the source of quantum state and the measurement device are assumed to be perfectly known and well characterized. With respect to the state of the art, our protocol lies in between of these two extremes. In fact, it has the property of being “source-device-independent”: the random generation rate does not depend on any assumption on the source state.

The source-device-independent method, requiring only assumptions on the measurement device and not on the source, makes device-independent-randomness an experimentally viable approach. Unpredictable numbers at high rate can be distilled even if an eavesdropper is providing the source of quantum states.

The procedure is based on the estimation of a bound on the conditional min-entropy derived by the Entropic Uncertainty Principle for position and momentum observables of infinite dimensional quantum systems [2]. This is a very effective Quantum Information theory tool which has been also recently exploited to prove the security of CV-QKD against coherent attacks [3]. By the above method, we experimentally demonstrated the generation of secure true random bits at a rate greater than 1 Gbit/s.

References

[1] Marangon, Davide G., Giuseppe Vallone, and Paolo Villoresi. "Source-device-independent Ultra-fast Quantum Random Number Generation." arXiv preprint arXiv:1509.07390 (2015).
[2] Furrer, Fabian, et al. "Position-momentum uncertainty relations in the presence of quantum memory." Journal of Mathematical Physics 55.12 (2014): 122205.
[3] Gehring, Tobias, et al. "Implementation of continuous-variable quantum key distribution with composable and one-sided-device-independent security against coherent attacks." Nature communications 6 (2015).

Quantum gate learning in qubit networks: Toffoli gate without time-dependent control

L. Banchi

University College London, UK

We put forward a strategy to encode a quantum operation into the unmodulated dynamics of a quantum network without the need for external control pulses, measurements or active feedback. Our optimisation scheme, inspired by supervised machine learning, consists in engineering the pairwise couplings between the network qubits so that the target quantum operation is encoded in the natural reduced dynamics of a network section. The efficacy of the proposed scheme is demonstrated by the finding of uncontrolled four-qubit networks that implement either the Toffoli gate, the Fredkin gate or remote logic operations. The proposed Toffoli gate is stable against imperfections, has a high fidelity for fault-tolerant quantum computation and is fast, being based on the non-equilibrium dynamics.

Reference

L. Banchi, N. Pancotti, S. Bose, npj Quantum Information 2: 16019 (2016)

A geometric approach to entanglement quantification with polynomial measures

Bartosz Regula, Gerardo Adesso

University of Nottingham

Quantifying entanglement in composite systems is a fundamental challenge, yet exact results are available only in a few special cases. This is because hard optimisation problems are routinely involved, such as finding the convex decomposition of a mixed state with the minimal average pure-state entanglement - the so-called convex roof. We show that entanglement quantification of any rank-2 state with any polynomial measure of entanglement can be expressed in terms of a geometric problem in the corresponding Bloch sphere, which can greatly simplify the calculations and provide an intuitive picture of a state's entanglement properties.

In particular, unveiling and exploiting the geometric structure of the concurrence for two qubits, we introduce methods for the analytical evaluation of convex roof-extended entanglement measures in classes of rank-2 states which have only one or two pure unentangled states in their ranges. We give explicit examples by quantifying the three-tangle exactly for several representative classes of three-qubit states, and we show the importance of such states by demonstrating their use in characterising generalised monogamy relations of four-qubit states.

References

B. Regula and G. Adesso, Phys. Rev. Lett. 116, 070504 (2016);
B. Regula, A. Osterloh, and G. Adesso, arXiv:1604.03419 (2016);
B. Regula, S. Di Martino, S. Lee, and G. Adesso, Phys. Rev. Lett. 113, 110501 (2014)

Contributed talks

Time-resolved Scattering of a Single Photon by a Single Atom

Alessandro Cere (1), Victor Victor Leong (1, 2), Mathias Seidler (1), Matthias Steiner (1, 2), and Christian Kurtsiefer (1, 2)

(1) Centre for Quantum Technologies, NUS, Singapore; (2) Department of Physics, National University of Singapore, Singapore

Scattering of light by matter has been studied extensively in the past. Yet, the most fundamental process, the scattering of single photons by single atoms, is largely unexplored.

One prominent prediction of quantum optics is the deterministic absorption of a traveling photon by a single atom, provided the photon waveform matches spatially and temporally the time-reversed version of a spontaneously emitted photon [1-3].

Here, we experimentally test this prediction using a single trapped atom and heralded single photons with different temporal profiles. In a time-resolved atomic excitation measurement, we find a 56(10)% increase of the peak excitation by photons with an exponentially rising profile compared to a decaying one, in agreement with a time-reversed Weisskopf-Wigner model [2]. Thus, tailoring the envelope of single photons allows better control of atom-photon interaction in quantum networks.

References

[1] M. Stobiska, et al., EPL 86, 14007 (2009)
[2] Y. Wang, et al., Phys. Rev. A 83, 063842 (2011)
[3] B. Srivathsan, et al., Phys. Rev. Lett. 113, 163601 (2014)

Efficient generation of photonic linear cluster states

Y. Pilnyak, N. Aharon, D. Istrati, E. Megidish, A. Retzker and H. S. Eisenberg

Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem 91904, Israel

The generation of entanglement between more than two particles is a major challenge for all physical realizations. It is required for the realization of many quantum information protocols, including quantum computing. Single photons are one of the most promising realizations of quantum bits (qubits), as they are easily manipulated, preserve their coherence for long times, and information can be stored in their many different degrees of freedom. Up to date, only eight photons have been entangled in a single state through their polarization degree of freedom. The main difficulties in increasing this number are the elaborated setups required and the low rates of state production.

I will present a novel and simple scheme that can in principle generate entanglement between any number of photons in a linear cluster state from a single fixed setup. This scheme combines photons from one source in a single path, but at different times, using an optical delay. It can be extended to create higher-dimensional cluster states, and even arbitrary graph states. Such states are useful for the one-way quantum computer scheme. Results from such a setup using heralded single photons will be presented. States of two and three entangled photons were measured, with good visibilities of their quantum interference.

References

E. Megidish, T. Shacham, A. Halevy, L. Dovrat and H.S. Eisenberg “A resource efficient source of multi-photon polarization entanglement”, Phys. Rev. Lett. 109, 080504 (2012).
E. Megidish, A. Halevy, T. Shacham, T. Dvir, L. Dovrat, and H. S. Eisenberg “Entanglement swapping between photons that have never coexisted”, Phys. Rev. Lett. 110, 210403 (2013).

Contributed talk

Hybrid quantum simulation of exciton transfer in silicon quantum photonics

R. Santagati (1), J. Wang (1), S. Paesani (1), A.A. Gentile (1), D. Bonneau (1), J.W. Silverstone (1), S. Morley-Short (1), P.J. Shadbolt (1), N. Wiebe (2), S. Miki (3), T. Yamashita (3), M. Fujiwara (4), M. Sasaki (4), H. Terai (3), M.G. Tanner (5), C.M

1 Centre for Quantum Photonics, H. H. Wills Physics Laboratory & Department of Electrical and Electronic Engineering, University of Bristol, Merchant Venturers Building, Woodland Road, Bristol BS8 1UB, United Kingdom; 2 Quantum Architectures and Computation Group, Microsoft Research, Redmond, Washington 98052, USA; 3 N. I. C. T., 588-2 Iwaoka, Kobe 651-2492, Japan; 4 N. I. C. T., 4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan; 5 School of Engineering, University of Glasgow, G12 8QQ, United Kingdom; 6 School of Chemistry, University of Bristol, Bristol BSB 1TS, United Kingdom

Quantum simulation is widely considered as one of the most promising applications for quantum technologies [1,2,3]. Recently variational eigen-solvers [4,5,6], combining quantum simulators together with classical optimization methods, have been proposed as a more amenable application for small quantum machines. In fact, they require less resources compared to the costly adiabatic state preparation proposed in the past as an efficient route to quantum simulation on quantum computers [2,4].

Here, we present a new variational approach, combining favorable aspects of the variational eigen-solvers together with advantages of quantum phase estimation [2]. This approach is based on the tomographical analysis of the control qubit undergoing a controlled unitary operation, where the injected target state is optimized to maximize purity and minimize an eigenstate energy estimator. The variational search of the ground-state, operated on the target register, relies on Bayesian-like optimization methods. Once the ground state is identified the iterative phase estimation algorithm (IPEA) [4] is performed, in order to improve the first estimate of the ground state energy.

We experimentally implemented this algorithm on a reconfigurable silicon quantum photonic chip able to perform non-compiled arbitrary controlled unitary operations [7], for finding the ground state of the exciton transfer Hamiltonian in chlorophyll. We found the ground state with a fidelity of 99.3%, which enabled us to run the IPEA with 32 bits precision.

This hybrid approach gives the quadratic advantage of IPEA compared to variational methods, maintaining the variational eigens-solver advantages over adiabatic state preparation for small/medium scale implementations. Moreover, it requires only the measurement of the control qubit independently of the size of the system.

This experimental implementation illustrates the potential of this new method for the next generation of quantum simulation experiments.

References

1. R. P. Feynman. Simulating physics with computers. - International J. of theoretical physics, 21, 467-488,1982.
2. S. Lloyd. Universal quantum simulators. Science. 273, 1074-1078, 1996.
3. A. A.Guzik and P. Walther. Photonic quantum simulators. Nat. Phys. 8, 285-291, 2012.
4. B. P. Lanyon, et. al. Towards quantum chemistry on a quantum computer. Nat. Chem. 2, 106111, 2010.
5. J. R. McClean, et. al. The theory of variational hybrid quantum-classical algorithms. arXiv:1509.04279, 2015
6. A. Peruzzo, et. al. A variational eigenvalue solver on a photonic quantum processor. Nat. Commun. 5, 1-7, 2014.
7. X. Zhou, et. al. Calculating unknown eigenvalues with a quantum algorithm. Nat. Photon. 7, 223-228, 2013.

Generalized suppression laws for validation of Boson sampling experiments

Andrea Crespi (1,2), Roberto Osellame (1,2), Roberta Ramponi (1,2), Marco Bentivegna (3), Fulvio Flamini (3), Nicolò Spagnolo (3), Niko Viggianiello (3), Luca Innocenti (3,4), Paolo Mataloni (3), Fabio Sciarrino (3)

Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche (IFN-CNR), Piazza Leonardo da Vinci, 32, I-20133 Milano, Italy
Dipartimento di Fisica, Politecnico di Milano, Piazza Leonardo da Vinci, 32, I-20133 Milano, Italy
Dipartimento di Fisica, Sapienza Università di Roma, Piazzale Aldo Moro 5, I-00185 Roma, Italy
Università di Roma Tor Vergata, Via della ricerca scientifica 1, I-00133 Roma, Italy

Hong-Ou-Mandel effect is the standard way to experimentally assess two-photon indistinguishability. In a general way, it can be interpreted as a suppression law for a specific input-output combination which is valid for two bosons in symmetric 2x2 interferometers. This notion has been recently generalized to the case where the Fourier transformation over any number of spatial modes is applied to arbitrary bosonic Fock states [1,2]. The resulting diagnostic tool can be used to certify the capability of a system to exhibit genuine multiparticle interference, in particular for Boson Sampling certification [3-6]. To this end, we performed 2-photon experiments in a 4-mode and an 8-mode interferometer [7], showing how the 3D capabilities of femtosecond laser writing can be exploited to realize the quantum analogue of the fast Fourier transform, enabling the use of multiparticle suppression laws in a much more scalable way for future large-scale photonic experiments.

References

[1] Tichy, M. C. et al. *Phys. Rev. Lett.* **113**, 020502 (2014).
[2] Tichy, M. C. et al. *Phys. Rev. Lett.* **104**, 220405 (2010).
[3] Broome, M. A. *et al*. *Science* **339**, 794–798(2013).
[4] Spring, J. B. *et al*. *Science* **339**, 798–801 (2013).
[5] Tillmann, M. *et al*. *Nat. Photon.* **7**, 540–544 (2013).
[6] Crespi, A. *et al. Nat. Photon.* **7**, 545–549 (2013).
[7] Crespi, A. *et al*. *Nat. Commun.* **7**:10469 (2016).

Purity of heralded photons: a comparison between backward and forward parametric down-conversion

A. Gatti (1,2), T.Corti (2), E. Brambilla (2)

(1) Istituto di Fotonica e Nanotecnologie del CNR, Milano, Italy; (2) Universita' degli Studi dell'Insubria, Como, Italy

Because of its relative ease of implementation, parametric down conversion is a widely used source both of entangled light and of single photons heralded by detection of the partner, the starting point of many quantum information protocols. In this latter case, entanglement must be avoided as much as possible, since the heralded photons are required to be in a pure state in order to provide high-visibility interference.

Here we focus on a non-conventional configuration, which became recently accessible to experimental realizations [1], where twin photons are generated in opposite directions thanks to a sub-micrometer poling period of the nonlinear material.

This work provides a characterization of the temporal correlation of counter-propagating twin photons, analysing the effects of the spectral properties of the pump on their degree of entanglement of. A peculiar feature of the backward geometry is the natural presence of two well separated time scales [2,3]: a long scale τGVS (on the order of the light transit time along the medium), reflecting the temporal separation of the counter-propagating waves during propagation, and a short one τGVM, accounting for the typical delay between co-propagating waves due to group-velocity mismatch. We show that when the duration of the pump pulse is intermediate between the two scales, the state becomes almost separable, with the co-propagating photon generated in the same spectro-temporal mode as the pump, while the backward photon has a much narrower spectral bandwidth ∼ 1/ τGVS.

We offer a physical interpretation of such a behavior, and a systematic comparison with the more conventional co-propagating geometry, where the purity can be enhanced by techniques of group velocity matching [4], and a separable state can be realized only at very special matching point, by employing ultrashort pump pulses. In comparison, the backward geometry offers the opportunity of generating high purity, highly monochromatic heralded photons for a wide range of pump durations and phase matching conditions.

References

[1] C. Canalias and V. Pasiskevicius, Nature Photonics 1, 459 (2007).
[2] Alessandra Gatti, Tommaso Corti and Enrico Brambilla, Phys. Rev. A 92, 053809 (2015).
[3] T.Corti A. Gatti and E. Brambilla, Phys. Rev. A 93, 023837 (2016).
[4] P. J. Mosley, J. S. Lundeen, B. J. Smith, P. Wasylczyk, A. B. U'Ren, C. Silberhorn, and I. A. Walmsley, Phys.Rev. Lett. 100, 133601 (2008); W. P. Grice, A. B. U'Ren, and I. A. Walmsley, Phys.Rev. A 64, 063815 (2001)

Simulating quantum transport by photonics and genetic engineering

F. Caruso

LENS, QSTAR, and Physics Dept., Florence University, Italy

Recent theoretical and experimental efforts have shown the remarkable and counterintuitive role of noise [1] in enhancing the transport efficiency of complex quantum systems, with particular relevance to the energy transport in natural light-harvesting photosynthetic proteins. Here, we show both theoretically and experimentally three different simulators of such quantum phenomena, respectively based on optical fiber cavity networks, integrated photonics, and geneticaly engineered viruses. The first one is based on a simple, scalable, and controllable optical fiber cavity network that allows us to analyze the performance of transport networks for different conditions of interference, dephasing, and disorder [2]. Concerning the second one, by mapping the maze problem in an integrated waveguide array, probed by coherent light, we successfully test our theoretical result that a quantum walker can efficiently reach the output of a maze by partially suppressing the presence of interference, with an unprecedented improvement in transport efficiency [3]. Finally, on the biological side, we have also created a tunable material consisting of a connected chromophore network on an ordered biological virus template at room temperature, and, using genetic engineering, we have established a link between the inter-chromophoric distances and emerging quantum transport properties [4]. These platforms are very promising simulators of quantum transport phenomena and could be used, in particular, to design and test optimal topologies of artificial nano-structures for future bio-inspired solar energy and quantum communication technologies.

References

[1] F. Caruso, V. Giovannetti, C. Lupo, and S. Mancini, “Quantum channels and memory effects”, Rev. Mod. Phys. 86, 1203 (2014).
[2] S. Viciani, M. Lima, M. Bellini, and F. Caruso, “Observation of Noise-Assisted Transport in an All-Optical Cavity-Based Network”, Phys. Rev. Lett. 115, 083601 (2015), PRL Editors’ Suggestion.
[3] F. Caruso, A. Crespi, A.G. Ciriolo, F. Sciarrino, and R. Osellame, “Fast Escape of a Quantum Walker from an Integrated Photonic Maze”, accepted in Nature Communications (2016), Eprint arXiv:1501.06438.
[4] H. Park, N. Heldman, P. Rebentrost, L. Abbondanza, A. Iagatti, A. Alessi, B. Patrizi, M. Salvalaggio, L. Bussotti, M. Mohseni, F. Caruso, H.C. Johnsen, R. Fusco, P. Foggi, P.F. Scudo, S. Lloyd, and A.M. Belcher, “Enhanced energy transport in genetically engineered excitonic networks”, Nature Materials 15, 211–216 (2016).

Unravelling the environment: the discrimination of wave-function collapse models under time-continuous measurements

M. G. Genoni (1)(2), O. S. Duarte (3)(2), A. Serafini (2)

1) University of Milan, Italy; (2) University College London, UK; (3) University of Sao Paulo, Brasil

Inspired by the notion that environmental noise is in principle observable, whilst fundamental noise due to spontaneous localisation would not be, we study the estimation of the diffusion parameter induced by wave function collapse models under continuous monitoring of the environment. We take into account finite measurement efficiencies and, in order to quantify the advantage granted by monitoring, we analyse the quantum Fisher information associated with such a diffusion parameter, identify optimal measurements in limiting cases, and assess the performance of such measurements in more realistic conditions.

References

[1] M. G. Genoni, O. S. Duarte and A. Serafini, arXiv:1605.09168 [quant-ph].

Dynamical and thermodynamical control of open quantum Brownian motion

F. Petruccione (1), I. Sinayskiy(1)

University of KwaZulu-Natal, Durban, South Africa and National Institute for Theoretical Physics (NITheP), KZN, Durban, South Africa

Open quantum Brownian motion was introduced as a new type of quantum Brownian motion for Brownian particles with internal quantum degrees of freedom. Recently, an example of the microscopic derivation of open quantum Brownian motion has been presented [1]. The microscopic derivation allows to relate the dynamical properties of open Quantum Brownian motion and the thermodynamical properties of the environment. In the present work, we study the possibility of control of the external degrees of freedom of the "walker" (position) by manipulating the internal one, e.g. spin, polarization, occupation numbers. In the particular example of the known microscopic derivation the connection between dynamics of the "walker" and thermodynamical parameters of the system is established. For the system of open Brownian walkers coupled to the same environment controllable creation of quantum correlations is investigated.

References

[1] I. Sinayskiy and F. Petruccione, Phys. Scr. T165, 014017 (2015)

Probing a dissipative process through quantum synchronization

G. L. Giorgi, F. Galve, R. Zambrini

IFISC (UIB-CSIC), Instituto de Física Interdisciplinar y Sistemas Complejos, Palma de Mallorca, Spain

A quantum probe is an individual quantum object that, interacting with a complex quantum system allows an external observer to extract information observing the behavior of the probe itself. This is due to the fact that the probe and the complex system develop correlations that will heavily affect the dynamics of the probe. We introduce a technique that allows one to probe a dissipative process exploiting the emergence of quantum synchronization. Given a qubit immersed in a dissipative environment, a coupling to an external probe is able to generate synchronization between the qubit and the probe itself. We show that the synchronization frequency is subject to a sharp discontinuity that can be observed by tuning the frequency of the probe. Knowing the value at which this discontinuity is observed allows one to reconstruct the shape of the spectral density.

Coherent and Dissipative Control for Quasi-Zeno Dynamics

M. Mueller

Dipartimento di Fisica e Astronomia, LENS, QSTAR, University of Florence, Italy

The dynamics of quantum systems can be manipulated by external control fields and measurements. Optimal control techniques have had great success in enabling quantum technology building blocks by calculating optimal pulse shapes of the external field [1]. Furthermore, it is known that in the limit of infinite coupling the dynamics of a system can be confined to a so-called Zeno subspace by different coherent and dissipative protocols [2], the standard way being sequences of instantaneous projective measurements where the quality of confinement is directly linked to the Fisher information obtained by the measurements [3].

This talk will report about efforts to combine the two approaches in an experimentally accessible regime near the Zeno limit. While Zeno subspaces can be used to protect qubits [4] additional optimal control pulses can be used to create entanglement between them. Varying the coupling strength and frequency allows to tune between Zeno protection and interaction. On a similar line of research we study how the quality of confinement or survival probability in the subspace depends on the interval length between two protecting measurements and how it is altered by noise [5,6] and correlations in the length of the interval as well as how this affects the Fisher information associated with these measurements.

References

[1] C. Brif, R. Chakrabarti, and H. Rabitz, New J. Phys. 12, 075008 (2010).
[2] P. Facchi, and S. Pascazio, J. Phys. A 41, 493001 (2008).
[3] A. Smerzi, Phys. Rev. Lett. 109, 150410 (2012).
[4] F. Schäfer, I. Herrera, S. Cherukattil, C. Lovecchio, F.S. Cataliotti, F. Caruso, and A. Smerzi, Nat. Comm. 4194 (2014).
[5] S. Gherardini, S. Gupta, F.S. Cataliotti, A. Smerzi, F. Caruso, and S. Ruffo, New J. Phys. 18, 013048 (2016).
[6] S. Gherardini, C. Lovecchio, M.M. Müller, F.S. Cataliotti, and F. Caruso, in preparation (2016).

How dynamical relations explain quantum coherence

H. F. Hofmann

Hiroshima University, Japan

The classical laws of motion emerge from the quantum coherences of superpositions when the complex phases of the probability amplitudes are identified with the correct expressions of the action. In recent works, we have identified the correct action functionals, which allows us to relate quantum mechanical phases directly to the corresponding classical laws of motion. In particular, we can show that the concept of trajectories is unnecessary and can be abolished completely once the action is formulated in terms of experimentally accessible physics. This result indicates that all of the controversies about the interpretation of quantum mechanics might have been caused by a fundamental misunderstanding regarding the relation between experimental evidence and theoretical concepts in quantum physics.

References

1. H. F. Hofmann, New J. Phys. 13, 103009 (2011)
2. H. F. Hofmann, Phys. Rev. A 89, 042115 (2014)
3. H. F. Hofmann, e-print arXiv: 1508.02779

Building versatile bipartite probes for quantum metrology

Alessandro Farace (1), Antonella De Pasquale (2), Gerardo Adesso (3), Vittorio Giovannetti (2)

(1) Max-Planck-Institute of Quantum Optics, Garching, Germany;
(2) NEST, Scuola Normale Superiore and Istituto Nanoscienze-CNR, Pisa, Italy;
(3) School of Mathematical Sciences, The University of Nottingham, UK

We consider bipartite systems as versatile probes for the estimation of transformations acting locally on one of the subsystems. We investigate what resources are required for the probes to offer a guaranteed level of metrological performance, when the latter is averaged over specific sets of local transformations. In other words, we look for probes that remain useful for a wide range of different estimation instances. We quantify the performance of the probes via the average skew information (AvSk), a convex quantity which we compute in closed form for bipartite states of arbitrary dimensions, and which is shown to be strongly dependent on the degree of local purity of the probes. Our analysis contrasts and complements the recent series of studies focused on the minimum (rather than the average) performance of bipartite probes in local estimation tasks, where instead a key role is played by quantum correlations other than entanglement. We provide explicit prescriptions to characterize the most reliable states maximizing the AvSk, and elucidate the role of state purity, separability and correlations in the classification of optimal probes. Our results can help in the identification of useful resources for sensing, estimation and discrimination applications when complete knowledge of the interaction mechanism realizing the local transformation is unavailable, and access to pure entangled probes is technologically limited.

References

[1] A. Farace et al., New J. Phys. 18, 013049 (2016)
[2] A. Farace et al., New J. Phys. 16, 073010 (2014)
[3] L. Rigovacca et al., Phys. Rev. A 92, 042331 (2015)

Generation and control of entanglemeny and steering in cavity optomechanics

M. Asjad, P. Tombesi, J. Li, I. Moaddel Haghighi, N. Malossi, S. Zippilli, D. Vitali

School of Science and Technology, University of Camerino, and INFN Sezione di Perugia, Italy

We present various schemes for the generation of entanglement between two mesoscopic mechanical resonators and two travelling optical fields in cavity optomechanical setups. We also describe the conditions under which one can generate continuous variable two-way steering between two distant optical modes propagating along fibers.

References

[1] M. Asjad, P. Tombesi, D. Vitali, arXiv:1604.00399
[2] M. Asjad, S. Zippilli, D. Vitali,arXiv:1603.02756
[3] J. Li, I. Moaddel Haghighi, N. Malossi, S. Zippilli, D. Vitali, New J. Phys. 17 (2015) 103037

Entropic nonsignalling correlations

Costantino Budroni (1), Rafael Chaves (2)

(1) Universität Siegen, Germany, (2) University of Freiburg and University of Cologne, Germany

Quantum nonlocality –the fact that correlations obtained in quantum experiments performed by distant parties are incompatible with local hidden variable models [1]– brings to light an intriguing aspect of quantum mechanics (QM) and relativistic causality. QM is in accordance with the nonsignalling principle, that is, local manipulations by an experimenter cannot influence the measurement outcomes of other distant experimenters. However, as demonstrated by Popescu and Rohrlich [2], special relativity alone cannot single out quantum mechanical correlations as there are theories, beyond QM, also in agreement with nonsignalling. This result not only has triggered the search for physically well motivated principles for quantum mechanics [3], but has also led to new insights about its limitations for information processing [4].

We introduce the concept of entropic nonsignalling correlations [5], i.e., entropies arising from probabilistic theories that are compatible with the nonsignalling principle. We characterize and show the relevance of these entropic correlations in a variety of different scenarios, ranging from typical Bell experiments to more complex causal structures such as bilocality and information causality scenario.

We discuss additional applications of entropic nonsignalling correlations, from genuine tripartite nonlocality to monogamy relations for entropic Bell inequality and activation of nonlocality in networks.

References

[1] J. S. Bell, Physics 1, 195 (1964).
[2] S. Popescu and D. Rohrlich, Foundations of Physics 24, 379 (1994).
[3] M. Pawłowski, T. Paterek, D. Kaszlikowski, V. Scarani, A. Winter, and M. Zukowski, Nature 461, 1101 (2009).
[4] W. van Dam, Nonlocality & communication complexity, Ph.D. thesis, Faculty of Physical Sciences, University of Oxford (1999).
[5] R. Chaves and C. Budroni, arXiv:1601.07555

Optomechanical tailoring of squeezed light

S. Mosca (1), A. Borrielli (2), I. Ricciardi (1), M. Parisi (1), M. Bonaldi (2),

P. De Natale (3), F. Marin (4), M. De Rosa (1)

(1) INO–CNR, Istituto Nazionale di Ottica, Pozzuoli (NA), Italy
(2) Institute of Materials for Electronics and Magnetism, Trento (TN), Italy
(3) INO–CNR, Istituto Nazionale di Ottica, Firenze (FI), Italy
(4) Università di Firenze, Sesto Fiorentino (FI), Italy

Over the past few years quantum optomechanics has become an extremely active research area. The interplay between mechanical and optical modes gives rise to a variety of effects, which open the way to new tests of quantum theory at unprecedented sizes and mass scales. Recent experiments have demonstrated mechanical quantum state preparation, entanglement and squeezing of mechanical as well as optical modes.
Our experiment aims to control and manipulate a squeezed state of light exploiting the opto-mechanical interaction. In particular, a squeezed vacuum field generated by an optical parametric oscillator operating below threshold will be sent to a single-ended high-finesse Fabry-Pérot cavity, whose end mirror is a mechanical microresonator supported by a silicon spring. The mirror has high mechanical quality factor (Q ~ 10^6) and low optical losses (5x10^4 of finesse when used in cavity).

We carried out an analysis of the expected effect on the reflected light by optomechanical cavity. The results predict that the optomechanical interaction can manipulate the squeezing, tailoring both the level and the quadrature angle as a function of the spectral frequency.

Large-N-approximated field theory for multipartite entanglement

P. Facchi (1,2), G. Florio (2,3), G. Parisi (4,5,6), S. Pascazio (1,2), A. Scardicchio (7,8)

(1) Dipartimento di Fisica, Universita' di Bari, (2) INFN, Sezione di Bari, (3) Dipartimento di Meccanica, Matematica e Management, Politecnico di Bari, (4) Dipartimento di Fisica, Universita' di Roma "Sapienza", (5) Centre for Statistical Mechanics and Complexity (SMC), CNR-INFM, (6) INFN, Sezione di Roma, (7) International Center for Theoretical Physics, Trieste (8) INFN, Sezione di Trieste

The study of entanglement is almost as old as quantum mechanics. While bipartite entanglement is well understood and quantified, the notion of multipartite entanglement is more elusive. This is due to a number of concomitant factors. First of all, for many-body quantum systems, the number of entanglement measures grows exponentially with the system size, making a characterization of quantum correlations complicated. Second, new properties arise when more quantum parties are involved, among these the intriguing appearance of frustration. In agreement with the classical notion, this is related to the impossibility of satisfying a number of requirements at the same time. Applied to entanglement, this means that given three (or more) parties A, B, and C, if the entanglement between A and B grows, that between A and C or B and C decreases.

We will study the properties of multipartite entanglement by adopting the concepts and tools of classical statistical mechanics. In order to explore the rich landscape that ensues, we shall make use of techniques that are based on the analysis of diagrams that naturally arise when one considers a high-temperature expansion of the distribution function of the measure of multipartite entanglement (the potential of multipartite entanglement). Unfortunately, the evaluation of the contributions of different kinds of graphs and their resummation is not a simple task. Following a procedure familiar from gauge theories, one would like to find a strategy to select and sum a family of diagrams which dominate the result in one particular limit.

By following this route we will be able to give a more general formulation of this problem, replacing the (complex) coefficients of the wave function with Nc-dimensional real vectors.

This generalization appears in a natural way by analyzing the mathematical structure of the measure used to characterize the multipartite entanglement. Clearly, the physics of the case Nc much larger than 2 will not be the same as in the original problem Nc =2, however, as it is often the case with large-Nc expansions, the two problems share some important ingredients and salient features

The symptoms of a phase transition are present for multipartite entanglement in the limit of large Nc. Moreover, we will see an explicit example where the frustration of multipartite entanglement disappears if the value of Nc is large enough.

References

1. P. Facchi et al. Phys. Rev. A, 92, 062330 (2015); 2. P. Facchi et al. J. Phys. A 43, 225303 (2010); 3. P. Facchi et al. New J. Phys. 12, 025015 (2010); 4. P. Facchi et al., Phys. Rev. A 87, 052324 (2013).

Metrology for Quantum Cryptography and the Italian Quantum Backbone

A. Avella, G. Brida, D. Calonico, C. Clivati, I. P. Degiovanni, F. Levi, M. Gramegna, M. Genovese, A. Meda, A.Mura, F. Piacentini, M. L. Rastello, I. Ruo Berchera, P. Traina

INRIM –Istituto Nazionale di Ricerca Metrologica-, Strada delle Cacce 91, 10135 Torino; ITALY

Quantum cryptography, or more properly Quantum Key Distribution (QKD) is essentially the generation of perfectly secure random keys between two parties that communicate by an open quantum channel. This enables the parties to establish a secret key from short pre-shared secret and public exchanges, something which has never been shown to be possible with classical, non-quantum means [1]. With increasing amounts of data being transmitted and stored online, there is an increasing need to secure that data. Researchers in the field consider QKD as the only truly secure key distribution technology (except secret courier) since it is secured by the laws of physics. Interestingly, conventional asymmetrical cryptography, which is almost exclusively used for key distribution today, could be rendered insecure by the advent of extremely powerful computers, including quantum computers, or new mathematical insights [1].

References

[1] N. Gisin, G. Ribordy, W. Tittel, and H. Zbinden, Quantum cryptography, Rev. Mod. Phys. 74, 145 (2002).

Microscopic description for the emergence of collective decoherence in extended systems

Fernando Galve1 , Antonio Mandarino2, Matteo G. A. Paris2 , Claudia Benedetti2, Roberta Zambrini1

1 Institute for Interdisciplinary Physics and Complex Systems, Mallorca, Spain 2 Quantum Technology Lab, Dipartimento di Fisica, Uni. degli Studi di Milano, I-20133 Milan, Italy

Among different probabilistic algorithms, a model based on quantum geometry could better represent natural language semantics. Semantic relationships seem not commutative [3]; they violates Leibniz's law as it happens in quantum logic [4]; many semantic relationships are not represented by morphosyntactic elements, as the vector state is not observable; the stabilisation of a semantic bind could be modelled by entanglement [5], [6]. We will show how the Bell states can be used to encode the basic fundamental semantic relationships represented by Greimas's semiotic square, thus providing a clue to develop new algorithms designed for information retrieval.

References

[2] Greimas, A.J. (1983) Structural Semantics: An Attempt at a Method, University of Nebraska press.

Atom-field dressed states in slow-light waveguide QED

Giuseppe Calajo[1], Francesco Ciccarello[2], Darrick Chang[3], Peter Rabl[1]

(1) Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria
(2) NEST, Istituto Nanoscienze-CNR and Dipartimento di Fisica e Chimica, Universita' degli studi di Palermo, Italy
(3) CFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain

We discuss the properties of atom-photon bound states in waveguide QED systems consisting of single or multiple atoms coupled strongly to a finite-bandwidth photonic channel. Such bound states are formed by an atom and a localized photonic excitation and represent the continuum analog of

the familiar dressed states in single-mode cavity QED. Here we present a detailed analysis of the linear and nonlinear spectral features associated with single- and multi-photon dressed states and show how the formation of bound states affects the waveguide-mediated dipole-dipole interactions

between separated atoms. Our results provide a both qualitative and quantitative description of the essential strong-coupling processes in waveguide QED systems, which are currently being developed in the optical and the microwave regime.

References

G. Calajò et al., Phys. Rev. A 93, 033833 (2016)

Why quantum computing will be the next turn in information retrieval: a semiotic overview on language and probability

Francesco Galofaro (1), Zeno Toffano (2), Bich Lien Doan (3)

(1) Politecnico, Milan; (2) Laboratoire de Signaux et Systèmes (L2S, UMR8506)- CNRS - Université Paris Saclay; (3) Laboratoire de Signaux et Systèmes (L2S, UMR8506) - CNRS - Université Paris Saclay

Big Data re-opened the debate between deterministic and probabilistic methods in linguistics [1]. Semantics seems to be a promising field for their application: Greimas [2] observed how semantic layers are stabilized in the text thanks to redundancy, thus transmitting less information. For example, the context stabilizes one of the possible meaning of ambiguous syntactic structures such as “the chicken is ready to eat.” by reducing the probability of the other meanings.

Among different probabilistic algorhitms, a model based on quantum geometry could better represent natural language semantics. Semantic relationships seems not commutative [3]; they violates Libniz' law as it happens in quantum logic [4]; many semantic relationships are not manifested by morphosyntactic elements, as the vector state is not obsevable; the stabilisation of a semantic bind can be modeled by entanglement [5], [6]. We will show how Bell's states can be use to encode the basic fundamental semantic relationships modeled by Greimas' semiotic square, thus providing a clue to develop new algorhitms aimed to information retrieval.

References

[1] Manning, C.D. (2003) “Probabilistic Syntax”, in Probabilistic linguistics, Cambridge Mass. : MIT press.
[2] Greimas, A.J. (1983) Structural Semantics: An Attempt at a Method, University of Nebraska press.
[3] Van Rijsbergen, K. (2004), The Geometry of Information Retrieval, Cambridge UK, Cambridge University Press.
[4] Takeuti, G. (1981) “Quantum set theory” in Bentrametti and Van Fraassen [eds.] Current Issues in Quantum Logic, Vol. 8 of Ettore Majorana International Science Series, New York, Plenum, pp. 303– 322.
[5] Barros, Toffano, Meguebli, Doan (2014) "Contextual Query Using Bell Tests", QI 2013 LNCS 8369, pp, 110-121.
[6] Dalla Chiara, Giuntini, Ledda, Leporini, Sergioli (2010), “Entanglement as a semantic resource” in Foundations of Physics, Volume 40, Issue 9, pp. 1494-1518..

Entanglement detection for discrete, continuous and hybrid variables

M. Gessner (1,2), L. Pezzè (1), and A. Smerzi (1)

(1) QSTAR, INO and LENS, Firenze, Italy; (2) INRIM, Torino, Italy

We derive a family of entanglement criteria which can be applied to multipartite systems of discrete or continuous variables, and hybrid combinations of both. They further detect the entanglement of states that are undetected by widely employed state-of-the-art methods in both cases of discrete and continuous variables. In particular, the entanglement of all pure entangled states can be revealed.

The Fisher information quantifies a quantum state's sensitivity to a unitary transformation. We show that for separable states, this quantity is bounded by the variances of the local operators that generate the transformation. Both the Fisher information and the variances of local observables are accessible in a wide range of experiments without knowledge of the full quantum state. Hence, the strategy proposed here generates a versatile class of efficient, and experimentally usable entanglement criteria.

References

M. Gessner, L. Pezzè, A. Smerzi, Physical Review A 94 (2), 020101(R) (2016).

Quantum steering inequality with tolerance for measurement-setting-errors: experimentally feasible signature of unbounded violation

Magdalena Stobińska (1)

(1) University of Gdansk, Gdansk, Poland

Quantum steering is a relatively simple test for quantumness of correlations, proving that the values of quantum-mechanical measurement outcomes come into being only in the act of measurement. By exploiting quantum correlations Alice can influence – steer – Bob's physical system in a way inaccessible in classical world, leading to violation of some inequalities. Demonstrating this and similar quantum effects for systems of increasing size, approaching even the classical limit, is a long-standing challenging problem. Here we provide experimentally feasible signature of unbounded violation of a steering inequality. We derive its universal form where tolerance for measurement-setting-errors is explicitly build-in by means of the Deutsch-Maassen-Uffink uncertainty relation. Then, generalizing the mutual unbiasedness, we apply the inequality to the multi-singlet and multi-particle bipartite Bell-state. However, the method is general and opens the possibility of employing multi-particle bipartite steering for randomness certification and development of quantum technologies, e.g. random access codes.

References

1. A. Rutkowski, A. Buraczewski, P. Horodecki, M. Stobinska, arXiv:1603.07861.
2. E. Schroedinger, Math. Proc. Camb. Phil. Soc. 32, 446 (1936).
3. M. Marciniak, A. Rutkowski, Z. Yin, M. Horodecki, R. Horodecki, Phys. Rev. Lett. 115, 170401 (2015).
4. H. M. Wiseman., S. J. Jones, A. C. Doherty, Phys. Rev. Lett. 98, 140402 (2007).

Robustness of asymmetry and coherence of quantum states

M. Piani (1), M. Cianciaruso (2,3), T. R. Bromley (3), C. Napoli (2,3), N. Johnston (4), G. Adesso (3)

(1) University of Strathclyde, United Kingdom; (2) Università degli Studi di Salerno and INFN Sezione di Napoli, Italy; (3) University of Nottingham, United Kingdom; (4) Mount Allison University, Canada

Quantum states may exhibit asymmetry with respect to the action of a given group [1]. Such an asymmetry of states can be considered as a resource in applications such as quantum metrology [2], and it is a concept that encompasses quantum coherence as a special case [3]. In Ref. [4] we introduce explicitly and study the robustness of asymmetry, a quantifier of asymmetry of states that we prove to have many attractive properties, including efficient numerical computability via semidefinite programming, and an operational interpretation in a channel discrimination context. We also introduce the notion of asymmetry witnesses, whose measurement in a laboratory detects the presence of asymmetry. We prove that properly constrained asymmetry witnesses provide lower bounds to the robustness of asymmetry, which is shown to be a directly measurable quantity itself. Both in Ref. [4] and in Ref. [5] we focus our attention on coherence witnesses and the robustness of coherence, for which we prove a number of additional results; these include an analysis of its specific relevance in phase discrimination and quantum metrology, an analytical calculation of its value for a relevant class of quantum states, and tight bounds that relate it to another coherence monotone previously defined in Ref. [6].

References

[1] S. D. Bartlett, T. Rudolph, and R. W. Spekkens, Rev. Mod. Phys. 79, 555 (2007).
[2] V. Giovannetti, S. Lloyd, and L. Maccone, Nat. Photon. 5, 222 (2011).
[3] I. Marvian, R. W. Spekkens, and P. Zanardi, arXiv:1510.06474 (2015).
[4] M. Piani, M. Cianciaruso, T. R. Bromley, C. Napoli, N. Johnston, and G. Adesso, Phys. Rev. A 93, 042107 (2016).
[5] C. Napoli, T. R. Bromley, M. Cianciaruso, M. Piani, N. Johnston, and G. Adesso, Phys. Rev. Lett. 116, 150502 (2016).
[6] T. Baumgratz, M. Cramer, and M. B. Plenio, Phys. Rev. Lett. 113, 140401 (2014).

Entanglement and coherence in quantum state merging

A. Streltsov (1), E. Chitambar (2), S. Rana (3), M. N. Bera (4), A. Winter (5), M. Lewenstein (6)

(1) ICFO, Spain; Freie Universität Berlin, Germany; (2) Southern Illinois University, USA; (3) ICFO, Spain; (4) ICFO, Spain; (5) Universitat Autònoma de Barcelona, Spain; ICREA, Spain; (6) ICFO, Spain; ICREA, Spain

Understanding the resource consumption in distributed scenarios is one of the main goals of quantum information theory. A prominent example for such a scenario is the task of quantum state merging where two parties aim to merge their parts of a tripartite quantum state [1,2]. In standard quantum state merging, entanglement is considered as an expensive resource, while local quantum operations can be performed at no additional cost. However, recent developments show that some local operations could be more expensive than others: it is reasonable to distinguish between local incoherent operations and local operations which can create coherence [3]. This idea leads us to the task of incoherent quantum state merging, where one of the parties has free access to local incoherent operations only. In this case the resources of the process are quantified by pairs of entanglement and coherence. Here, we develop tools for studying this process, and apply them to several relevant scenarios. While quantum state merging can lead to a gain of entanglement, our results imply that no merging procedure can gain entanglement and coherence at the same time. We also provide a general lower bound on the entanglement-coherence sum, and show that the bound is tight for all pure states. Our results also lead to an incoherent version of Schumacher compression: in this case the compression rate is equal to the von Neumann entropy of the diagonal elements of the corresponding quantum state. For more details see [4].

References

[1] M. Horodecki, J. Oppenheim, and A. Winter, Nature 436, 673 (2005).
[2] M. Horodecki, J. Oppenheim, and A. Winter, Commun. Math. Phys. 269, 107 (2007).
[3] T. Baumgratz, M. Cramer, and M. B. Plenio, Phys. Rev. Lett. 113, 140401 (2014).
[4] A. Streltsov, E. Chitambar, S. Rana, M. N. Bera, A. Winter, and M. Lewenstein, arXiv:1603.07508.

Poster presentations

Nonlinearity as a resource for quantum technologies

F. Albarelli(1), A. Ferraro(2), M. Paternostro(2), M. G. A. Paris (1), M. A. C. Rossi (2)

(1) Università degli Studi di Milano, Italy;
(2) Queen's University, United Kingdom;

I will present the results of two different works, giving an overview of the potential role of nonlinearity for quantum technologies.

The first work is about nonlinearity in the context of anharmonic oscillators.

Considering various quantum-oscillator systems, we addressed the role played by the anharmonicity of their potential in the establishment of nonclassical features. Specifically, we showed that a monotonic relation exists between the the entropic nonlinearity of the considered potentials and their ground state nonclassicality, as quantified by the negativity of the Wigner function; confirming the idea that nonlinearity is a resource for the generation of nonclassicality and may serve as a guideline for the engineering of quantum oscillators.

The second work is about nonlinearity in the context of quantum metrology.

We addressed the characterization of dissipative bosonic channels and we showed that estimation of the loss rate by Gaussian probes (coherent or squeezed) is improved in the presence of Kerr nonlinearity. In particular, enhancement of precision may be substantial for short interaction time, i.e. for media of moderate size, e.g. biological samples.

References

1. F. Albarelli et al. Phys. Rev. A 93, 032112
2. M. A. C. Rossi, F. Albarelli, M. G. A. Paris arXiv:1602.07626

Entanglement transfer in a quadripartite system

A. Allevi (1), M. Bondani (2), I.I. Arkhipov (3), J. Perina Jr. (3), and O. Haderka (4)

(1) University of Insubria, Italy;
(2) Institute for Photonics and Nanotechnologies, CNR, Italy;
(3) Joint Laboratory of Optics of Palacky University and Institute of Physics of CAS, Czech Republic;
(4) Institute of Physics of CAS and Joint Laboratory of Optics of Palacky University, Czech Republic.

The generation of multi-partite entangled states represents a useful resource for the realization of quantum information protocols. Here we present a compact scheme, in which two second-order nonlinear optical interactions, i.e. a parametric down conversion (PDC) and an up-conversion, simultaneously occur in the same nonlinear crystal thus producing a quadripartite entangled state [1].
The theoretical description of the system is presented and the entanglement properties are discussed in terms of some relevant criteria (Lee nonclassicality depth [2], logarithmic negativity [3] and noise reduction factor [4]).

From the experimental point of view, the realization of the scheme is obtained in the visible range by sending two pulsed pump fields in a BBO crystal. The characterization of the quadripartite state is based on the exploitation of photon-number resolving detectors, which are used to prove the entanglement transfer from the twin parties, generated by the PDC process, to the two up-converted modes [5].

The experimental results suggest the exploitation of such a scheme in quantum communication channels for the conversion of entangled states, generated at telecom wavelengths, to the visible range, where the detection technology is much more mature and efficient.

References

1. I.I. Arkhipov et al., manuscript in preparation.
2. C. T. Lee, Phys. Rev. A 44, R2775 (1991).
3. G. Vidal and R. F. Werner, Phys. Rev. A 65, 032314 (2002).
4. I. P. Degiovanni et al., Phys. Rev. A 79, 063836 (2009).
5. A. Allevi et al., manuscript in preparation.

Quantum Security in Large-Scale QRNA-Based Distributed Systems

M. Amoretti (1), S. Carretta (2)

(1) Department of Information Engineering, University of Parma, Italy; (2) Department of Physics and Earth Sciences, University of Parma, Italy

The quantum recursive network architecture (QRNA) introduced by Van Meter et al. [1] supports the creation of distributed quantum states over autonomous, heterogeneous networks of spatially separated systems.

In this work, we consider QRNA-based distributed systems where fixed nodes, provided with quantum memories [2] and connected by optical fiber links, may be organized according to any topology and hierarchy, but neither base stations nor administrators are needed, as all nodes are functionally equivalent and able to communicate with each other. For such systems, we propose a security scheme, based on quantum key distillation [3], enabling: i) high-probability eavesdropping detection; ii) secure communication between nodes; iii) high-probability intrusion detection. In particular, we introduce two eavesdropping detection protocols (denoted as EAVDET2 and EAVDET3), characterized by increasing efficiency. Compared to a previously proposed protocol by Nagy and Akl [4] (denoted as EAVDET1, for simplicity), our ones are much more convenient, in terms of eavesdropping detection probability versus sacrificed quantum resources. For the EAVDET1-2-3 and intrusion detection protocols, we provide correctness proofs, security analysis and comparative cost analysis. Regarding secure communication, we propose a sound procedure, involving state-of-the-art information reconciliation and privacy amplification techniques.

Importantly, our security scheme enables large-scale, highly secure QRNA-based distributed systems, requiring quantum channels only to support the establishment of entangled pairs between nodes. Otherwise, only classical channels are needed.

References

1. R. Van Meter, J. Touch, C. Horsman, Recursive Quantum Repeater Networks, Progress in Informatics, no. 8, pp. 65-79 (2011)
2. F. Bussières, N. Sangouard, M. Afzelius, H. de Riedmatten, C. Simon and W. Tittel, Prospective applications of optical quantum memories, J. Mod. Opt., vol. 60, n.18, pp. 1519-37 (2013)
3. A. K. Ekert, Quantum cryptography based on Bell's theorem, Physical Review Letters, vol. 67, no. 6, pp. 661-663 (1991)
4. N. Nagy, M. Nagy, S. G. Akl, Quantum security in wireless sensor networks, Natural Computing, vol. 9, no. 4, pp. 819-830 (2010)

Dissipation effects in quantum annealing

Luca Arceci(1), Simone Barbarino(1), Rosario Fazio(2, 3), Giuseppe E. Santoro(1, 2)

(1) SISSA, Via Bonomea 265, 34136 Trieste, Italy
(2) ICTP, Strada Costiera 11, 34151 Trieste, Italy
(3) NEST, Scuola Normale Superiore and Istituto Nanoscienze-CNR, 56126 Pisa, Italy

Quantum annealing, alias adiabatic quantum computation, has become a topic of intense research due to the first commercially available programmable machines based on superconducting flux quantum bits. It was suggested a few years ago [1] that thermal effects due to the environment might be beneficial to a machine based on a quantum adiabatic evolution. However, a thorough solution of the dissipative Landau-Zener problem, a prototypical example of adiabatic evolution in presence of a dissipative bosonic bath, shows that thermal effects
depend crucially on how the spin couples to the bath of harmonic oscillators [2,3]: remarkably, no improvement over the coherent quantum dynamics is obtained when the spin couples only via sigma^z, in contrast with the claims of [1].

We are therefore re-examining this issue by carefully comparing weak-coupling quantum master equation results to exact numerical results [3] obtained from the quasi-adiabatic path-integral (QUAPI) approach [4].

References

[1] M. H. S. Amin et al., Phys. Rev. Lett. 100, 060503, (2008)
[2] K. Saito et al., Phys. Rev. B 75, 214308 (2007)
[3] S. Javanbakht et al., Phys. Rev. A 91, 052103 (2015)
[4] N. Makri, J. Math. Phys. 36, 2430 (1995)

Photons in flat bands

M. Biondi (1), E. P. L. van Nieuwenburg (1), G. Blatter (1), S. D. Huber (1), S. Schmidt (1), F. Baboux (2), L. Ge (3), T. Jacqmin (2), E. Galopin (2), A. Lemaître (2), L. Le Gratiet (2), I. Sagnes (2), A. Amo (2), J. Bloch (2), H. E. Türeci (4).

(1) ETH Zurich, Switzerland; (2) LPN Marcoussis, France; (3) CUNY, NY, USA; (4) Princeton, NJ, USA.

Frustrated systems are notoriously difficult to simulate on a classical computer and thus represent excellent candidates as testbeds for quantum simulation. Photonic quantum simulators based on interacting light-matter systems are considered as ideal platforms to study the non-equilibrium dynamics of open many-body systems such as strongly correlated states of photons.

Here, we report of recent theoretical as well as experimental results on the simulation of geometrical frustration in interacting photonic lattices far from equilibrium. In particular, we discuss two recent discoveries at the interface of condensed matter physics and quantum optics: [1] the theoretical prediction of crystalline phases of light in a frustrated qubit-cavity array and [2] the experimental achievement of bosonic condensation into a flat energy band. These works pave the way for quantum simulations of frustrated systems far from equilibrium and open up novel perspectives in the experimental investigation of exotic phases of light with interesting spatial structures.

References

[1] M. Biondi et al., Phys. Rev. Lett. 115, 143601 (2015);
[2] F. Baboux et al., Phys. Rev. Lett. 116, 066402 (2016).

Group theory and Bell inequalities

K. Bolonek-Lasoń

University of Lodz, Poland

The Bell inequalities can be derived from the assumption that the relevant probabilities are obtained as marginals from the joint probability distribution for all dynamical variables entering the problem. Once the Bell inequality is established one looks for quantum mechanical systems which fail to obey them. Recently, the method allowing to find such systems has been proposed which is based on the representation theory of finite groups (Ugur Guney, M. Hillery, Phys. Rev. A90 (2014), 062121 and Phys. Rev. A91 (2015), 052110).

In my talk I consider the example of such procedure which uses the representations of symmetry group S_4. It appears that the symmetry underlying the breakdown of the corresponding Bell inequalities is that of regular tetrahedron. I analyze a number of orbits defining the quantum mechanical probabilities and determine the degree of breakdown of Bell inequalities. The corresponding nonlocal quantum games are discussed and efficiency of quantum strategies is compared with those of their classical counterparts.

Quantum theory of squeezing in shock waves

Maria Chiara Braidotti (1,2), Antonio Mecozzi (2) and Claudio Conti (1,3)

(1) Institute for Complex Systems, National Research Council (ISC-CNR), Via dei Taurini 19, 00185 Rome, Italy; (2) Department of Physical and Chemical Sciences, University of L'Aquila, Via Vetoio 10, I-67010 L'Aquila, Italy; (3) Department of Physics, University Sapienza, Piazzale Aldo Moro 5, 00185 Rome, Italy;

Squeezed states are pure quantum states not having a classical counterpart, which proved to play an important role in modern quantum optics. Recently, their connection with quantum information and their employment in cryptography, quantum computation and gravitational wave detection has attracted great attention.

Spectral properties of the squeeze operator S(z) were discussed in the late 80s, where it was state that it has a purely continuous spectrum that covers the unitary circle in the complex plane. However, currently, this statement has been argued stating that it is possible to find a family of not-proper discrete eigenvalues, linked to the eigenvectors (Gamow vectors) of a rigged Hilbert space. [1]

In this talk, we want to show that this quantum light appears in the development of the shock phenomenon.

A shock wave is a singular solution of a hyperbolic partial differential equation, which is a class of equations that describe a wide variety of wave-like phenomena in physics, ranging from fluido-dynamics to plasmas and Bose-Einstein condensation (see e.g. [2,3]).

Recently, it has been proved that shock waves evolution in a nonlinear and highly nonlocal medium can be described thanks to the use of the eigenstates of a reversed harmonic oscillator (RHO). [4]

Here we show that thanks to the Gamow vector formalism, the squeezing operator S(z) can be seen as a wave-function propagator of quantum mechanics. Indeed, we can express the evolution of a Gaussian wave-function in a nonlinear nonlocal medium as a squeezing operator acting on the eigenfunctions of a RHO. Theoretical analysis and numerical simulations reveal that the quadrature (x-p) and (x+p), where x is the position operator and p is the momentum operator, are squeezed during the excitation of a shock wave of Gaussian light beam. This gives evidence of the presence of squeezed light during a shock development.

These results open a new road to a deep knowledge of the shock phenomenon and links quantum optics and its applications to nonlinear waves in extreme regimes.

References

1. D. Chruscinski, Phys. Lett. A, 327, 290-295 (2004)
2. W. Wan, Shu Jia and J. W. Fleischer, Nat. Phys. 3, 46 - 51 (2007)
3. M. Conforti, F. Baronio and S. Trillo, Phys. Rev. A 89, 013807 (2014)
4. S. Gentilini, M. C. Braidotti, G. Marcucci, E. DelRe and C. Conti, Phys. Rev. A, 92, 023801 (2015)

Accessible quantification of multiparticle entanglement

Marco Cianciaruso (1,2,3), Thomas R. Bromley (1), and Gerardo Adesso (1)

(1) School of Mathematical Sciences, The University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom
(2) Dipartimento di Fisica "E. R. Caianiello", Università degli Studi di Salerno, Via Giovanni Paolo II, I-84084 Fisciano (SA), Italy
(3) INFN, Sezione di Napoli, Gruppo Collegato di Salerno, I-84084 Fisciano (SA), Italy

Entanglement is a key ingredient for quantum technologies and a fundamental signature of quantumness in a broad range of phenomena encompassing many-body physics, thermodynamics, cosmology, and life sciences. For arbitrary multiparticle systems, entanglement quantification typically involves nontrivial optimisation problems, and may require demanding tomographical techniques. I will discuss an experimentally feasible approach that we have developed for the evaluation of geometric measures of multiparticle entanglement. This framework provides analytical results for particular classes of mixed states of N qubits, and computable lower bounds to global, partial, or genuine multiparticle entanglement of any general state. For global and partial entanglement, useful bounds are obtained with minimum effort, requiring local measurements in just three settings for any N. For genuine entanglement, a number of measurements scaling linearly with N is required. I will then demonstrate the power of this approach to estimate and quantify different types of multiparticle entanglement in a variety of N-qubit states useful for quantum information processing and recently engineered in laboratories with quantum optics and trapped ion setups.

Reference

1. M. Cianciaruso, T. R. Bromley, and G. Adesso, arXiv:1507.01600 (2015).

Measuring total correlations via the Operator Schmidt Decomposition

M. Caiaffa (1), M. Piani (1)

(1) SUPA and Department of Physics, University of Strathclyde, Glasgow G4 0NG, UK

One of the main focuses of the current research in Physics is to exploit the exemplar features that nature exhibits at the quantum scale. Entanglement is considered a key resource in quantum information science. Its usefulness for conceiving and implementing new technologies and computational protocols that outperform their classical counterparts has been proved, and several applications are well established by now [1]. Correlations between quantum systems do not reduce to entanglement per se: there are correlations also in absence of entanglement, and there are various degrees of entanglement, with stronger entanglement leading to phenomena like steering and non-locality [2-3]. Thus, it would be helpful to have ways to study and quantify correlations in a unified framework. With this in mind, we consider the so-called Operator Schmidt Decomposition (OSD), i.e. the correspondent at the level of operators of the standard Schmidt decomposition for pure quantum states [4,5]. We prove several properties of the OSD, and we propose a measure of total correlations based on the value of the Operator Schmidt coefficients. We show that this measure satisfies the properties to be expected by a measure of total correlations. In addition, we show that the value assumed by this measure can reveal properties like entanglement and steering.

References

1. M.A. Nielsen, I.L. Chuang: "Quantum Computation and Quantum Information." Cambridge University Press, Cambridge (2000)
2. R.F. Werner, Phys. Rev. A 40, 4277 (1989)
3. H.M. Wiseman, S.J. Jones, A.C. Doherty, Phys. Rev. Lett. 98, 140402 (2007)
4. N. Johnston, Nathaniel. "Norms and cones in the theory of quantum entanglement." arXiv preprint arXiv:1207.1479 (2012)
5. G. De las Cuevas et al., NJP 15, 123021 (2013)

Paying the Price - The cost of achieving finite time adiabatic dynamics

Yuanjian Zheng(1), Steve Campbell(2), Gabriele De Chiara(2), Dario Poletti(1,3)

(1) Singapore University of Technology and Design, 8 Somapah Road, 487372 Singapore
(2) Centre for Theoretical Atomic, Molecular and Optical Physics, Queen's University Belfast, Belfast BT7 1NN, United Kingdom
(3) MajuLab, CNRS-UNS-NUS-NTU International Joint Research Unit, UMI 3654, Singapore

Recent years have witnessed a surge of interest in the study of thermal nanomachines that are capable of converting disordered forms of energy, such as heat, into useful work. It has been shown for both classical and quantum systems that external drivings can allow a system to evolve adiabatically even when driven in finite time, such techniques are commonly known as shortcuts to adiabaticity (STA) [1].
It was suggested to use such external drivings to render the unitary processes of a thermodynamic cycle quantum adiabatic, while being performed in finite time [2]. This could considerably augment the performance of nano-thermodynamic engines as work exchanges are extremised by adiabatic protocols. However, implementing additional external driving requires resources which affect the overall performance of the system. We analyse the implications of considering the necessary power in applying these STA, subsequently showing that this cost may outweigh the possible gains in work extraction for slow enough processes due to the relative degree of adiabaticity in the dynamics, while for relatively faster processes, the use STA can improve the work exchange. Furthermore, we devise a general strategy that exploits the definition of work as a two-time measurement of energy to improve the performance of work transfer. In particular, we show that it is possible to achieve sizable energy savings by gathering information from the first measurement and then applying a specifically tailored driving to the protocol. We apply our framework to driving a critical many-body system through a quantum phase transition, where the closing of the energy gap at the critical point makes the driving Hamiltonian of increasing complexity [3] and show that this complexity necessitates a divergence in the cost of achieving finite time adiabatic dynamics [4].

References

[1] E. Torrontegui, S. Ibanez, S. Martinez-Garaot, M. Modugno, A. del Campo, D. Guery-Odelin, A. Ruschhaupt, X. Chen, J. G. Muga, Adv. At. Mol. Opt. Phys. 62, 117 (2013).
[2] A. del Campo, J. Goold, M. Paternostro, Sci. Rep. 4, 6208 (2014).
[3] S. Campbell, G. De Chiara, M. Paternostro, G. M. Palma, R. Fazio, Phys. Rev. Lett. 114, 177206 (2015).
[4] Y. Zheng, S. Campbell, G. De Chiara, D. Poletti, arXiv:1509.01882

Hybrid and multipartite entanglement in vector vortex beams

Gonzalo Carvacho (1), Francesco Graffitti (1), Vincezo D'Ambrosio (1), Chiara Vitelli (1), Bruno Piccirillo(2,3), Lorenzo Marrucci (2,3), Beatrix C. Hiesmayr (4) and Fabio Sciarrino (1)

(1)Dipartimento di Fisica, " Sapienza " Università di Roma, I-00185 Roma, Italy
(2)Dipartimento di Fisica, Università di Napoli Federico II, Complesso Universitario di Monte S. Angelo, 80126 Napoli, Italy
(3)CNR-SPIN, Complesso Universitario di Monte S. Angelo, 80126, Napoli, Italy
(4)University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria

By exploiting the "q-plate" [1] we can generate light beams having a vectorial field structure or polarization that varies over the transverse profile and a central optical singularity are called vector vortex (VV) beams [2] and may exhibit specific properties, such as focusing into "light needles" or rotation invariance. Individual photons in such beams exhibit a form of single particle quantum entanglement between different degrees of freedom (Intrasystem entanglement). On the other hand, the quantum states of two photons can be also entangled with each other (Inter-system entanglement). Additionally, by changing the basis we can consider GHZ-states (Greenberger-Horne-Zeilinger) which are a family of many particles highly-entangled that show unique properties related to their extreme non-classical being [3]. A complete basis of GHZ-states can be constructed by properly choosing local basis rotations. We demonstrate this experimentally for a 16 dimensional Hilbert space with decomposition into four parts by entangling two photons in polarisation and orbital angular momentum. Mixing GHZ-states unmasks different entanglement features based on their particular local geometrical connectedness and can be represented by a magic simplex. In particular, a specific GHZ-state in a complete orthonormal basis has a "twin" GHZ-state for which equally mixing leads to full separability in opposition to any other basis-state. In order to observe these theoretical predictions we have developed a quantum technological platform able to generate and manipulate GHZ-states with high control, exibility and brightness allowing a scaling in degrees of freedom and advanced operational manipulations. Furthermore an investigation on the geometry of the twin GHZ-states has been carried out exploring the properties of the magic simplex.

References

[1] Marrucci et al., Phys. Rev. Lett. 96, 163905 (2005).
[2] Zhan, Q., Advances in Optics and Photonics 1, 1-57 (2009)
[3] Hiesmayr, B. C et al., P., Phys. Rev. A 79, 062308 (2009

Study of optoelectronic properties of a shallow donor confined in inhomogenous quantum dot “IQD”

Y.Chrafih (1), K.Rahmani (2), I.Zorkani (3)

(1) Faculty of Science and Technology, University of Sultan Moulay Slimane Morroco, (2) Faculty Of Science Dhar El Mehraz Fez Morroco

This work is devoted to the study of optoelectronic properties of a donor impurity confined in inhomogeneous quantum dot (IQD) in the presence of external fields.

The binding energy and diamagnetic susceptibility and the polarisability are investigated for a shallow donor confined in Inhomogeneous Quantum Dots ’’IQD’’ in the presence of external fields. And also to study the effect of those external fields and that of the temperature of these measured physical quantities. The Calculations are performed in the framework of the effective mass approximation using the Hass variational approach. We describe the effect of the quantum confinement by an infinite deep potential.

The Inhomogenous Quantum dot (IQD) is modeled by [Ga1-xAlxAs/GaAs (Well) /Ga1-xAlxAs] and we describe the effect of the quantum confinement by a finite and infinite deep potential in this structures.

References

A. Mmadi, K. Rahmani, I. Zorkani and A. Jorio “Diamagnetic Susceptibility of a Magneto-Donor in Inhomogeneous Quantum Dots”, Superlattices and Microstructures 57 (2013) 27.
A. Mmadi, A. Jorio, I. Zorkani and K. Rahmani, “Magnetic field effect on the Diamagnetic Susceptibility of hydrogenic donor in Cylindrical Quantum Dot”. The African Review of Physics 8 (2013) 219
Zorkani I, Mmadi A, Didi Seddik A, Jorio A, “Magnetic Field Effects on the Optical Absorption and Polarizability of Donor in Quantum Dot’’ J.Nanotech. Prog. Int. (JONPI) volume 4, issue 1, 2013
K. Rahmani, I. Zorkani “Magnetic and electric field effects on the binding energy of a shallow donor in quantum dot – quantum well”. M.J.Condensed.Mater Volume 11, Number 2 (2009) pp 35-39.

Optical Demonstration of a Bit-Flip Correction for Enhanced Sensitivity Measurements

L. Cohen, Y. Pilnyak, D. Istrati, A. Retzker, and H. S. Eisenberg

Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem 91904, Israel

The sensitivity of classical and quantum sensing is impaired in a noisy environment. Thus, one of the main challenges facing sensing protocols is to reduce the noise while preserving the signal. Recently, a proposal to use a quantum error correction protocol to recover sensitivity in the presence of a bit-flipping noise was published [1]. The main idea is to use a protected entangled qubit to correct the bit-flip.

In this talk, we will present a linear optics implementation of this protocol on the polarization degree of freedom of photons and its experimental demonstration [2].

A pair of entangled photons is generated using non-collinear type II spontaneous parametric down conversion. One photon measures a birefringence phase and is vulnerable to a bit flip, while its pair is protected and used for the correction. The error correction is performed by polarization rotations and a projection on a polarizing beam splitter. Our proof of principle demonstration is a novel solution in case of short correlation time bit-flip. The results show a significant recovery of the interference oscillations and about 87% of the sensitivity, independent of the noise rate.

Additionally, we will discuss how our scheme can be generalized to an arbitrary number of N photon pairs. In this case, the sensitivity is increased in principle by a factor of N^(1/2) compared to the shot noise limit, the limit of classical measurements, despite of the existing noise.

References

[1] Gilad Arrad, Yuval Vinkler, Dorit Aharonov, Alex Retzker, Increasing sensing resolution with error correction. Phys. Rev. Lett. 112, 150801 (2014).
[2] L. Cohen, Y. Pilnyak, D. Istrati, A. Retzker, H. S. Eisenberg, Demonstration of a Bit-Flip Correction for Enhanced Sensitivity Measurements. arXiv:1603.07159 (2016).

General Boundary Formulation of Quantum Theory

D. Colosi

Universidad Nacional Autónoma de México

The General Boundary Formulation (GBF) of quantum theory represents an extension of the standard formulation: The main ingredients of the GBF are the mathematical framework of topological quantum field theory and a generalisation of the Burn rule to compute probability of quantum processes. Among the different advantages of the GBF are the possibility to describe the quantum dynamics in the absence of a metric background structure and in a manifestly local formalism. In particular, in the GBF quantum states live on hypersurfaces of codimension one in space-time and generalised amplitudes are associated with space-time regions (of codimension zero). All the information on the quantum dynamics that takes place within a region is encoded in the boundary of the region. The poster present a non-technical introduction of the GBF underlying the ideas at the basis of this new formulation of quantum theory as well as the results obtained so far.

References

D. Colosi, J.Phys.Conf.Ser. 626 (2015) no.1, 012031
D. Colosi and D. Rätzel, SIGMA 9, 019 (2013)
D. Colosi and R. Oeckl,Phys. Rev. D 78, 025020 (2008)
R. Oeckl, Phys.Rev. D 73 (2006), 065017
R. Oeckl, Adv.Theor.Math.Phys. 12 (2008), 319-352

Momentum Resolved Spectroscopy Using Atomic Quantum Probes

F. Cosco (1), M. Borrelli (1), F. Plastina (2,3) and S. Maniscalco (1)

(1) Turku Centre for Quantum Physics, Department of Physics and Astronomy, University of Turku, FI-20014 Turun yliopisto, Finland
(2)Dipartimento di Fisica, Universita` della Calabria, 87036, Arcavata di Rende (CS), Italy
(3) INFN - Gruppo Collegato di Cosenza, Cosenza, Italy

We propose a non-invasive probing scheme to detect and characterise the superfluid excitations of a cold atomic gas loaded into an optical lattice using a single quantum impurity that acts as a probe. The protocol relies on weak collisional interactions and consequent measurements that are optimised in the impurity position. By tuning a few controllable external parameters in the impurity-lattice interaction and using two subsequent sets of measurements the full dispersion relation of the superfluid phonons can be reliably extracted.

Broadband Single-Photon Pulses in Hot Atomic Vapors

L. S. Costanzo (1,2), A. S. Coelho (3), D. Pellegrino (2), M. S. Mendes (4), L. Acioli(4), K. N. Cassemiro (4), D. Felinto (4), A. Zavatta (1,2) and M. Bellini (1,2)

(1) Istituto Nazionale di Ottica (INO-CNR), (2) European Laboratory for Non Linear Spectroscopy (LENS), (3) Departamento de Engenharia, Instituto Camillo Filho, 64049-230 Teresina, PI, Brazil, (4) Departamento de Fisica, Universidade Federal de Pernambuco, 50670-901 Recife, Brazil.

The propagation of weak ultrashort pulses through a dense resonant atomic vapor has been investigated for the formation of the so called zero-area pulses, where a negligible absorption is accompanied by a dramatic reshaping of the temporal pulse envelope. Here we present the first experimental demonstration of zero-area pulse formation for an ultrashort single photon. We propagate heralded single-photon pulses through a cell containing resonant rubidium vapor and find that the transmitted single-photon wavepackets preserve their nonclassical character and acquire the strong temporal modulation characteristic of zero-area pulses.

References

1. L. S. Costanzo et. al., Phys. Rev. Lett. 116, 023602 (2016).
2. C. Polycarpou, K. N. Cassemiro, G. Venturi, A.Zavatta, and M. Bellini, Phys. Rev. Lett. 109, 053602 (2012).

Continuous Variable Qubit Generation with a Quantum State Orthogonalizer

A. S. Coelho (1), L. S. Costanzo (1,2), A. Zavatta (1,2), C. Hughes (3), M. S. Kim (3) and M. Bellini (1,2)

(1) Istituto Nazionale di Ottica (INO-CNR), (2) European Laboratory for Non Linear Spectroscopy (LENS), (3) QOLS, The Blackett Laboratory, Imperial College London

The universal quantum NOT operation is defined as the operation that brings any quantum state to its orthogonal one. However, quantum laws prevent the perfect realization of this operation without some prior knowledge of the initial state, just like it is impossible to perfectly and deterministically clone or amplify a quantum state without prior information.

We present an experimental demonstration of a universal strategy for producing a quantum state that is orthogonal to an arbitrary, infinite-dimensional, pure input one, even if only a limited amount of information about the latter is available. Arbitrary coherent superpositions of the two mutually orthogonal

states are then produced by a simple change in the experimental parameters.

We use input coherent states of light, however the scheme works equally well for arbitrary input fields and constitutes a universal procedure, which may thus prove a useful building block for quantum state engineering and quantum information processing with continuous-variable qubits.

References

1. A. S. Coelho et. al., Phys. Rev. Lett 116., 110501 (2016).
2. M. R. Vanner, M. Aspelmeyer and M. S. Kim, Phys. Rev. Lett. 110, 010504 (2013).

Observing Multi-Photon Interference and Suppression Laws in 3D Photonic Chips

A. Crespi (1,2), R. Osellame (2,1), R. Ramponi (2,1), M. Bentivegna (3), F. Flamini (3), N. Spagnolo (3), N. Viggianiello (3), L. Innocenti (4) , P. Mataloni (3) and F. Sciarrino (3)

(1) Dipartimento di Fisica - Politecnico di Milano, Milano, Italy
(2) Istituto di Fotonica e Nanotecnologie - Consiglio Nazionale delle Ricerche, Milano, Italy
(3) Dipartimento di Fisica - Sapienza Università di Roma, Roma, Italy
(4) Dipartimento di Fisica - Università di Roma Tor Vergata, Roma, Italy

The theoretical and experimental investigation of multi-photon interference in multi-port interferometers has raised an increasing interest in the recent years. In fact, when many identical photons are injected in a large multi-mode interferometer implementing a random unitary transformation, the output distribution rapidly becomes hard to compute (the Boson-Sampling problem) [1]. Large-scale realizations of these devices have been envisaged as possible specialized quantum computers, that could outperform classical ones on specific tasks [2]. On the contrary, if symmetric multi-ports are considered, such as devices implementing the Fourier or the Hadamard transform of the input modes, the output distribution may be calculated efficiently, and presents several distinctive features. In particular, for specific input states, the majority of the possible output states is suppressed, because of destructive quantum interference, and such suppressed states can be predicted by simple analytical laws [3, 4]. The suppression is observed fully when perfectly identical particles are injected, while it disappears for distinguishable ones. Thus, symmetric multi-ports could used as benchmark devices to assess the quality of multi-photon source and their indistinguishability, as well as they may be employed for testing the functioning of future experimental Boson-Sampling setups [5].
Here we present integrated multi-mode interferometers, realized by femtosecond laser waveguide writing, that perform the quantum Fourier transform over the optical modes [6]. The waveguide circuits are realized according to a novel three-dimensional layout, that implements in optics the Fast-Fourier-Transform algorithm [7]. In particular, we realize devices with 4 and 8 modes and we test them by injecting two photons, with different degrees of distinguishability, in all the possible couples of inputs. For maximally indistinguishable photons we observe that the output distribution reduces to a few allowed output states, while all the others are suppressed, as predicted theoretically. In particular, we confirm the analytic suppression law of the output states devised by Tichy [3,5].

The novel and compact architecture here demonstrated allows to scale to larger systems with reduced experimental effort. In addition, other transformations [4] besides the Fourier one could be investigated with the same approach.

References

1. S. Aaronson, and A. Arkhipov, in Proceedings of the forty-third annual ACM symposium on Theory of computing, (ACM, 2011), 333–342.
2. J. Huh, G. G. Guerreschi, B. Peropadre, J. R. McClean, and A. Aspuru-Guzik, Nature Photon. 9, 615–620 (2015).
3. M. C. Tichy, M. Tiersch, F. de Melo, F. Mintert, and A. Buchleitner, Phys. Rev. Lett. 104, 220405 (2010).
4. A. Crespi, Phys. Rev. A 91, 013811 (2015).
5. M. C. Tichy, K. Mayer, A. Buchleitner, and K. Molmer, Phys. Rev. Lett. 113, 020502 (2014).
6. A. Crespi et al. Nat. Commun. 7, 10469 (2016).
7. R. Barak, and Y. Ben-Aryeh, J. Opt. Soc. Am. B 24, 231–240 (2007).

How to Amend Entanglement Breaking Channels

Á. Cuevas (1), A. Mari (2), A. De Pasquale (2), A. Orieux (1, *), M. Massaro (1, **), F. Sciarrino (1), V. Giovannetti (2), P. Mataloni (1)

(1) University of Rome La Sapienza, Rome, Italy; (2) NEST, Squola Normale Superiore and Istituto Nanoscenze-CNR, Pisa, Italy; (*) Télécom ParisTech, Paris, France; (**) Universität, Paderborn, Germany.

A noisy channel can destroy the entanglement resource of quantum communication protocols. In particular a channel is Entanglement Breaking or order 2 (EB-2) if completely destroys the entanglement of any input state when it is applied two times. This kind of channels are usually considered as useless for quantum communication purposes.

We present three experimental techniques that allow to partially recover the entanglement of a decohered system-ancilla (S-A) pair of photons. All three procedures consider the action of a particular kind of noise acting only on S, and by applying different corrections to their map structures it is possible to restore the feasibility of the quantum communication channel.

The first experiment used a polarization maximally-entangled state, where S passed through a transmission line of four EB-2 (M+N+M+N). M is formed by an Amplitude Damping Map (ADM) followed by a Unitary Operation (U), and N is formed by another U followed by another ADM. We proved theoretical and experimentally that adjusting the damping parameters, M+Id+M+Id and Id+N+Id+N are EB channels, and by a counterintuitive mechanism, the entire structure M+N+M+N does not. We called this technique as Cut & Paste, and shows that noisy channels can amend each other, converting a sequence of EB channels into a non-EB channel.

The second experiment used a so called Filtering technique, where a unitary operator F was set as M+F+M and N+F+N. We found that the output state recovered a big amount of entanglement. Similarly, an entanglement revival was found in the third experiment, where F filtered a sequence of two Dephasing Channel (D), by working as D+F+D.

In all tests, the entanglement was quantified by the concurrence of the state, extracted from tomography analysis, versus the rotation angle of the unitary operators (Half Wave Plates) in each map case.

References

1. A. S. Holevo, Russian. Math. Surveys 53, 1295 (1999).
2. M. Horodecki, P. W. Shor and M. B. Ruskai, Rev. Math. Phys 15, 629 (2003).
3. A. De Pasquale & V. Giovannetti. Physical Review A 86, 052302 (2012).
4. A. De Pasquale, A. Mari, V. Giovannetti and A. Porzio, Phys. Rev. A 87, 062307 (2013).

Towards optical phase measurement at the Heisenberg limit

S. Daryanoosh, S. Slussarenko, H. M. Wiseman, and G. J. Pryde

Centre for Quantum Dynamics, Griffith University

Optical phase measurement through its application in quantum metrology has pushed the precision limit with which some physical quantities can be measured accurately. At the very fundamental level, the laws of quantum mechanics dictate that the uncertainty in phase estimations scales as 1/N, where N is the number of quantum resources employed in the protocol [1]. This is the Heisenberg limit (HL) which is quadratically better than the standard quantum limit (SQL) with uncertainty asymptotically scaling as 1/\sqrt{N} [1]. Several experiments have demonstrated that the SQL can be beaten by using an entangled state as the probe and a specific measurement scheme for ab initio estimation of unknown phases [2,3]. It has also been shown experimentally that even in the absence of the entanglement one can measure an unknown phase with imprecision scaling at the HL [4].

In this work we present a new protocol able to estimate an optical phase at the Heisenberg limit, and then experimentally explore fundamental and practical issues in generating high-quality novel entangled states, for use in this protocol and beyond. Our aim in this study is to measure an unknown phase with uncertainty attaining the exact HL. There is a condition that should be met to address this objective: preparation of an optimal state [6]. This would cover part of the presentation through which we explain how to experimentally realize such an optimal state with the current technological limitations and the feasibility of the scheme. Our numerical simulation of the phase measurement gate together with the experimental outcomes show that the created state should have a high fidelity and purity to be able to have the phase uncertainty achieving the exact HL. Therefore, we briefly explain the modeling for experimental imperfections and finally present the results of experimental phase measurements.

References

1. V. Giovannetti, S. Lloyd, and L. Maccone, Science 306, 1330-1336 (2004)
2. G. Y. Xiang, B. L. Higgins, D. W. Berry, H. M. Wiseman, and G. J. Pryde, Nature Photonics 5, 43-47 (2010).
3. A. A. Berni, T. Gehring, Bo M. Nielsen, V. Höndchen, M. G. A. Paris, and U. L. Andersen, Nature Photonics bf 9, 577-582 (2015).
4. B. L. Higgins, D. W. Berry, S. D. Bartlett, H. M. Wiseman, and G. J. Pryde Nature 450, 393-397 (2007).
5. D. W. Berry, S. D. Bartlett, B. L. Higgins, and G. J. Pryde.
IEEE J. Sel. Top. Quant. Electron. 15, 1661-1672 (2009).

Exploring topological phases in a quantum walk exploiting Orbital Angular Momentum of light

F. Cardano (1), A. D'Errico (1), P. Massignan (2,3), A. Dauphin (2), M. Maffei (1,2), V. Cataudella (1, 4), G. De Filippis (1, 4), B.Piccirillo (1), C. de Lisio (1), M. Lewenstein (2,3), L.Marrucci (1,5).

(1) Dipartimento di Fisica, Università di Napoli Federico II, Complesso Universitario di Monte Sant'Angelo, via Cintia, Napoli 80126, Italy;
(2)ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain;
(3) ICREA-Institució Catalana de Recerca i Estudis Avançats, E-08010 Barcelona, Spain;
(4) CNR-SPIN, Complesso Universitario di Monte Sant'Angelo, Via Cintia, Napoli 80126, Italy;
(5) CNR-ISASI, Via Campi Flegrei 34, Pozzuoli (NA) 80078, Italy

Topological phases of matter have recieved widespread interest from fields like quantum computing, spintronics and metrology [1]. These phases are characterized by global topological order which manifests in phenomena like robust edge states.
Quantum walks have proven to be ideal platforms to investigate the fundamental features of topological phases [2]. In a discrete quantum walk a particle with an internal degree of freedom (like spin or polarization) moves on a lattice and its position is changed according to the internal state. At every step the spin state of the particle is changed by a rotation operator, thus mimicking the coin toss of the classical random walk.

Here we present a specific quantum walk protocol that shows the general features of one dimensional periodically driven systems with chiral symmetry [3-5], and discuss how we can implement in a photonic architecture. In this platform the space of light's Orbital Angular Momentum (OAM) implements a one dimentional lattice [6-7], while the internal degree of freedom is encoded in the photon's polarization. By exploiting a tunable spin-orbit interaction in suitable devices called q-plates, the position of the photon on this lattice, that is its OAM, is changed in a way which depends on its polarization. Accordingly, by realizing a sequence of q-plates and waveplates we are able to implement such quantum dynamics. We provide a full topological characterization of this system, and investigate theoretically and experimentally the associated topological features.

References

1. M.Z. Hasan, C.L. Kane, Reviews of Modern Physics, (2010)
2. T. Kitagawa, Quantum Information Processing 11,pp 1107–1148. (2012)
3. F. Nathan and M. S Rudner, New Journal of Physics, 17(12):125014, (2015)
4. J. Asboth .Physical Review B, 86(19):195414, 2012
5. J. K. Asboth and H. Obuse, Physical Review B, 88(12):1-5, (2013)
6. F. Cardano et al. Science Advances.Vol 1, No. 2, (2015)
7. F. Cardano et al. Nature Communications, 7:1-8, (2016).

Spontaneous emission in quantum nonlinear Schrödinger solitons

L. Di Mauro Villari (1), F. Biancalana (2), C. Conti (1) (3)

(1) Institute for complex Systems, National Research Concil (ISC-CNR), Via dei Taurini 19, 00185 Rome (IT); (2) School of Engineering and Physical Sciences, Heriot-Watt University, EH14 4AS Edinburgh (UK); (3) University of Rome La Sapienza, Department of Physics, Piazzale Aldo Moro 5 00185, Rome (IT)

In nonlinear waves theory solitons are solutions of integrable nonlinear partial differential equations as the nonlinear Schrödinger equation (NLSE) that describes an optical pulse propagating in nonlinear dielectric media. These solutions are shape invariant during propagation and inter- act elastically. The quantum version of solitons were originally considered in particle physics and more recently studied in optical fibers. The growing interest in integrate quantum optics makes this topic timely again as quantum solitons appear when the electromagnetic field is quantized in one-dimensional nonlinear media [1].

In our work we study the fundamental properties of quantum nonlinear Schrödinger solitons, from analytical and numerical point of view. The quantized nonlinear Schrödinger equation can be solved by the Bethe ansatz [2]. At variance with the classical soliton the quantum soliton spreads and dif- fuses its phase upon evolution. Computing the soliton spectrum we show that the spreading is mediated by the emission of specific frequencies, a phenomenon not previously addressed.

We test our results transforming the quantum nonlinear Schrödinger equation in a stochastic differential equation by the positive P-representation. We integrate the stochastic NLSE with a second order stochastic Runge-Kutta algorithm. The soliton spontaneous emission is of fundamental inter- est since it is related to an exact solution of a quantum completely integrable model.

References

[1] P. Drummond and M. Hillery, The Quantum Theory of Nonlinear Optics (Cambridge University Press, 2013).
[2] Y. Lai and H. Haus, Phys. Rev. A pp. 854–866 (1989).

Quantum tomography and interference with Surface Plasmon Polaritons

F. Dieleman (1), M. Tame (2), M. Kim (1), S. Maier (1)

(1) Imperial College London, UK
(2) University of KwaZulu-Natal, Durban, South Africa

Surface Plasmon Polaritons are the result of the coupling of photons with plasmons, the quantum of the plasma oscillation of the free electrons in for example metals. The quantum properties of this coupled entity between photons and electrons have recently been studied on the single quantum level in nanophotonic structures like plasmonic cavities and waveguides. First direct evidence of the bosonic nature of SPPs is shown here by observing a two-SPP interference [1], the plasmonic version of the Hong-Ou-Mandel experiment [2], in a scattering based plasmonic beam splitter. A non-classical visibility of the interference of 72 % is obtained. This scattering based beam splitter has an interaction region on the order of a single wavelength, overall showing the potential of highly confined plasmonic waveguides for integrated – quantum – photonics. Strongly increased light-matter interactions from this high confinement especially have spurred a wide range of quantum plasmonics research.[3] Furthermore, preliminary results of quantum tomography work on the plasmonic two-photon interference is shown. A polarization based tomography set-up is used to reconstruct the density matrix of the output of the Hong-Ou-Mandel interference, allowing to quantify the entanglement generated in the interference.

References

[1] G. Di Martino et al., Physical Review Applied 1, 034004 (2014)
[2] C. K. Hong et al., Physical Review Letters 59, 2044 (1987)
[3] M. S. Tame et al., Nature Physics 9, 329 (2013)

Towards the simulation of a supersolid state with Rydberg dressing

R. Faoro(1), A.D. Bounds(1), N.C. Keegan(1), R.K. Hanley(1), P. Huillery(1), E.M. Bridge(1) and M.P.A. Jones(1)

(1) Joint Quantum Centre Durham-Newcastle, Durham University, Durham, UK

Cold Rydberg atoms are a promising tool for studying many-body physics because of their strong and long-range dipole-dipole and van der Waals in- teractions. Van der Waals interaction can be easily controlled varying the detuning of the Rydberg excitation. Off-resonant coupling to the Rydberg state, the so-called \Rydberg dressing"" [1], introduces a new tunable, soft- core interaction between the atoms that potentially can lead to the formation of a Rydberg supersolid phase [2]. Direct dressing of the ground state of alkaline atoms with p-state Rydberg energy levels has been recentely demon- strated [3, 4].

The narrow intercombination lines of strontium allow two-photon excitation to Rydberg states with low decoherence and a near-isotropic $5sns^3S_1$ Rydberg state [5] make strontium an ideal system for the investigation of "Rydberg dressing". Moreover the interactions between strontium atoms in a dressed state can be used to generate a high degree of spin-squeezing in optical lattice clocks, which could be used to reduce the instability of the frequency measurement below that imposed by the quantum projection noise limit [6]. We have developed an ultra-narrow UV laser system [7] for the excitation of triplet Rydberg states in strontium, and we will present results on high-resolution one and two-electron spectroscopy as well as progress towards Rydberg dressing.

References

[1] G. Pupillo et al., Phys. Rev. Lett. 104, 223002 (2010).
[2] N. Henkel et al., Phys. Rev. Lett. 104, 195302 (2010).
[3] T. Keating et al., Phys. Rev. A 91, 012337 (2015).
[4] J. Zeiher et al., arXiv:1602.06313v2 (2016).
[5] C. L. Vaillant et al., J. Phys. B: At. Mol. Opt. Phys. 45, 135004 (2012).
[6] L. I. R. Gil et al., Phys. Rev. A 87, 053409 (2013).
[7] E. M. Bridge et al., Optics Express, 24, 2281-2292 (2016).

QUantum Communication Between Remote Mechanical Resonators

S. Felicetti (1), S. Fedortchenko (1), R. Rossi Jr. (2), S. Ducci (1), I. Favero (1), T. Coudreau (1), and P. Milman (1)

(1) Laboratoire Matérieaux et phénomènes Quantiques, Université Paris Diderot
(2) Universidade Federal de Viçosa - Campus Florestal, LMG818 Km6, Minas Gerais, Florestal 35690-000, Brazil

Mechanical resonators represent one of the most promising candidates to mediate the interaction between different quantum technologies, bridging the gap between efficient quantum computation and long-distance quantum communication. In our work, we introduced a novel interferometric scheme where the interaction of a mechanical resonator with input/output quantum pulses is controlled by an independent classical drive. We designed protocols for state teleportation and direct quantum state transfer, between distant mechanical resonators. The proposed device, feasible with state-of-the-art technology, can serve as building block for the implementation of long-distance quantum networks of mechanical resonators.

References

Preprint at arXiv:1605.08327

A direct approach to Measurement Based Quantum Computing in Continuous Variable

G. Ferrini (1,2,3), J. Roslund (2), F. Arzani (2), C. Fabre (2) and N. Treps (2)

(1) Institute of Physics, Johannes-Gütenberg Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany
(2) Laboratoire Kastler Brossel, UPMC Univ. Paris 6, ENS, CNRS; 4 place Jussieu, 75252 Paris, France
(3) Laboratoire Matériaux et Phénomènes Quantiques, Université Paris-Diderot, CNRS UMR 7162, 75013, Paris, France

Measurement based quantum computation (MBQC) is a quantum computational model equivalent to the circuit model in terms of computational power, but based on a different setting. In its traditional formulation [1,2], the manipulation of the input state is achieved by entangling it to a highly entangled resource state, the cluster state, and by performing suitable local projective measurements on the nodes of the cluster state, thereby projecting the remaining nodes onto the desired computation result.
In this work we introduce a different scheme for measurement based quantum computation in Continuous Variables.

Our approach does not explicitly rely on the use of ancillary cluster states to achieve its aim, but rather on the detection of input state and ancillary squeezed states in a suitable mode basis, followed by digital post-processing. Practically speaking, we provide a recipe to optimize the adjustable parameters that are employed at the detection level to obtain the relevant statistics of the measurement outcomes, corresponding to the desired computation.

References

[1] N. C. Menicucci, P. van Loock, M. Gu, C. Weedbrook, T. C. Ralph, and M. A. Nielsen, Phys. Rev. Lett. 97, 110501 (2006)
[2] M. Gu, C. Weedbrook, N. C. Menicucci, T. C. Ralph, and P. van Loock, Phys. Rev. A 79, 062318 (2009).

Entanglement routing in an ion-cavity system: a first step for quantum networks

D. A. Fioretto (1) ,K. Friebe (1), M. Lee (1), M. Teller (1), K. Schüppert (1) , F. Ong (1), J. Schupp (2), B. Lanyon (2), R. Blatt (1-2), T. Northup (1)

(1) Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria
(2) Institut fur Quantenoptik und Quanteninformation der Osterreichischen Akademie der Wissenschaften, 6020 Innsbruck, Austria

Optical cavities can be used as efficient quantum interfaces between photons and ions to realize a quantum network [1, 2]. In such a system, photonic channels connect ions stored in different network nodes. A trapped ion coupled to a cavity can be considered as a building block for a quantum network, and the future applications span from a first ion-based quantum repeater to distributed quantum computing.

An interesting protocol that can be implemented in such experiment is the possibility to distribute entanglement across distant ions [3]. In recent years, our team's work has been focused on investigating entanglement of two trapped ions in a cavity and studying photon emission of collective states of ions [4, 5], but in order to have a reliable node in a quantum network, two additional features are required.

The first capability is the possibility to entangle a photon with an ion and then route this entanglement to another ion efficiently and deterministically. In this poster, I will present a proposal for routing based on the implementation of an high fidelity SWAP gate.

Second, in order to extend the distance between quantum nodes, a long-lived memory robust against decoherence also has to be implemented. In order to achieve this goal, our team is working on an extension of our ion-photon entanglement protocol [4] in which the logical qubit is encoded into two physical ions using decoherence-free subspace states. This encoding in trapped calcium ions has already been shown to be robust, avoiding dephasing up to 20 seconds [6].

References

[1] I. Cirac, P. Zoller, H.J. Kimble and H. Mabuchi, Quantum State Transfer and Entanglement Distribution among Distant Nodes in a Quantum Network , Phys. Rev. Lett. 78, 3221 (1997)
[2] H.J. Kimble, The quantum internet, Nature 453, 1023 (2008)
[3] N. Sangouard, R. Dubessy, and C. Simon, Quantum repeaters based on single trapped ions, Phys. Rev. A 79, 042340
[4] A. Stute, B. Casabone, P. Schindler, T. Monz, P. O. Schmidt, B. Brandstätter, T. E. Northup and R. Blatt, Tunable ion-photon entanglement in an optical cavity, Nature 485, 482 (2012)
[5] B. Casabone, A. Stute, K. Friebe, B. Brandstätter, K. Schüppert, R. Blatt and T. E. Northup, Heralded entanglement of two ions in an optical cavity, Phys. Rev. Lett. 111, 100505 (2013)
[6] H. Häffner, F. Schmidt-Kaler, W. Hänsel, C.F. Roos, T. Körber, M. Chwalla, M. Riebe, J. Benhelm, U. D. Rapol, C. Becher, R. Blatt, Robust Entanglement, Appl. Phys. B 81, 151 (2005)

Reconfigurable laser written interferometer for photonic applications at telecom wavelength

F. Flamini (1), L. Magrini (1), S. A. Rab (1), N. Spagnolo (1), V. D'Ambrosio (1), P. Mataloni (1,2), F. Sciarrino (1,2), A. Crespi (3,4), T. Zandrini (3,4), R. Osellame (3,4)

(1) Sapienza Università di Roma, Italia;
(2) Istituto Nazionale di Ottica (INO-CNR), Firenze, Italia;
(3) Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche (IFN-CNR), Milano, Italia;
(4) Politecnico di Milano, Italia.

Efficient and reliable quantum networks represent a necessary element in any application of quantum computing and quantum cryptography. An essential feature of any component of these networks is the capability of finely controlling their functioning to realize a tunable device for dynamic protocols and measurements [1]. Furthermore, the need for both stability and scalability in telecommunication implementations has prompted a progressive miniaturization of such optical devices, leading to important achievements enabled by the integrated technologies. In addition to lithography [2], a powerful approach to transfer linear optics elements on an integrated platform is the femtosecond laser writing technique. Indeed, this fabrication procedure allows the unique engineering of complex three-dimensional circuital structures either polarization sensitive or insensitive, due to the low birefringence, for polarization entanglement applications [3-6]. Here we report the first realization of a reconfigurable integrated Mach-Zehnder interferometer, properly designed for the telecom wavelength 1550 nm, fabricated with femtosecond laser writing technique. The dynamical control over the phase is obtained through a thermo-optic effect, by changing the current flowing in resistive heaters placed close to the waveguides. Single-photon and two-photon measurements demonstrate the correct functioning of the reconfigurable circuit, paving the way for broader, multi-photon applications in several areas of quantum communication and quantum computation .

References

1. N. A. Peters et al., "Dense wavelength multiplexing of 1550 nm QKD with strong classical channels in reconfigurable networking environments," New J. Phys. 11, 045012 (2009).
2. J. C. Matthews et al., "Manipulation of multiphoton entanglement in waveguide quantum circuits," Nature Photonics 3, 346-350 (2009).
3. L. Sansoni et al., "Two-particle bosonic-fermionic quantum walk via integrated photonics," Physical Review Letters 108, 010502 (2012).
4. A. Crespi et al., "Integrated multimode interferometers with arbitrary designs for photonic boson sampling," Nature Photonics 7, 545-549 (2013).
5. N. Spagnolo et al., "Three-photon bosonic coalescence in an integrated tritter," Nature Communications 4, 1606 (2013).
6. G. D. Marshall et al., "Laser written waveguide photonic quantum circuits," Optics Express 17, 12546-12554 (2009).

Signatures of entanglement with a quantum system in the dynamics of a macroscopic magnetic environment

C. Foti (1,2), A. Cuccoli (1,2), P. Verrucchi (3,1,2)

(1) Dipartimento di Fisica, Università di Firenze; (2) INFN Sezione di Firenze; (3) Istituto dei Sistemi Complessi, Consiglio Nazionale delle Ricerche, Firenze

We study a composite bipartite quantum system in such a way that the quantum character of one component is not affected even if the other one becomes macroscopic. The problem is related with the analysis of the quantum-to-classical crossover, but the approach implies that the whole system stays genuinely quantum, by this meaning that the Hilbert space of the whole system will always be alive and kicking.
In particular, we aim at investigating if the evolution of the macroscopic part can testify the coupling with its microscopic quantum companion. To accomplish this goal, we refer to a magnetic system, made by N particles of spin-1/2 whose total spin S is a constant of motion; its quantum microscopic partner is a quantum mechanical oscillator, with which it exchanges energy, thus going beyond pure-dephasing models, that exclusively describe decoherence. Choosing an oscillator, with its infinite-dimensional Hilbert space, guarantees a richer dynamics with respect to that obtained referring to a system with a smaller Hilbert space, such as a qubit or a finite number of qubits. To describe how the magnetic system becomes macroscopic, we formally introduce a large-S limit, that give us meaningful analytic results out of the overwhelmingly complicated evolution of the overall system. We thus can write the propagator as a composition of terms where we single out the *back-action* effects, i.e. the dynamical effects of the oscillator on the magnet.

Coherent averaging

J.M.E Fraisse (1), D. Braun (1)

(1) Eberhard-Karls-Universität Tübingen, Institut für Theoretische Physik, 72076 Tübingen , Germany

In 2011 Braun and Martin proposed a new scheme for quantum metrology [1]. This so-called coherent averaging method has a star structure, with a central part, called the quantum bus, connected through pairwise interactions to N probes. It was shown via perturbation theory that this scheme allows one to reach the Heisenberg limit (HL) when estimating a parameter encoded in the interactions, and remarkably this can be achieved using separable pure initial states. They also showed that under certain conditions the measurement of an observable acting only on the quantum bus is enough to reach the HL.

In [2] we extended the results to parameters encoded in the free evolution of the probes or of the bus. It turns out that that the HL is also reachable when estimating a parameter encoded in the free evolution of the probes, but not when estimating a parameter encoded in the free evolution of the bus.

These results are restricted to the regime of validity of perturbation theory. In addition we studied a specific case of spin systems, where both probes and bus are qubits, in a non- perturbative way using numerics. It allows us to test the perturbative results and to check the behavior of the system out of the regime of validity of the perturbation theory.

References

[1] Daniel Braun and John Martin. Heisenberg-limited sensitivity with decoherence-enhanced measurements. Nature Communications, 2:223, March 2011.
[2] Julien Mathieu Elias Fraïsse and Daniel Braun. Coherent averaging. Annalen der Physik, 527(9-10):701–712, October 2015.

Multipartite entanglement in first-order and second-order quantum phase transitions of the Lipkin-Meshkov-Glick model

M. Gabbrielli (1), L. Pezzè (2) and A. Smerzi (3)

(1) University of Florence, Italy; (2) INO-CNR, Italy; (3) INO-CNR, Italy

The Lipkin-Meshkov-Glick (LMG) Hamiltonian was originally introduced in nuclear physics and describes an ensemble of two-level systems mutually interacting via an infinite-range coupling and subject to an external transverse field. This model effectively outlines a large variety of physical systems in different fields, ranging from Josephson junctions between superconductors to small ferromagnetic particles. At zero temperature, a system governed by the LMG Hamiltonian with ferromagnetic coupling exhibits a second-order (continuous) quantum phase transition that separates a symmetric phase from a ordered phase when suitably tuning the spin-spin coupling strength, whereas a first-order (discontinuous) quantum phase transition occurs at zero external field for antiferromagnetic coupling [1]. Some entanglement properties -- especially at null temperature -- have already been investigated in this model using quantum-information indicators like concurrence, entropy and fidelity [2].
Here we extend this investigation to finite temperature, adopting the quantum Fisher information to quantify the amount of metrologically-useful multipartite entanglement present in the system [3]. We explore the thermodynamical limit thanks to a numerical exact diagonalization, and finite-size corrections are also addressed. For limited regimes of parameters, analytical results can be provided. We aim to disclose the effect of thermal fluctuation on multiparticle entanglement for applications in interferometry: in particular, our work sheds light on the robustness of a two-mode interferometric linear scheme based on a Bose-Einstein condensate trapped in a double-well potential [4].

References

[1] V. V. Ulyanov and O. B. Zaslavskii, Phys. Rep. 216, 179 (1992)
[2] R. Orús, S. Dusuel and J. Vidal, Phys. Rev. Lett. 101, 025701 (2008)
[3] P. Hyllus et al., Phys. Rev. A 85, 022321 (2012)
[4] A. Trenkwalder et al., Nat. Phys. 12, 826 (2016).

Gaussian systems for quantum enhanced multiple phase estimation

C. Gagatsos, D. Branford, A. Datta

University of Warwick, United Kingdom

Phase estimation is a common problem in metrology with the aim being to estimate parameters with high precision, making efficient usage of some finite resources. The estimation of single phases with a range of states is well understood, yet applications such as imaging require measurement of a large number of distinct phases. Prior work has shown that by employing strategies which simultaneously measure multiple phases can lead to an improved estimation relative to multiple independent phase measurements. Such states are not easy to make, instead Gaussian states can be produced experimentally and are known to perform well for single phase estimation. We analyse the performance of pure Gaussian states for multiple phase estimation, identifying optimal states for estimation and comparing their performance to strategies which employ fixed number or Gaussian probe states. The probe states go through a general passive optical element and the resulting state picks up a phase in each mode. Even though the probe states are Gaussian, the computation of the quantum Fisher information (QFI) matrix demands to calculate non-Gaussian integrals, as the QFI matrix elements are the deviations of the photon number. We manage to circumvent this difficulty mainly by computing the Q representation of the final state in full generality. Therefore, for the case at hand, we give a general, fully worked out formula for the QFI. By assuming equal squeezing and that the interferometer is an orthogonal transformation we prove that putting all initial energy into squeezing is an optimal choice. We proceed by proving that estimating all phases simultaneously has an advantage over estimating each phase individually. We prove that a detection scheme which achieves the quantum limit found in this work exists. We discuss the role of reference mode and correlations.

References

1. C. M. Caves, Phys. Rev. D 23, 1693 (1981)
2. V. Giovannetti, S. Lloyd, and L. Maccone, Nat Photon 5, 222 (2011)
3. P. C. Humphreys, M. Barbieri, A. Datta, and I. A. Walmsley, Phys. Rev. Lett. 111, 070403 (2013)
4. K. Matsumoto, Journal of Physics A: Mathematical and General 35, 3111 (2002)

Quantum Darwinism and memory effects in bosonic and spin environments

F. Galve[1], G. L. Giorgi[2], S. Maniscalco[3] & R. Zambrini[1]

1 Institute for Interdisciplinary Physics and Complex Systems, Mallorca, Spain
2 Istituto Nazionale di Ricerca Metrologica, Turin, Italy
3 Turku Centre for Quantum Physics, University of Turku , Finland

The phenomenon of Quantum Darwinism, by which a quantum environment is able to redundantly store many copies of the classical information about the quantum open system of interest, is a rather rare event in the immensity of a many-body Hilbert space, typically a product of very specific kind of interactions and initial states. For its completion, independent observers need to be able to interrogate different (small) pieces of the environment, and agree upon outcomes concerning the system. We analyze here two different kind of system+environment setups: the first one is the quantum Brownian motion[1], where we show that the resonant/nonresonant transition underpins both the failure of quantum Darwinism and the onset of non-Markovian dissipation. The second is a pure dephasing spin setup[2], where we show that the initial state of the environment, which we initialize under different ground state phases of the XX model, has different abilities for storing redundant information, which is also strongly related to the non-Markovian character of the dissipation it produces.

References

[1] F. Galve, S. Maniscalco and R. Zambrini, Sci. Reps. 6, 19607 (2016).
[2] G. L. Giorgi, F. Galve and R. Zambrini, Phys. Rev. A 92, 022105 (2015)
.

Stochastic quantum measurements, Zeno and ergodicity

Stefano Gherardini

Department of Physics and Astronomy, LENS and QSTAR, University of Florence, Italy

Quantum measurements are crucial for observing the properties of a quantum system, although, however, they unavoidably perturb its state and dynamics in an irreversible way. Here, we study the dynamics of a quantum system being subjected to a sequence of projective measurements applied at random times. In the case of independent and identically distributed intervals of time between consecutive measurements, we analytically demonstrate that the survival probability of the system to remain in the projected state assumes a large deviation (exponentially decaying) form in the limit of an infinite number of measurements. This allows us to estimate the typical value of the survival probability, which can therefore be tuned by controlling the probability distribution of the random time intervals. Our analytical results are numerically tested for Zeno-protected entangled states, which also demonstrate that the presence of disorder in the measurement sequence further enhances the survival probability when the Zeno limit is not reached (as it happens in experiments) [1]. Moreover, a more recent application to a Bose-Einstein condensate (BEC) of Rubidium (^{87}Rb) atoms, trapped on an atom chip, theoretically and experimentally prove the validity of the (Von-Neumann) ergodic hypothesis for the quantum system trajectories in the measurement subspace approaching the quantum Zeno regime [2]. Such studies, thus, provide a new tool for protecting and controlling the amount of quantum coherence in open complex quantum systems by means of tunable stochastic measurements.

References

[1] S. Gherardini, S. Gupta, F.S. Cataliotti, A. Smerzi, F. Caruso and S. Ruffo, New J. Phys. 18, 013048 (2016).

[2] S. Gherardini, C. Lovecchio, M.M. Mueller, F.S. Cataliotti, F. Caruso, arXiv preprint arXiv: 1604.08518 (2016).

Waveguide coupling of single photons from a solid state emitter

Samuele Grandi (1), Sebastien Boissier (1), Michael Nielsen (2), Claudio Polisseni (1), Kyle D. Major (1), Alex S. Clark (1), Rupert Oulton (2), Ed A. Hinds (1)

(1) Imperial College London, QOLS, Centre for Cold Matter, UK; (2) Imperial College London, Experimental Solid State, UK;

The organic dye molecule dibenzoterrylene (DBT) in an anthracene crystal matrix is a promising candidate for single photon emission. At cryogenic temperatures, this system presents a narrow lifetime-limited transition at 785nm, with a quantum yield close to unity [1]. Moreover, DBT molecules have been shown to act as a mediator for photon-photon interactions, by inducing a phase-shift on a passing photon when another photon is present [2]. These features make DBT molecules a powerful tool for quantum information purposes, including use as single photon sources and controlled quantum gates. For these to be achieved, the interaction between the molecule and the radiation field must be enhanced.

We plan to accomplish this task by integrating single molecules in nano-photonic structures. We have designed and fabricated single mode ridge waveguides, optimised to have maximum overlap between their evanescent field and the molecule. To further enhance the interaction, we have inserted a nano-trench in a waveguide, further increasing the coupling to the structure. Simulations shown an expected 52% of the light radiated from to the molecule to be harnessed in the waveguide. A growth method developed in our group allows deposition of a thin film of anthracene doped with DBT on top of the structures [3]. To move beyond the diffraction limit, we have designed a plasmonic hybrid waveguide. These waveguides provide an adiabatic transition to the plasmonic regime, while minimising the losses typically associated with interactions between light and metals [4]. A gap in a thin layer of gold confines the light in a titanium dioxide substrate below. As the gap width is reduced along the waveguide, the mode adiabatically leaves the dielectric and moves into the gap, where a molecule will be deposited. The tight confinement will further improve the coupling between emitter and guided mode.

References

1. A. Nicolet et al., ChemPhysChem 8, 1215 (2007).
2. J. Hwang and E. A. Hinds, New J. Phys. 13, 085009 (2011).
3. C. Polisseni et al., Optics Express 24, 5615 (2016).
4. M. Nielsen et al., NanoLetters 16, 1410 (2016).

Action as an expression of deterministic laws of motion in quantum mechanics

K. Hibino, H. F. Hofmann

Hiroshima University, Japan

The foundation of physics is the description of motion based on deterministic laws that describe the change of observable physical properties in time. In quantum mechanics, it is not possible to observe the undisturbed time evolution of a physical property. Instead, the experimental evidence for the fundamental laws of motion is limited to relations between initial and final conditions. In this presentation, we show that the quantum mechanical relation between initial and final conditions can be expressed in terms of the action which appears as a complex phase in the time evolution of the overlap between initial and final conditions in Hilbert space. We therefore conclude that the action is the most fundamental expression of deterministic laws of motion, with equal validity in both classical physics and quantum theory.

References

1. H. F. Hofmann, e-print arXiv:1508.02779

Entanglement-assisted quantum metrology

Zixin Huang (1), Chiara Macchiavello(2), Lorenzo Maccone(2)

(1) School of Physics, University of Sydney, NSW 2006, Australia , (2) Dip. Fisica and INFN Sez. Pavia, University of Pavia, via Bassi 6, I-27100 Pavia, Italy

Entanglement-assisted quantum communication employs pre-shared entanglement between sender and receiver as a resource. We apply the same framework to quantum metrology, introducing shared entanglement between the preparation and the measurement stage, namely using some entangled ancillary system that does not interact with the system to be sampled. This is known to be useless in the noiseless case, but was recently shown to be useful in the presence of noise. Here we detail how and when it can be of use. For example, surprisingly it is useful when randomly time sharing two channels where ancillas do not help (depolarizing). We also prove for the first time, achievability of the quantum Cramer-Rao bound where for the noisy channels (amplitude damping, depolarising and general Pauli), entangling the probe to an ancilla provides improved phase estimation. We derived an experiment to test these results, where no additional photons are required for the ancillas.

References

1. V. Giovannetti, S. Lloyd, and L. Maccone, Science 306, 1330 (2004)
2. R. Demkowicz-Dobrzanski, L. Maccone, Phys. Rev. Lett. 113, 250801 (2014)
3. W. Dur, M. Skotiniotis, F. Frowis, B. Kraus, Phys. Rev. Lett. 112, 080801 (2014).
4. R. Demkowicz-Dobrzanski, J. Kolodynski New Journal of Physics, 15, 073043 (2013).
5. A. Chiuri et al, Phys. Rev. Lett. 107, 253602 (2011)

Efficient validation of scattershot boson sampling experiments

A. Crespi (1,2), R. Osellame (1,2), R. Ramponi (1,2), M. Bentivegna (3), F. Flamini (3), N. Spagnolo (3), N. Viggianiello (3), L. Innocenti (4), P. Mataloni (3), F. Sciarrino (3).

(1) Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche (IFN-CNR), Milano, Italy; (2) Dipartimento di Fisica, Politecnico di Milano, Milano, Italy; (3) University of Rome La Sapienza, Italy; (4) Queen's University Belfast, UK

Quantum mechanics promises a computational speedup over classical analogues for specific relevant tasks. In the attempt of building a quantum device able to efficiently solve a classically-hard computational problem, photonic quantum interference in linear optics represents a promising candidate, both for the currently available integrated platforms and for the strong theoretical evidences of its hard-computability. In this scenario, it is crucial to find unambiguous proofs of genuine multiphoton quantum behavior. Recently, the suppression of specific output combinations arising in Fourier interferometers has demonstrated its ability to efficiently rule out classical and semi-classical models. In this work we develop and implement a new generalization of this technique which is suitable for the certification of true quantum multiphoton interference in random-input experiments. This technique can be efficiently adopted in Scattershot Boson Sampling experiments, which was shown to allow scalable use of parametric downconversion sources for experimental proofs of quantum speedup.

References

Aaronson, S. & Arkhipov, A. The computation complexity of linear optics. In Proceedings of the 43rd annual ACM symposium on Theory of computing, 333–342 (ACM Press, 2011).
Tichy, M. C., Mayer, K., Buchleitner, A. & Molmer, K. Stringent and efficient assessment of Boson-Sampling devices. Phys. Rev. Lett. 113, 020502 (2014)
Crespi, A. Suppression laws for multiparticle interference in Sylvester interferometers. Phys. Rev. A 91, 013811 (2015).
Crespi, A., Osellame, R., Ramponi, R., Bentivegna, M., Flamini, F., Spagnolo, N., Viggianiello, N., Innocenti, L., Mataloni, P. and Sciarrino, F. Suppression law of quantum states in a 3-D photonic fast Fourier transform chip. Nature Commun. 7, 10469 (2016).

Covariance matrix inequalities and their implications in continuous variable quantum information: recoverability, steering, and beyond

G. Adesso (1), C. Hirche (2), L. Lami (2), A. Winter (2-3)

(1) University of Nottingham
(2) Universitat Autònoma de Barcelona
(3) ICREA - Institució Catalana de Recerca i Estudis Avançats

It has been shown recently that a well-known mathematical inequality among the log-determinants of minors of a positive matrix has striking applications in the context of simultaneous quantum Gaussian steering of a tripartite system. For Gaussian states, this inequality can be shown to be equivalent to the strong subadditivity of the Rényi 2-entropy. Here we generalise that scalar inequality in two different ways. In the first place, we find a much stronger operator inequality from which the scalar one can be easily recovered and that to the extent of our knowledge was not known before. In the second place, we exploit recent advances in recoverability theory to find a remainder term for the scalar version of the above inequality. Several consequences are drawn from these results. As an example of application, we consider a tripartite continuous-variable system ABC and use our strengthened inequalities to provide quantitative upper bounds on the A->C Gaussian steerability given some knowledge of of the B->C reduced covariance matrix. Along the way, we develop new techniques based on the Schur complement that have many potential applications in quantum optics.

Joint work with Gerardo Adesso, Christoph Hirche and Andreas Winter.

Preparation of Macroscopic Quantum States

L. Latmiral, F. Mintert

QOLS, Blackett Laboratory, Imperial College London, London SW7 2BW, United Kingdom

The study of quantum properties of massive systems represents a great platform to investigate the foundations of physics as well as to develop new enhanced quantum technologies. We present here a scheme where a massive mirror modeled as a harmonic oscillator is coupled to a light field through an optomechanical cavity. By driving the system with appropriate frequency patterns we prepare interesting quantum superposition states of the mirror such as coherent cat states. The optical and the mechanical part being completely uncorrelated after each interaction period, our protocol reveals to be robust against thermal noise and requires very low initial cooling. Indeed, the experimental implementation only demands quantum optical control, the readout of mechanical motion being achieved via the light field reflected from the cavity. Our proposal thus opens a promising route to explore and exploit macroscopic quantum phenomena with table-top experiments .

General bounds for sender-receiver capacities in multipoint quantum communications

R.Laurenza, S.Pirandola

Computer Science and York Centre for Quantum Technologies, University of York

We investigate the maximum rates for transmitting quantum information, distilling entanglement and distributing secret keys between a sender and a receiver in a multipoint communication scenario, with the assistance of unlimited two-way classical communication involving all parties. First we consider the case where a sender communicates with an arbitrary number of receivers, so called quantum broadcast channel. Here we also provide a simple analysis in the bosonic setting where we consider quantum broadcasting through a sequence of beamsplitters. Then, we consider the opposite case where an arbitrary number of senders communicate with a single receiver, so called quantum multiple-access channel. Finally, we study the general case of a quantum interference channel where an arbitrary number of senders communicate with an arbitrary number of receivers. Since our bounds are formulated for quantum systems of arbitrary dimension, they can be applied to many different physical scenarios involving multipoint quantum communication.

Peres-Mermin square with arbitrary unitary operators

A. Laversanne-Finot (1), A. Ketterer (1), M. R. Barros (2), S. P. Walborn (2), T. Coudreau (1), A. Keller (3), P. Milman (1)

(1) Université Paris Diderot, Sorbonne Paris Cité, MPQ, UMR 7162 CNRS, F-75205 Paris, France
(2) Instituto de Fisica, Universidade Federal do Rio de Janeiro, Caixa Postal 68528, Rio de Janeiro, RJ 21941-972, Brazil
(3) Institut des Sciences Moléculaires d'Orsay, Bâtiment 350, UMR8214, CNRS-Université Paris-Sud, Université Paris-Saclay 91405 Orsay, France

In classical mechanics systems have intrinsic properties that are later revealed by the measurements. In particular the result of one measurement does not depend on the subsequent measurements performed. We say that classical mechanics is non-contextual. It is possible to demonstrate the contextual nature of quantum mechanics by the violation of inequalities based on correlation measurements of well chosen observables. Surprisingly it is possible to find inequalities that are violated by any state [1]. These inequalities have been designed separately for both discrete and continuous variable measurements [2]. In this talk I show how to test contextuality in the Peres-Mermin scenario with measurements of observables acting on Hilbert spaces of arbitrary dimension. By unifying this two strategies we are able to derive general conditions to have a state independent maximal violation of the inequality [3]. This condition allow us to characterize the spectral decomposition of observables that are suitable for maximal state independent violation of the non-contextual bound. As a consequence of this result, we find that it is impossible to obtain a maximal state-independent violation of non-contextuality with discrete observables of odd dimensions.

References

1. A. Cabello, Phys. Rev. Lett. 101, 210401 (2008)
2. A. Asadian, C. Budroni, F. E. S. Steinhoff, P. Rabl, and O. Gühne, Phys. Rev. Lett. 114, 250403 (2015)
3. A. Laversanne-Finot, A. Ketterer, M. R. Barros, S. P. Walborn, T. Coudreau, A. Keller, P. Milman, arXiv:1512.03334, (2015)

Ancillary Qubit Spectroscopy of Vacua in Cavity and Circuit Quantum Electrodynamics

Jared Lolli (1), A. Baksic (1), D. Nagy (1,3), V. E. Manucharyan (2), and C. Ciuti (2)

(1) Université Paris Diderot, Sorbonne Paris Cité, Laboratoire Matériaux et Phénomènes Quantique; (2) Joint Quantum Institute and Center for Nanophysics and Advanced Materials, University of Marylan; (3) Institute for Solid State Physics and Optics, Wigner Research Centre, Hungarian Academy of Science.

When atoms and photons interact strongly enough, the system enters in regimes characterized by non conventional properties. We investigate theoretically how the spectroscopy of an ancillary qubit can probe cavity (circuit) quantum electrodynamics ground states containing photons (1).

We consider three classes of systems (Dicke, Tavis-Cummings and Hopfield like models), where exotic vacua are the result of ultrastrong coupling between N two-level systems and a single-mode bosonic field. An ancillary qubit detuned with respect to the boson frequency is shown to reveal distinct spectral signatures depending on the type of vacua.

In particular, the Lamb shift of the ancilla is sensitive to both ground state photon population and correlations. Ancillary Qubit Spectroscopy is simulated, taking into account the dissipation via a consistent master equation for the ultrastrong coupling regime.

References

1. J. Lolli, A. Baksic, D. Nagy, V. E. Manucharyan and C. Ciuti, Phys. Rev. Lett., 114, 183601 (2015)

Exploring topological phases in 2D with discrete time quantum walk

Maria Maffei(1) , Alexandre Dauphin(2) , Pietro Massignan(2) , Maciej Lewenstein(2), Lorenzo Marrucci(1)

(1) University of Naples Federico II, Italy; (2) ICFO - Institut de Ciencies Fotoniques, Barcelona, Spain

We present a novel protocol of topological 2D discrete time quantum walk (DTQW) implementable in a photonic architecture which is the bi-dimensional generalization of the platform we already used to simulate and characterize a one-dimensional topological system [1]. The single step of this new 2D DTQW consists of four non-commuting unitary operations. Each unitary block corresponds effectively to a hopping of different amplitude between two inequivalent nearest neighbour cells of a bipartite rectangular lattice. We reduced the number of free parameters from four to two setting three of the hopping amplitudes to the same value. Time by time, fixing one of the two parameters to a value and letting the other one change, we explored the whole topological diagram of our system. We did a full characterization of this new protocol according to the topological classification of the Floquet-Bloch systems recently developed by Rudner et al. [2]: we computed the two invariants W0 and Wπ which give the correct number of reflection-less propagating edge states with energy equal to 0 and π in 2D periodic Floquet systems. We also calculated the Chern number of the static particle-hole symmetric Hamiltonian which effectively describes the dynamics of the walk at times being integer multiple of its period. Tuning the control parameter of the phase transition, the Chern number and the windings assume all the values between -1 and 1: we verified that in every topological sector the Chern number is equal to the difference between the values of the two windings. Finally, we proved that this result is independent from the chosen time-frame, that means that it is valid for every permutation of the four blocks forming the single step of the walk.

References

[1] F. Cardano et al., arXiv:1507.01785 (2015).
[2] M. S. Rudner et al., PRX 3, 031005 (2013).

A quantum algorithm for solving the heat equation with Neumann boundary conditions

A. Mahasinghe

Department of Mathematics, University of Colombo, Sri Lanka

We present an efficient quantum algorithm, which can solve the two dimensional heat equation with respect to periodic Neumann boundary conditions. The solution of the discretised version of the heat equation with these conditions is expressible using circulant matrices, as a sparse circulant exponentiation (1). We use this as the key ingredient of our algorithm. We show that the quantum implementation of sparse and Fourier sparse Toeplitz matrices in (2) can be modified into a quantum algorithm for this particular version of the heat equation. Using the results in (3), Hermition embedding in (1), Halmos dilation and quantum random access memory in (4), we design the algorithm to the encoded initial quantum state, and derive the desired state after a respective measurement. Apart from the quantum random access memory, the sparse Hamiltonian lemma (5) also influences the complexity of our algorithm. The final time complexity and resource cost of our algorith is in polylog scale.

References

[1] G. Strang and S. MacNamara. SIAM Review, 56(3), 525-546 (2014)
[2] A. Mahasinghe and J.B. Wang. Phys. A: Math. Theor., vol. 49, 275301 (2016)
[3] S.P. Jordan and P. Wocjan. Phys. Rev. A, vol. 80, 062301 (2009)
[4] V. Giovannetti et al. Phys. Rev. Lett., vol. 100, 160501 (2008)
[5] D. Aharonov and A. Ta-Shma. Proc. 35th Annual ACM Symp. on Theory of Computing (NewYork: ACM) (2003)

Time Asymmetric Quantum Mechanics in Nonlocal Nonlinear Optics

G. Marcucci (1), M. C. Braidotti (1,3), S. Gentilini (1,2), E. DelRe (1,2), C. Conti (1,2)

*(1) Institute for Complex Systems (ISC-CNR), Via dei Taurini 19, 00185, Rome (IT);*p*(2) Department of Physics, University Sapienza, Piazzale Aldo Moro 5, 00185, Rome (IT);*p*(3) Department of Physical and Chemical Sciences, University of L'Aquila, Via Vetoio 10, I-67010 L'Aquila (IT).*p

The theories of modern physics, such as quantum mechanics and general relativity, do not allow to model irreversible phenomena. It is well known that a state with complex energy cannot be the eigenstate of a self-adjoint operator, as the Hamiltonian. Therefore, resonances (i.e. states with exponentially decaying observables) are not vectors belonging to the conventional Hilbert space. One can describe these resonances in an unusual mathematical formalism, based on the so-called Rigged Hilbert Space (RHS). In the RHS, the states with complex energy are denoted as Gamow vectors (GV), and they model decay processes with quantized decay rates.

In our work, we consider the reversed harmonic oscillator (RHO), the simplest system in the RHS, and we show the way the RHO models the intrinsic irreversibility of light propagation in nonlocal nonlinear media. We discuss the expansion of a wavepacket in GV and background functions. We apply the theory to a Gaussian wavepacket in an optically nonlinear medium, and we study its propagation. We show that the Gamow vector decay rates are quantized and depend on the power. We also report experimental results. Our work furnishes support to the idea that irreversible and nonlinear wave propagation can be investigated using RHS Quantum Mechanics.

References

1. S. Gentilini, M. C. Braidotti, G. Marcucci, E. DelRe, and C. Conti. Nonlinear Gamow vectors, shock waves, and irreversibility in optically nonlocal media. Phys. Rev. A, 92:023801, 2015;
2. S. Gentilini, M. C. Braidotti, G. Marcucci, E. DelRe, and C. Conti. The physical realization of the Glauber quantum oscillator. Sci. Rep., 5:15816, 2015.

Modeling Leggett-Garg inequality violation

S. V. Moreira (1), A. Keller (2), T. Coudreau (1), P. Milman (1)

(1) Université Paris Diderot, Laboratoire Matériaux et Phénomènes Quantiques
(2) Université Paris Sud, Institut des Sciences Moléculaires d'Orsay

The Leggett-Garg inequality is a widely used test of the "quantumness" of a system and involves correlations between measurements realized at different times. According to its widespread interpretation, a violation of the Leggett-Garg inequality disproves macroscopic realism and noninvasiveness. Nevertheless, recent results point out that macroscopic realism is a model-dependent notion and that one should always be able to attribute to invasiveness a violation of a Leggett-Garg inequality. This opens some natural questions: How do we provide such an attribution in a systematic way? How can apparent macroscopic realism violation be recast into a dimensional-independent invasiveness model? The present work answers these questions by introducing an operational model where the effects of invasiveness are controllable through a parameter associated with what is called the measurability of the physical system. Such a parameter leads to different generalized measurements that can be associated with the dimensionality of a system, to measurement errors, or to back action.

References

S. V. Moreira et al. Phys. Rev. A, 92, 062132 (2015)

Simulating dissipative many-body systems with cold Rydberg atoms

C. Simonelli (1,2), M. Archimi (2), D. Capecchi (2), F. Castellucci (2), L. Asteria (2), G. Masella (2), E. Arimondo (1,2), D. Ciampini (1,2), O. Morsch (1,2)

(1) INO-CNR, Pisa, Italy; (2) Dipartimento di Fisica, Pisa , Italy

We present experimental results on the dynamics of strongly interacting dissipative Rydberg gases. These gases are off-resonantly excited to Rydberg states, which leads to a facilitation process whereby already excited atoms favour the excitation of further atoms at a well-defined distance (1). Together with a dissipative process due to spontaneous decay ("self-destruction"), facilitation dynamics (or "offspring-production") underlies directed percolation from an absorbing (passive) to an active state of the dissipative many-body system (2). We show evidence for the continuous phase transition between those states in our experiments, both in 1D and 3D sample geometries. These results pave the road towards quantum many-body simulations of percolation-type phase transitions in the coherent regime.

References

1. M. M. Valado et al. Phys. Rev. A 93, 040701(R) (2016).
2. M. Marcuzzi et al. New J. Phys. 17, 072003 (2015).

A Bayesian view of Single-Qubit Clocks, and an Energy versus Accuracy tradeoff

M. Gopalkrishnan (1), Varshith Kandula (2), Praveen Sriram (2), Abhishek Deshpande (1),(3) and Bhaskaran Muralidharan (2)

(1) School of Technology and Computer Science, Tata Institute of Fundamental Research, India
(2) Department of Electrical Engineering, IIT Bombay, India
(3) Department of Mathematics, Imperial College, UK

A clock is a device that couples a periodic or approximately periodic motion to a counter that increments upon ``ticks'' of the periodic motion.
In principle, in the absence of noise, classical mechanics allows the harnessing of perfectly periodic motion from a simple harmonic oscillator, so that the duration between ticks is exact. Do the laws of quantum mechanics allow clocks with perfect inter-tick durations? One difficulty manifests immediately. Though a quantum system may display periodic motion, quantum measurement only provides partial information about the full quantum state. The first question we address here is: what are the limits to accuracy of inter-tick durations for resource-limited quantum systems?

In practice, man-made clocks require energy: wall clocks run on batteries, mechanical pendulum clocks and watches run down and need to be wound up. Is it the case that the laws of quantum mechanics require clocks to be dissipating? This is the second question we address.

We make a step towards addressing these questions by describing clocks as information processing devices that employ Bayesian inference, and use this framework to analyze the case of a clock constructed from a single qubit. We find that, at least with a single qubit, quantum mechanics does not allow exact timekeeping, in contrast to classical mechanics which does. We find the optimal ratio of angular velocity of precession to rate of the exponential distribution that leads to maximum accuracy. Further, we find an energy versus accuracy tradeoff --- the energy cost is at least k_BT times the improvement in accuracy as measured by the entropy reduction in going from the prior distribution to the posterior distribution.

References

M. Gopalkrishnan et.al., ArXiv:1602:00508, (2016).

Detecting a many-body mobility edge with quantum quenches

P. Naldesi, E. Ercolessi e T. Roscilde

The many-body localization (MBL) transition is a quantum phase transition involving highly excited eigenstates of a disordered quantum many-body Hamiltonian, which evolve from ``extended/ergodic" (exhibiting extensive entanglement entropies and fluctuations) to ``localized" (exhibiting area-law scaling of entanglement and fluctuations). The MBL transition can be driven by the strength of disorder in a given spectral range, or by the energy density at fixed disorder -- if the system possesses a many-body mobility edge. Here we propose to explore the latter mechanism by using ``quantum-quench spectroscopy", namely via quantum quenches of variable width which prepare the state of the system in a superposition of eigenstates of the Hamiltonian within a controllable spectral region. Studying numerically a chain of interacting spinless fermions in a quasi-periodic potential, we argue that this system has a many-body mobility edge; and we show that its existence translates into a clear dynamical transition in the time evolution immediately following a quench in the strength of the quasi-periodic potential, as well as a transition in the scaling properties of the quasi-stationary state at long times. Our results suggest a practical scheme for the experimental observation of many-body mobility edges using cold-atom setups.

Quantum walks in synthetic gauge fields with 3D integrated photonics

O. Boada (1), L. Novo (1,2), F. Sciarrino (3), Y. Omar(1,2)

(1) Physics of Information and Quantum Technologies Group, Instituto de Telecomunicacoes, Lisbon (2) Instituto Superior Tecnico, Universidade de Lisboa, Portugal (3) Dipartimento di Fisica, Sapienza Universita di Roma, Roma, Italy

There is great interest in designing photonic devices capable of disorder-resistant transport and information processing. In this work we propose to exploit 3D integrated photonic circuits in order to realize 2D discrete-time quantum walks in a background synthetic gauge field. The gauge fields are generated by introducing the appropriate phase shifts between waveguides. Polarization-independent phase shifts lead to an Abelian or magnetic field, a case we describe in detail. We find that, in the disordered case, the magnetic field enhances transport due to the presence of topologically protected chiral edge states which do not localize. Polarization-dependent phase shifts lead to effective non-Abelian gauge fields, which could be adopted to realize Rashba-like quantum walks with spin-orbit coupling. Our work introduces a flexible platform for the experimental study of multi-particle quantum walks in the presence of synthetic gauge fields, which paves the way towards topologically robust transport of many-body states of photons.

Full quantum state reconstruction of symmetric two-mode squeezed thermal states via spectral homodyne detection and a state-balancing detector

S. Cialdi, C. Porto, D. Cipriani, S. Olivares and M. G. A. Paris

University of Milan, Italy

Homodyne detection is an effective tool to characterize the quantum states of light in a narrow spectral range and it plays a relevant role in continuous-variable quantum information protocols and to investigate properties of quantum systems. We suggest and demonstrate a scheme to reconstruct the symmetric two-mode squeezed thermal states of spectral sideband modes from an optical parametric oscillator. The method is based on both a single homodyne detector and the error signal from the active stabilization of the oscillator cavity [1]. The measurement scheme has been successfully tested on different two-mode squeezed thermal states usually employed to encode signals or to probe complex systems. In particular here we focus on uncorrelated coherent states and entangled states. Our procedure is a versatile diagnostic tool, suitable to be embedded in quantum information experiments as well as to investigate the properties of complex systems involving continuous variable systems in the spectral domain.

References

[1] S. Cialdi et al. Phys. Rev. A, 93, 043805 (2016)

Estimation of coherent errors from stabilizer measurements

D. Orsucci (1), M. Tiersch (2), H. J. Briegel (3)

(1) University of Innsbruck, (2) University of Innsbruck, (3) University of Innsbruck

In the context of Measurement-Based Quantum Computation (MBQC) a way to maintain the coherence of the graph state is given by measuring stabilizer operators. Aside from performing Quantum Error Correction (QEC), it is possible to exploit the information gained from these measurements to characterize a coherent source of errors; that is, an error channel that applies a fixed -- but unknown -- unitary operation. Specifically, we study the case in which the error channel acts differently on each qubit of the graph state, and is given by a rotation of the Bloch sphere around either the x, y or z axis. The possibility to reconstruct the channel for each qubit depends non-trivially on the topology of the graph state.

References

(1) M. Tiersch, E. J. Ganahl, and H. J. Briegel, Scientific Reports 5, 12874 (2015).
(2) J. Combes, C. Ferrie, C. Cesare, M. Tiersch, G. J. Milburn, H. J. Briegel, and C. M. Caves, e-print arXiv:1405.5656 (2014).
(3) M. Hein, W. Dür, J. Eisert, R. Raussendorf, M. Nest, and H. J. Briegel, e-print arXiv:0602096 (2006).

Experimental implementation of Bayesian phase estimation algorithms on a silicon quantum photonic chip

S. Paesani (1), A.A. Gentile (1), R. Santagati (1), J. Wang (1), N. Wiebe (2), D.Tew(3), J.L. O'Brien (1), M. Thompson (1)

(1) Centre for Quantum Photonics, University of Bristol, Bristol, UK; (2) Quantum Architectures and Computation Group, Microsoft Research, Redmond, Washington, USA; (3) School of Chemistry, University of Bristol, Bristol, UK

Quantum algorithms promise exponential speedups over classical algorithms, allowing the possibility to accomplish tasks otherwise unachievable in classical machines, most notably the calculation of material properties [1,2] and the factorization of big numbers [3]. Quantum Phase Estimation (PE) lays at the very heart of many of these speedups and its application will thus be essential for quantum computers. Kitaev's iterative phase estimation algorithm (IPEA) represents a very interesting route for the short and medium term implementations of this algorithm, as it relays on a small number of qubits and logic gates and classical post-processing [4]. However, phase estimation methods can become rapidly impractical to implement in non-fault tolerant schemes, as the errors arising from noise (e.g. decoherence) are more likely to happen in the most significant digits of the estimated phase [Svore?]. Recently Wiebe and Granade theoretically proposed a new Bayesian approach to quantum phase estimation, called Rejection Filtering Phase Estimation (RFPE) algorithm, which is proved to be faster and much more robust to noise than previous PE algorithms [Wiebe]. RFPE represents a very appealing path to push short/medium term experiments on non-fault tolerant devices over the classical regime. In this talk we will present the first implementation of the RFPE algorithm. The experiment is performed on a fully reconfigurable silicon photonic chip, where two path-encoded qubits are generated and processed on-chip with high-fidelity operations. Our scheme can implement state preparation and a non-compiled control-unitary operation, which provide the logic scheme for PE algorithms, achieving a precision of more than 32 digits for IPEA. We compare the results obtained by RFPE and IPEA, demonstrating the robustness of the Bayesian approach and its practicability for short term demonstration of quantum algorithms capable of outperforming classical ones.

References

[1] S. Lloyd, Science, 73, 1073 (1996)
[2] B. P. Lanyon et al., Nature Chem., 2, 106 (2010)
[3] P. Shor, Proc. 35th Ann. Symp. Found. Comp. Sci., 124, (1994)
[4] A.Y. Kitaev, arXiv:quant-ph/9511026 (1995)
[5] K.M. Svore, Quantum Information and Computation, 14, 306 (2014)
[6] N. Wiebe, arXiv:1508.00869 [quant-ph], (2015)

Graphene based nano-sensors

G Mazzamuto(1), S Pazzagli(2), A Reserbat-Plantey(3), K Schädler(3), F S Cataliotti(1,2), F Koppens(3) and C Toninelli(2,4)

(1) LENS and Università di Firenze, Via Nello Carrara 1, I-50019 Sesto Fiorentino, Italy
(2)Dipartimento di Fisica ed Astronomia, Via Sansone 1, I-50019 Sesto Fiorentino, Italy
(3)ICFO-Institut de Ciencies Fotoniques, Mediterranean Technology Park, E-08860 Castelldefels, Barcelona, Spain
4)INO, Istituto Nazionale di Ottica, Largo Fermi 6, I-50125 Firenze, Italy

In this work we study by optical means different geometries and composition of a hybrid quantum system made of a mono-layer graphene coupled to an organic molecule-based single quantum emitter made of dibenzoterrylene (DBT) molecules embedded in nm-thick anthracene (An) crystal. The interaction between the DBT:An system and graphene can be investigated with a home-built confocal microscope equipped with CW and pulsed lasers for excitation, APDs and an EMCCD camera coupled to a spectrometer for detection and a cryostat for low temperature (2.8K) measurements. This setup allows to perform single molecule experiments involving lifetime, excitation and fluorescence spectra, and autocorrelation measurements. The bright and stable emission in the near-IR of the DBT:An system together with the unique combination of optical and mechanical properties of graphene make the resulting hybrid nanostructure a promising tool for applications in nanoscale position-sensing.

References

1. G. Mazzamuto et al. New J. Phys. 16, 113007 (2014)
2. C. Muschik et al. Phys. Rev. Lett. 112, 223601 (2014)
3. L. Gaudreau et al. Nano Letters 13, 5 (2013)

Correlation Plenoptic Imaging

F. V. Pepe (1,2), M. D'Angelo (2,3), A. Garuccio (2,3), G. Scarcelli (4)

(1) Museo storico della fisica e centro studi e ricerche "Enrico Fermi"
(2) INFN Sezione di Bari
(3) Università degli Studi di Bari, Dipartimento Interateneo di Fisica
(4) Fischell Department of Bioengineering, University of Maryland

Plenoptic Imaging is a novel optical technique for achieving tridimensional imaging in a single shot. PI resembles standard imaging, however, a microlens array is inserted in the native image plane and the sensor array is moved behind the microlenses. On the one hand, the microlenses act as imaging pixels to gain the spatial information of the scene. On the other hand, each microlens reproduces on the sensor array an image of the camera lens, thus providing the angular information associated with each imaging pixel. The recorded propagation direction is exploited to computationally retrace the geometrical light path, thus enabling the refocusing of different planes within the scene and the extension of the depth of field (DOF) of the acquired image.
Plenoptic imaging is currently used in digital cameras enhanced by refocusing capabilities. A plethora of innovative applications in stereoscopy and microscopy are also being developed. However, the potentials of PI are strongly limited by the inherent inverse proportionality between image resolution and maximum achievable DOF.

We exploit the second-order spatio-temporal correlation properties of light to overcome this limitation. Using two correlated beams, from either a chaotic or an entangled photon source, we can perform imaging in one arm, and simultaneously obtain the angular information in the other arm. In fact, we demonstrate that the second order correlation function possesses plenoptic imaging properties (i.e., it encodes both spatial and angular information), and is thus characterized by a key re-focusing capability. Both theoretical and experimental results will be presented.

From a fundamental standpoint, the plenoptic application is one of the first situation where the counterintuitive properties of correlated systems are effectively used to beat intrinsic limits of standard imaging systems. From a practical standpoint, our protocol can dramatically enhance the potentials of PI, paving the way towards its promising applications.

References

M. D'Angelo, A. Garuccio, F. V. Pepe, G. Scarcelli, arXiv:1604.00343

Majorana Zero Mode, Local Quench and Disturbance Propagation in the Ising chain

G. Francica (1), T.J.G. Apollaro (2), N. Lo Gullo (3), F. Plastina (1)

(1) Dip. Fisica, Università della Calabria; (2) Dip. Fisica e Chimica, Universitò di Palermo; (3) Dip. Fisica, Università di Milano

We study the effect of local quenches in a quantum many-body spin systems to understand how local perturbations propagate through the system. In particular, we report on the study of the Ising model in transverse field in the presence of a local field impurity on one of the edges. We find that this system possesses a rich phase diagram with different phases characterized by the presence or absence of two clearly distinguishable localized modes, one of which has a topological character. Such a Majorana zero-mode enables a characterization of the Ising phase transition to be performed through a local-only measurement performed on the impurity. Furthermore, the dynamics following a sudden removal of the defect, discussed in terms of quasiparticles emitted from a region close to the impurity, is strongly affected by its presence.

References

G. Francica, T.J.G. Apollaro, N. Lo Gullo, F. Plastina, "Majorana Zero Mode, Local Quench and Disturbance Propagation in the Ising chain", in preparation

Quantum estimation of the diamagnetic term in light-matter interaction

M. A. C. Rossi (1), M. Bina (1), M. G. A. Paris (1), M. G. Genoni (1, 2), G. Adesso (3), T. Tufarelli (3)

(1) University of Milano, Italy; (2) University College London, United Kingdom, (3) University of Nottingham, UK

Should the Dicke model of light-matter interaction include a diamagnetic term in the ultra-strong coupling regime (USC)? This question has generated intense debate in the literature, and is particularly relevant in the modern contexts of Cavity QED and Circuit QED. The USC regime is entered when the light-matter coupling is so large that the rotating-wave approximation breaks down, this brings about exciting new physics, but also formidable computational challenges. Effective models featuring a small number of degrees of freedom (DOF), such as the Dicke Hamiltonian, are extremely useful in this context. However, there is disagreement in literature regarding the presence of the diamagnetic term [1–3]. We propose that the issue could be addressed experimentally via an appropriate measurement. Applying the tools of quantum estimation theory [4] to a general Dicke model, we quantify how much information about the diamagnetic term (or lack thereof) is contained in the ground state of the coupled system [5]. We find that feasible measurements such as homodyne detection and photon counting are able to extract a significant fraction of such information, which becomes optimal in experimentally relevant regimes. These measurements could be performed by suddenly switching off the light-matter coupling, and collecting the radiation that naturally leaks out of the system. Should the model admit a critical point, we also find that both measurements become asymptotically optimal in its vicinity.

References

1. P. Nataf and C. Ciuti, Nat. Commun. 1, 72 (2010).
2. O. Viehmann, J. von Delft, and F. Marquardt, Phys. Rev. Lett. 107, 113602 (2011).
3. S. De Liberato, Phys. Rev. Lett. 112, 016401 (2014).
4. M. G. A. Paris, Int. J. Quantum Inf. 7, 125 (2009).
5. T. Tufarelli, K. R. McEnery, S. A. Maier, and M. S. Kim, Phys. Rev. A 91, 063840 (2015).

Synchronization of two ensembles of atoms via quantum and classical channels

A. Roth, K. Hammerer

Leibniz Universität Hannover, Institut für Theoretische Physik

Superradiant ensembles of atoms using an ultra-narrow optical transition can be used as active atomic clocks, promising a much lower linewidth and therefore much better precision than current optical atomic clocks. We show that in a cascaded setup of two frequency-detuned superradiant ensembles, i.e. master & slave, the slave ensemble frequency synchronizes to the input in a wide frequency range. Furthermore we show that this synchronization does not rely on the quantum coupling between both ensembles, but can be simulated using a classical channel.

Additionally we show that the synchronization in a symmetric coupling setup, i.e. both atomic ensembles couple to the same cavity mode, can also be simulated using a classical coupling channel between both ensembles.

Sub-shot-noise (shot-noise enhanced) microscope

I.Ruo-Berchera(1), N.Samantaray(1,2), A.Meda(1) & M.Genovese(1).

(1) INRIM, strada delle Cacce 91, 10135 Torino, Italy.
(2) Politecnico di Torino, Corso Duca degli Abruzzi, 24 10129, Torino, Italy.

Quantum imaging aims to take advantage of quantum nature of light to overcome limits of classical optics in terms of resolution and sensitivity. One of the main issue is to reduce the intrinsic photon noise below shot noise limit reaching sub-shot-noise sensitivity in the measurement of some specific parameter concerning systems for example phase and absorption. The shot-noise becomes evident in imaging experiments for small number of photons detected by the pixels of the CCD camera making it unfavorable to reconcile the absorption profile of a faint object. Brida et al[1] gave a first experimental realization of sub-shot noise quantum imaging(SSNQI) scheme for weak absorbing object exploiting the spatial photon number non classical correlation in multi-mode twin beam generated by type-II SPDC process. Since the noise in both signal and idler arm of TWB is correlated, it is possible to obtain the image profile by placing the object in one arm and then subtracting the correlated noise from the other arm. Ideally this represents a complete noise free scenario but in practice the sensitivity deteriorates by overall system loss. The SSNQI is advantageous[2] over any classical scheme when less than half photon pairs are lost. Anyway, there is a trade-off between the sensitivity, improved by the method and the resolution which depends on the coherence area of the correlation in the far field of the PDC emission. We have brought the technique to the microscopic imaging domain towards the realization of a sub-shot-noise microscope. For this purpose we have increased the resolution twenty times down to few µm and at the same time we have reduced the losses by improving the far field correlation. The main difficulties with respect to classical microscopy are that the imaging systems should be able to reduce the aberration without introducing any losses. The trade-off between the resolution and sensitivity has been explored in detail. This strategy may find potential application in biological samples when low light illumination is required.

References

[1] Brida et al, Nature Photonics 4, 227 - 230 (2010).
[2] Brida et al, Phys. Rev. A 83,033811 (2011).

Pattern classification on the quantum Bloch sphere

E. Santucci (1), G. Sergioli (2), L. Didaci (3), R.Giuntini (4)

(1) University of Cagliari, Italy; (2) University of Cagliari, Italy; (3) University of Cagliari, Italy; (4) University of Cagliari, Italy.

The main contribution of our work is the introduction of a new framework to encode the classification process by means of the mathematical language of density matrices.
Recently, many attempts to apply the quantum formalism in the areas of pattern recognition and image understanding have been made [1,2,5,6] and some results seem to suggest possible computational advantages through this kind of approach. Nevertheless, an extensive and universally recognized treatment of the topic is still missing [4,3].
The representation of patterns by the use of quantum states leads to i) the possibility of exploiting quantum algorithms to boost the computational intensive parts of the classification process, ii) the possibility of using quantum-inspired algorithms for solving classical problems more effectively.
Firstly, we provide a one-to-one correspondence between patterns (i.e. n-dimensional feature vectors) and pure density operators (i.e. points in the n-dimensional Bloch hypersphere). By using this correspondence, we give a representation of the Nearest Mean classifier (NMC) in terms of quantum objects by defining an "ad hoc" Normalized Trace Distance which coincides with the Euclidean distance between patterns in the real space. Consequently, we have found a quantum version of the discriminant function by means of Pauli components, represented as a plane which intersects the Bloch sphere. We suggests, as a potential development, to find a quantum algorithm that implements the normalized trace distance between density patterns with a resulting reduction of the computational complexity of the NMC process.
Secondly, we introduce a purely quantum classifier (QC) through a new definition of "quantum centroid" which turns out to be more informative than the classical one because it takes into account also information about the distribution of the patterns.
Therefore, the main result consists in showing how this quantum classifier performs a significant reduction of the error and an improvement of the accuracy and precision of the algorithm with respect to the NMC (and also to other commonly used classifiers) on a classical computer. At this purpose, the performances of QC and NMC on different datasets will be shown and compared. Finally, possible practical applications to clinical imaging and face recognition will be proposed.

References

[1] D. Aerts, B. D'Hooghe, Classical logical versus quantum conceptual thought: examples in economics, decision theory and concept theory, Quantum interaction, Lecture Notes in Comput. Sci., 5494:128-142, Springer, Berlin (2009).
[2] H. Freytes, G. Sergioli, and A. Aricò, Representing continuous t-norms in quantum computation with mixed states, J. Phys. A, 43(46):465306, 12 (2010).
[3] A. Manju, M.J. Nigam, Applications of quantum inspired computational intelligence: a survey, Artificial Intelligence Review, 42(1):79-156 (2014).
[4] C.D. Manning, P. Raghavan, and H. Schütze, Introduction to information retrieval, Vol.1, Cambridge University Press, Cambridge (2008).
[5] M. Schuld, I. Sinayskiy, F. Petruccione, An introduction to quantum machine learning, Contemp. Phys., 56(2), arXiv:1409.3097 (2014).
[6] C. A. Trugenberger, "Quantum pattern recognition", Quantum Inf. Process, 1(6):471-493 (2002).

Experimental realization of equiangular three-state quantum key distribution

M. Schiavon (1), G. Vallone (1), P. Villoresi (1)

(1) University of Padova, Italy

Quantum key distribution (QKD) is a cryptographic technique whose security is based on the laws of quantum mechanics. Relevant QKD schemes include the BB84, which uses four states in two non-orthogonal bases and is secure up to a bit error rate of about 11% [1], and the B92, using just two non-orthogonal states but with a security threshold dependent on channel losses [2]. The security of B92 can be enhanced by adding a third state. The optimal three state protocol, introduced in 2000 by Phoenix-Barnett-Chefles (PBC00) [3], uses states that form an equilateral triangle in the X-Z plane of the Bloch sphere and is secure, in the asymptotic case, up to an error rate of 9.81% [4]. An improvement of this protocol, introduced by Renes in 2004 (R04) [5], allows to estimate the error rate directly from the number of inconclusive events, thus avoiding the public transmission of part of the key for error estimation.

We aim to present our recent experimental demonstration of an entanglement-based version of the R04 protocol [6]. We use a source of polarization-entangled photons based on a Sagnac interferometer and two identical POVMs for Alice and Bob that use only passive optical elements in a linear scheme. With this setup, we obtain an asymptotic secure key rate higher than 10 kbit/s and a mean QBER of 1.6% for at least 2 hours of continuous acquisition. We then extend a recent study of the finite key security of the PBC00 [7] to the R04, evaluating the secure key rate for both collective and general attacks.

References

[1] V. Scarani et al., Rev. Mod. Phys. 81, 1301 (2009)
[2] K. Tamaki and N. Luetkenhaus, Phys. Rev. A 69, 032316 (2004)
[3] S. Phoenix, S. Barnett and A. Chefles, J. Mod. Opt 47, 507 (2000)
[4] J.-C. Boileau et al., Phys. Rev. Lett. 94, 040503 (2005)
[5] J. M. Renes, Phys. Rev. A 70, 052314 (2004)
[6] M. Schiavon, G. Vallone and P. Villoresi, arXiv:1603.07605 (2016)
[7] M. Mafu, K. Garapo and F. Petruccione, Phys. Rev. A 90, 032308 (2014)

Quantum Galileo's experiments and mass estimation in a gravitational field

L. Seveso (1), V. Peri (2), M. G. A. Paris (3)

Università degli Studi di Milano

We address the problem of estimating the mass of a (quantum) particle interacting with a classical gravitational field. In particular, we analyze in details the ultimate bounds to precision imposed by quantum mechanics and study the effects of gravity in a variety of settings. Our results show that the presence of a gravitational field generally leads to a precision gain, which can be significant in a regime half-way between the quantum and classical domains. We also address quantum enhancement to precision, i.e. the advantages coming from taking into account the quantum nature of the probe particle, and show that non-classicality is indeed a relevant resource for mass estimation. In particular, we suggest schemes for mass-sensing measurements using quantum probes and show that upon employing non-classical states like quantum coherent superpositions one may improve precisions by orders of magnitude. In addition, we discuss the compatibility of the weak equivalence principle (WEP) within the quantum regime using as a guide the notion of Fisher Information. We find that the information on the probe's mass that can be extracted through position measurements is unchanged by turning on a uniform gravitational field. This conclusion is somehow at variance with certain views expressed in the literature that the WEP cannot hold in the quantum regime. In fact, our results show that in an information-theoretic framework, no clash occurs between quantum mechanics and the WEP.

Quantifying Identical Particle Entanglement

E. Sindici (1), M. Piani (1)

(1) Department of Physics and SUPA, University of Strathclyde, Glasgow G4 0NG, United Kingdom

Inter-particle entanglement (IPE) for identical bosons and fermions is a fundamental property of quantum systems which is still not well understood, unlike mode entanglement, yet it yields potential applications in quantum-enhanced metrology and deeper insights in cold atom systems. [1] We identify the symmetrization requirement for bosonic and fermionic states to be crucial in the difficulties arising in quantifying IPE [2] and propose an entanglement measure based on standard entanglement negativity. Given a target (anti)symmetrized state ρ, we evaluate its inter-particle entanglement as the minimum negativity of an unsymmetrized state which upon projection on the (anti)symmetric subspace yields ρ, up to a normalization constant. The proposed quantification can be implemented as a Semi-Definite Program (SDP). We explore the bipartite case and pave the way for the study of multipartite identical particle entanglement in many-body systems.

References

[1] Kolodynski et al., quant-ph 1405.7703v2 (2014)
[2] Ghirardi et al., quant-ph 0410086v1 (2004)

Quantum state transfer via Bloch oscillations

D. Tamascelli(1, 2) , S.Olivares (1, 3), S. Rossotti (1) R. Osellame (4, 5) and M. G. A. Paris (1,3)

(1) Università degli Studi di Milano, Italy
(2) Universität Ulm, Germany
(3) CNISM UdR Milano Statale, Italy
(4) Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche, Milano, Italy
(5) Politecnico di Milano, Italy

The realization of reliable quantum channels, able to transfer a quantum state with high fidelity, is a fundamental step in the construction of scalable quantum devices. In this paper we describe a transmission scheme based on the genuinely quantum effect known as Bloch oscillations. The proposed protocol makes it possible to carry a quantum state over different distances with a minimal engineering of the transmission medium and can be implemented and verified on current quantum technology hardware.

References

D. Tamascelli et al. arXiv:1511.09235 [quant-ph]

Atomic thermal motion effect on efficiency of a high-speed quantum memory

K. Tikhonov, T. Golubeva, Yu. Golubev

Saint-Petersburg State University, Russia

Over the last decade various protocols of quantum memory, based on the interaction between signal and driving light pulses with an ensemble of immobilized atoms were proposed [1,2]. Certainly, an approximation of motionless atoms is natural, when one implements quantum memory protocol on the impurities in crystals. There atomic motion is restricted by nodes of a crystal lattice, and any spatial fluctuations are negligibly small. Besides, this approximation provides us with reliable results, if a full memory cycle from the beginning of a writing stage and until the end of a signal retrieval is short enough, and the root-mean-square velocity is relatively small.

The approximation of motionless atoms plays a significant role in analysis of multimode memory process because it allows us to follow the conversion of a time dependence of signal into a spatial distribution of a collective spin at the writing stage. However, since the purpose of quantum memory is long-term storage of information in the generated spatial coherence mode, then to adequate assessment of the potential of such protocols we have to introduce thermal motion of atoms in a model and estimate the influence of "blur" on a spatial distribution of collective coherence.

We theoretically discuss the influence of atomic thermal motion on the efficiency of multimode quantum memory [3,4] in two configurations: over the free expand of atoms cooled beforehand in a magneto-optical trap, and over complete mixing in a closed cell at room temperature. We consider the high-speed quantum memory in terms of eigenmodes of the full memory cycle [5]. We show that distortion of these eigenmodes leads to a reduction of efficiency and storage time, which has complicated character due to a multimode regime of the memory. We also show how to optimize the protocol to make it significantly better and robust for applications.

References

1. K. Hammerer et al. Rev. Mod, Phys, 82, 1041 (2010)
2. A.I. Lvovsky et al. Nat. Photon, 3, 706 (2009)
3. T.Y. Golubeva et al. Phys. Rev. A, 83, 053810 (2011)
4. T.Y. Golubeva et al. Eur. Phys. J. D, 66, 275 (2012)
5. K. Tikhonov et al. Phys. Rev. A, 89, 013811 (2014)

Compressive sensing for hyperentangled state in polarization and time bin

M. Tomasin(1), G. Vallone(1), F. Raffaelli (1,2), P. Villoresi(1)

(1) University of Padova, dept. Of engineering of information; (2) Centre for Quantum Photonics, H.H. Wills Physics Laboratory, University of Bristol

Quantum state tomography is the standard tool for characterizing a quantum state.
This technique consists in inferring a density matrix from many different measurements on a quantum state[1, 2].
The accurate and efficient reconstruction of a density matrix increases in complexity with increasing dimension of the system. For instance, a small quantum system with 8-qubit requires thousands of experimental configurations.
Recentely, a technique used in classical signal processing, called "compressive sensing"[3,4], has been implemented for quantum state reconstruction[5]. The advantage of this method consists in increasing the efficency of the process, by an exponentially reduction of the experimental configurations needed for state reconstruction. This is possible when the density matrix is compressible in some basis, therefore it is a sparse matrix.
In this work, we apply this method for the estimation of a hyperentangled state in the polarization and time-bin degree of freedom (DOF). We also consider the case where we have additional information about the state, for example when we deal with quantum states in a laboratory. We study the possible use of this additional information to enhance the efficiency of quantum compressive sensing.

References

[1] D.F.V. James, P.G. Kwiat, W.J. Munro, and A.G. White, "Measurement of qubits", PhysRevA.64.052312, 2001
[2] K. Banaszek, M. Cramer, D. Gross, "Focus on quantum tomography", New Journal of Physics, vol. 15, no. 12, 2013
[3] D. L. Donoho, "Compressed sensing," in IEEE Transactions on Information Theory, vol. 52, no. 4, pp. 1289-1306, 2006
[4] E. Candes, M. Wakin, "An introduction to compressive sampling", IEEE Signal Processing Mag., vol. 25, no. 2, pp. 21-30, 2008
[5] D. Gross, Y. Liu, S.T Flammia, S. Becker, J. Eisert, "Quantum State Tomography via Compressed Sensing", PhysRevLett.105.150401, 2010

Optimized protocols for discrimination of collective decoherence for classical environments

J. Trapani, M.G.A. Paris

Università degli Studi di Milano

We address the study of optimized protocols for discrimination of which kind classical decoherence a quantum system undergoes. In particular, we probe the environment with a two-mode system prepared in either an entangled or a separable state and investigate which measurement brings to the best discrimination strategy to exploit local or common decoherence effects.

Connecting electronic - vibrational entanglement, quantum coherence and asymmetry in a molecular system

Mihaela Vatasescu

Institute of Space Sciences - INFLPR, Bucharest - Magurele, Romania

As fundamental quantum properties and quantum resources, entanglement and coherence are intertwined in two prominent research directions uniting quantum information theory and molecular physics: quantum computation using molecular internal degrees of freedom and quantum biology. These recent developments show the increasing interest in using quantum information concepts to describe molecular phenomena.

We characterize both entanglement and quantum coherence in a molecular system by connecting the linear entropy of electronic-nuclear entanglement with Wigner-Yanase skew information measuring vibronic coherence and local quantum uncertainty on electronic energy. Quantifiers of entanglement and quantum coherence are derived for a molecular system in a pure entangled state $\rho_{el,vib}(t)$ of the bipartite Hilbert space $\mathcal{H}=\mathcal{H}_{el} \times \mathcal{H}_{vib}$ of finite dimension $N_{el}\times N_v$, and relations between them are established. For the specific case of the electronic-nuclear entanglement, we find the linear entropy of entanglement as having a more complex informational content than the von Neumann entropy. By keeping the information carried by the vibronic coherences in a molecule, linear entropy seizes vibrational motion in the electronic potentials as entanglement dynamics. Quantum coherence in the bipartite entangled state $\rho_{el,vib}(t)$ is characterized by using measures of coherence and asymmetry based on l_1 norm and Wigner-Yanase skew information. We show that the linear entropy of entanglement is connected to two types of skew information for the electronic Hamiltonian, corresponding to the bipartite entangled state $\rho_{el,vib}(t)$ and reduced electronic state $\rho_{el}(t)$, respectively. We analyze entanglement oscillations in an isolated molecule, and show examples for the control of entanglement dynamics in a molecule through the creation of coherent vibrational wave packets in several electronic potentials by using chirped laser pulses.

References

M. Vatasescu, Phys. Rev. A 92, 042323 (2015);
D. Girolami, Phys. Rev. Lett. 113, 170401 (2014);
D. Girolami, T. Tufarelli, and G. Adesso, Phys. Rev. Lett. 110, 240402 (2013);
T. Baumgratz, M. Cramer, and M. B. Plenio, Phys. Rev. Lett. 113, 140401 (2014);
A. Streltsov, U. Singh, H. S. Dhar, M. N. Bera, and G. Adesso, Phys. Rev. Lett. 115, 020403 (2015);
E. P. Wigner and M. M. Yanase, Proc. Natl. Acad. Sci. USA 49, 910 (1963).
I. Marvian, R. W. Spekkens, P. Zanardi, Phys. Rev. A 93, 052331 (2016)

Observing single-photon interference along satellite-ground channels

Giuseppe Vallone (1), Daniele Dequal (1), Marco Tomasin (1), Francesco Vedovato (1), Matteo Schiavon (1), Vincenza Luceri (2), Giuseppe Bianco (3), Paolo Villoresi (1)

(1) Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Padova
(2) e-GEOS spa, Matera
(3) Matera Laser Ranging Observatory, Agenzia Spaziale Italiana, Matera

One of the main challenges in quantum mechanics is establishing if fundamental bounds to quantum interference exist: for instance, can it be measured by observers in relative motion and at an arbitrary large distance? In order to answer such kind of questions, it is necessary to observe quantum interference in unexplored conditions which involve moving terminals in Space.

We experimentally demonstrated (1) interference at single-photon level with visibility up to 67% along three different satellite-ground channels with a total path length up to 5000 km. We exploited a superposition of two photon temporal modes (as in the time-bin quantum cryptographic technique) reflected by a rapidly moving satellite equipped with corner-cube retroreflectors thousand kilometers away and observed the single-photon interference at a ground station (the MLRO Observatory of Italian Space Agency - Matera - Italy). The relative velocity of the satellite respect to the ground introduces a varying modulation in the interference pattern which can be predicted by special relativistic calculation.

These results attest to the viability of the use of photon temporal modes for testing the interplay between quantum mechanics and gravitation in the context of quantum optics experiments in Space, as recently proposed in the optical version of the Colella-Overhauser-Werner experiment.

Furthermore, time-bin technique was never implemented for quantum communication over long-distance free-space channels to date, fearing that atmospheric turbulence might spoil the interference. We have shown that atmospheric turbulence is not detrimental for time-bin encoding because the two temporal modes, separated by few nanoseconds, are identically distorted by the propagation in turbulent air. Our results attest to the feasibility of the time-bin or phase encoding method for space quantum communications that can be useful for ensuring secure communications at planetary scale.

References

(1) Interference at the Single Photon Level Along Satellite-Ground Channels, G. Vallone, D. Dequal, M. Tomasin, F. Vedovato, M. Schiavon, V. Luceri, G. Bianco, P. Villoresi, Phys. Rev. Lett. (in press)

Entanglement-swapping assisted EPR steering over high-loss quantum channel with no detection loophole

M. Weston (1), S. Slussarenko (1), H. Chrzanowski (1) (2), S. Wollmann(1) and G. Pryde (1)

(1) Centre for Quantum Dynamics, Griffith University, Brisbane, Australia
(2) Department of Physics, University of Oxford, Oxford, United Kingdom

Entanglement is a key resource for many quantum information protocols, such as secure communication, networking quantum computers and remote processing of quantum information. As such, violations of a loophole free Bell inequality are highly sought after to completely verify remote shared entanglement between two parties. Though these violations have been demonstrated, performing these over long distances is technologically challenging due to losses through the fibre opening up the detection loophole. An alternative approach that we employ to overcome these challenges, whilst guaranteeing shared entanglement over long distances, is quantum steering (EPR-steering) [1].
EPR steering is an asymmetric protocol that provides enhanced loss tolerance with the additional assumption that one party and his apparatus is trusted. The aim of the protocol is that one untrusted party (Alice) needs to convince a trusted party (Bob) that she can steer his measurement outcomes. In the loss-tolerant quantum steering protocol [2] Alice is prevented from exploiting the fair-sampling assumption to cheat, by Bob requiring her to announce a measurement a certain fraction ε of trials (Alice's heralding efficiency), from which he constructs a secure steering inequality.

We consider a case where high channel loss (say, 10s to 100s of km of optical fibre) reduces Alice's heralding efficiency, preventing her from violating the inequality [2]. Here we design and experimentally demonstrate a protocol using entanglement swapping to herald the presence of a photon in Alice's arm. With this higher effective heralding efficiency EPR-steering can be performed with the detection loophole closed.

We use two telecom-wavelength, high heralding efficiency, polarization-entangled photon sources [3]. A high entanglement swapping singlet-state fidelity is achieved and the steering inequality is violated by two standard deviations with 14dB of added channel loss, equivalent to about 75km of telecom fibre. Currently, we are extending our results to higher channel losses.

References

[1] D. J. Saunders, et al., Nature Physics 6, 845 (2010)
[2] A. J. Bennet, et al., Physical Review X, 2, 031003 (2012)
[3] M. M. Weston et al., arXiv:1603.03555v1 (2016)

Thermodynamics of trajectories of harmonic oscillators

Simon Pigeon (1), Lorenzo Fusco (1), André Xuereb (2,1), Gabriele De Chiara (1), Mauro Paternostro (1)

(1) School of Mathematics and Physics, Queen's University Belfast; (2) Department of Physics, University of Malta

We consider a paradigmatic system in quantum mechanics, a quantum harmonic oscillator connected to N arbitrary baths whose dynamics is governed by a master equation in Lindblad form. This system is a fundamental building block of quantum optics and is used to describe a large variety of quantum degrees of freedom, including the motion of trapped ions and molecules, cavity and circuit quantum electrodynamic systems, and many–body systems. One of our key results is an analytical expression for the large-deviation function of this frequently-encountered infinite Hilbert space dimension problem (e.g., continuous-variable system). In the simple case where the harmonic oscillator is coupled to two thermal baths, we will compare our result to its classical counterpart, showing perfect agreement at high temperatures and an unexpected quantum suppression at low temperatures. Our technique can also handle the case of a driven harmonic oscillator, once more presenting analytical results for the large-deviation function. Far from being an exclusively descriptive approach, this allows to engineer the output of a quantum harmonic oscillator to read physically meaningful internal quantities.

References

[1] S. Pigeon, et al., New J. Phys. 17, 015010 (2015).
[2] S. Pigeon, et al., Phys. Rev. A 92, 013844 (2015).
[3] S. Pigeon, et al., New J. Phys. 18, 013009 (2016).
[4] S. Pigeon and A. Xuereb, arXiv:1602.07136 (2016)

Quantum Estimation via Sequential Measurements

Kazuya Yuasa (1), Daniel Burgarth (2), Vittorio Giovannetti (3), Airi N. Kato (4)

(1) Waseda University, Tokyo, Japan; (2) Aberystwyth University, UK; (3) Scuola Normale Superiore, Pisa, Italy; (4) University of Tokyo, Japan

Estimating parameters of quantum systems (e.g., parameters in their Hamiltonians) is important from both practical and fundamental aspects. In standard strategies, parameters are estimated from the data accumulated by many independent and identical experiments: every time one performs a measurement, the system needs to be reset in a specific initial state.

In this presentation, I present a scheme in which we are not required to re-initialize the system after every measurement: we simply repeat measurements, and a parameter is estimated from a single sequence of measurement data. Our idea is to make use of a quantum mixing channel: a quantum channel (a CPTP map) is called mixing if its repeated actions on a quantum system drive the system from an arbitrary initial state to a unique final state. This feature enables us to estimate a parameter irrespective of the initial state of the system, and provides us with self-averaging quantities on the basis of a central limit theorem, which allow us to estimate a parameter just by a single run. Moreover, in contrast to standard strategies, the correlations among measurement data are available for estimation in the present scheme, with which we can enhance the precision of the estimation beyond standard strategies, when only weak (unsharp) measurement is available.

We prove the central limit theorem for the non-i.i.d. data in the general setting under the assumption of the mixing of the quantum channel of the estimation process, and demonstrate the enhancement in the precision of estimation by making use of correlation data for a problem of estimating the temperature of a reservoir via sequential measurements on a quantum probe in contact with the reservoir.

References

D. Burgarth, V. Giovannetti, A. N. Kato, and K. Yuasa, New J. Phys. 17, 113055 (2015).

Quantum annealing speedup over simulated annealing on random Ising chains

T. Zanca (1), G. E. Santoro (1, 2, 3)

(1) SISSA, Trieste, Italy; (2) CNR-IOM Democritos National Simulation Center, Trieste, Italy; (3) ICTP, Trieste, Italy.

We show clear evidence of a quadratic speedup of a quantum annealing (QA) Schr\"odinger dynamics over a Glauber master equation simulated annealing (SA) for a random Ising model in one dimension, via an equal- footing exact deterministic dynamics of the Jordan-Wigner fermionized problems. This is remarkable, in view of the arguments of H. G. Katzgraber et al. [Phys. Rev. X 4, 021008 (2014)], since SA does not encounter any phase transition, while QA does. We also find a second remarkable result: that a ``quantum-inspired'' imaginary-time Schr\"odinger QA provides a further exponential speedup, i.e., an asymptotic residual error decreasing as a power law $\tau^{-\mu}$ of the annealing time τ.

References

1. A. B. Finnila, M. A. Gomez, C. Sebenik, C. Stenson, and J. D. Doll, Chem. Phys. Lett. 219, 343 (1994).
2. T. Kadowaki and H. Nishimori, Phys. Rev. E 58, 5355 (1998).
3. J. Brooke, D. Bitko, T. F. Rosenbaum, and G. Aeppli, Science
284, 779 (1999).
4. G. E. Santoro, R. Martonak, E. Tosatti, and R. Car, Science 295,
2427 (2002).

The large dimensional limit of multipartite entanglement

Sara Di Martino(1), Paolo Facchi(2,3), Giuseppe Florio(4,3)

(1) Física Teòrica: Informacío i Fenòmens Quàntics, Departament de Física, Universitat Autònoma de Barcelona, 08193 Bellaterra (Barcelona), Spain.
(2) Dipartimento di Fisica and MECENAS, Università di Bari, I-70126 Bari, Italy.
(3) INFN, Sezione di Bari, I-70126 Bari, Italy.
(4) Dipartimento di Meccanica, Matematica e Management, Politecnico di Bari, Via E. Orabona 4, I–70125 Bari, Italy.

Since its early origins entanglement has been considered as one of the most basic and intriguing features of quantum mechanics. However, the characterization and quantification of quantum correlations is not a simple task. On one side bipartite entanglement, i.e. the entanglement of two subsystems, is well understood and can be completely characterized, but on the other hand, multipartite entanglement is less understood and more elusive even if widely investigated.

Our aim is to study the properties of multipartite entanglement of a system composed by n dlevel particles (qudits). Focussing our attention on pure states we want to tackle the problem of the maximization of the entanglement for such system. In particular we consider the problem of minimizing the local purities of the system. It has been shown that in general not for all subsystems this function can reach its lower bound [1]. However it can be proved that for all values of n a d can always be found such that the lower bound can be reached.

Adopting the concepts and tools of classical statistical mechanics, we introduce a Hamiltonian representing the average bipartite purity over all balanced bipartition [2] and examine its hightemperature expansion. In particular we make use of techniques that are based on the analysis of diagrams that naturally arise when one considers this expansion of the distribution function. We prove that the sum of these diagrams converges and we analyze its behavior as d goes to infinite.

References

1. A. J. Scott. Phys. Rev. A, 69:052330 (2004).
2. Paolo Facchi, Giuseppe Florio, Ugo Marzolino, Giorgio Parisi, and Saverio Pascazio. Journal of Physics A: Mathematical and Theoretical, 42(5):055304 (2009).

Entanglement and extreme spin squeezing of unpolarized states

G. Vitagliano (1), I. Apellaniz (1), G. Toth (1,2,3), B. Luecke (4), J. Peise (4) and C. Klempt (4)

(1) University of the Basque Country, Spain
(2) IKERBASQUE Foundation for Science, Spain
(3) Wigner Research Center for Physics; (4) Leibniz Universitat Hannover, Germany

We study the problem of detecting entanglement and its depth in spin systems composed of very many particles. We derive entanglement criteria based only on few easy measurable quantities such as the mean values and variances of collective spin components. With these, we generalize the notion of spin-squeezing [1,2], traditionally related to entanglement and quantum metrology, by including Dicke states and unpolarized states in general. The criteria derived, in fact, are proven to detect a wider class of entangled states with respect to well-known past approaches [1,2,3] and have been used in a recent experiment [4] to prove that the produced Dicke-like state had a depth of entanglement of at least 28 particles.

References

1. A. Sorensen, L.-M. Duan, J. Cirac, and P. Zoller, Nature 409, 63 (2001)
2. A. S. Sørensen and K. Mølmer, Phys. Rev. Lett. 86, 4431 (2001)
3. L.-M. Duan, Phys. Rev. Lett. 107, 180502 (2011)
4. B. Luecke, J. Peise, G. Vitagliano, J. Arlt, L. Santos, G. Toth, and C. Klempt, Phys. Rev. Lett. 112, 155304 (2014)
5. G. Vitagliano, P. Hyllus, I. L. Egusquiza, and G. Toth, Phys. Rev. Lett. 107, 240502 (2011)
6. G. Vitagliano, I. Apellaniz, I. L. Egusquiza, and G. Toth, Phys. Rev. A 89, 032307 (2014).

Brachistochrone of Entanglement for Spin Chains

Alberto Carlini[1,2,3,*] and Tatsuhiko Koiké[4,†]

1 Dipartimento di Scienze ed Innovazione Tecnologica,Università del Piemonte Orientale, Alessandria, Italy
2 Istituto Nazionale di Fisica Nucleare, Sezione di Torino, Gruppo Collegato di Alessandria, Italy
3 NEST, Istituto di Nanoscienze-CNR, I-Pisa, Italy
4 Department of Physics, Keio University, Yokohama, Japan

We study the time-optimal unitary evolution of entanglement between indirectly coupled qubits in a trilinear Ising chain where the intermediate qubit is controlled via a local magnetic field. We find the time-optimal unitary evolution law, and we quantify residual entanglement via the two-tangle between the indirectly coupled qubits. Entanglement plays a role for *W* and *GHZ* initial quantum states, and for the bi-separable initial state in which the indirectly coupled qubits have a nonzero value of the 2-tangle.

Experimental Verification of an Indefinite Causal Order

G. Rubino (1), L. A. Rozema (1), A. Feix (1)-(2), M. Araújo (1)-(2), J. M. Zeuner (1), L. M. Procopio (1), Č. Brukner (1)-(2), P. Walther (1)

(1) Quantum Optics, -Nanophysics, -Information Group, Faculty of Physics, University of Vienna, Boltzmanngasse 5, Vienna A-1090, Austria
(2) Institute for Quantum Optics & Quantum Information (IQOQI), Austrian Academy of Sciences, Boltzmanngasse 3, Vienna A-1090, Austria

Investigating the role of causal order in quantum mechanics has recently revealed that the causal distribution of events may not be a-priori well-defined in quantum theory. While this has triggered a growing interest on the theoretical side, creating processes without a causal order is an experimental task.

Here we report the first decisive demonstration of a process with an indefinite causal order. To do this, we quantify how incompatible our set-up is with a definite causal order by measuring a 'causal witness'. This mathematical object incorporates a series of measurements which are designed to yield a certain outcome only if the process under examination is not consistent with any well-defined causal order. In our experiment we perform a measurement in a superposition of causal orders – without destroying the coherence – to acquire information both inside and outside of a 'causally non-ordered process'.

Using this information, we experimentally determine a causal witness, demonstrating by almost seven standard deviations that the experimentally implemented process does not have a definite causal order.