Poster Abstracts

1. What we talk about when we talk about non-Markovianity

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We present a detailed critical study of several recently proposed non-Markovianity measures. We analyse their properties for single qubit and two-qubit systems in both pure-dephasing and dissipative scenarios. More specifically we investigate and compare their computability, their physical meaning, their Markovian to non-Markovian crossover, and their additivity properties with respect to the number of qubits. The bottom-up approach that we pursue is aimed at identifying similarities and differences in the behavior of non-Markovianity indicators in several paradigmatic open system models. This in turn allows us to infer the leading traits of the variegated phenomenon known as non-Markovian dynamics and, possibly, to grasp its physical essence.

2. Linear-optical simulation of the cooling of a cluster-state Hamiltonian system

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A measurement-based quantum computer could consist of a local-gapped Hamiltonian system, whose thermal states -at sufficiently low temperature- are universal resources for the computation. Initialization of the computer would correspond to cooling the system. We perform an experimental quantum simulation of such cooling process with entangled photons. We prepare three-qubit thermal cluster states exploiting the equivalence between local dephasing and thermalisation for these states. This allows us to tune the system's temperature by changing the dephasing strength. We monitor the entanglement as the system cools down and observe the transitions from separability to bound entanglement, and then to free entanglement. We also analyze the performance of the system for measurement-based single-qubit state preparation. These studies constitute a basic characterization of experimental cluster-state computation under imperfect conditions.

3. Direct Measurement of Photonic Spatial Correlations

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Continuous variable entanglement is a powerful resource for quantum information tasks. However, to quantify or even identify entanglement in an infinite-dimensional Hilbert space is in general far from trivial. In order to address this problem we propose and implement a method to perform a direct measurement of moments of the distribution that characterizes the spatial entanglement of photon pairs, without the reconstruction of the marginals. We use a spatial light modulator to couple the spatial degrees of freedom and the polarization of the fields, imprinting on the field profile an appropriate phase shift. The method relies on polarization-only measurements, so our results should be increasingly useful for investigations involving more than two photons, as it decreases drastically the number of measurements required.

Reference:
M. Hor-Meyll, J. O. de Almeida, G. B. Lemos, P. H. Souto Ribeiro, "Ancilla-assisted Measurement of Photonic Spatial Correlations and Entanglement", Phys. Rev. Lett. **112**, 053602 (2014).

4. Distributions of orbital angular momentum and topological charge in shaped optical vortices

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A light beam may possess two kinds of angular momentum, spin and orbital, that are intrinsic features of light as shown in ref. [1]. The spin angular momentum (SAM) is associated with the circular polarization states of light. The orbital angular momentum (OAM) is related in the classical regime to a rotation of the wavefront direction around a reference point. This wavefront rotation implies that in OAM beams the classical Poynting vector (or momentum flow) also rotates with respect to the same reference point. The most frequently used OAM beams are Laguerre-Gauss or Bessel modes, where the photon is in an OAM eigenstate and has a well defined topological charge (TC). While the OAM modal spectrum of a light beam is a well defined quantity that can be used to characterize the OAM content of a light beam, there are no direct counterparts for the classical OAM and the TC. In this work, we discuss how the classical OAM and the TC can be placed in the same framework as the modal OAM through the definition of classical OAM and TC distributions. This is important because the classical and modal OAM and the TC are physically distinct quantities of a light beam. By describing these quantities in an equivalent framework, it becomes possible to further understanding of the physical mechanisms behind interactions between OAM beams and matter. We demonstrate through experiments the behavior of the above distributions for several light beams, and discuss some physical implications.

Reference:
[1] - A. M. Yao and M. J. Padgett, Adv. Opt. Photon. **3**, 161-204 (2011).

5. Applying the Simplest Kochen-Specker Set for Quantum Information Processing

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Kochen-Specker (KS) sets are key tools for proving some fundamental results in quantum theory and also have potential applications in quantum information processing. However, so far, their intrinsic complexity has prevented experimentalists from using them for any application. The KS set requiring the smallest number of contexts has been recently found. Relying on this simple KS set, here we report an input state-independent experimental technique to certify whether a set of measurements is actually accessing a pre-established quantum six-dimensional space encoded in the transverse momentum of single photons.

6. Experimental realization of arbitrary, partially polarized states of light

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We present a device that serves as a secondary source of light with prescribed polarization properties. By employing the well-known quantum mechanical method of Schmidt purification in a Mach-Zender array, it is shown that partially polarized states with well defined properties can be prepared. We exhibit the possibility of having almost complete control over the degree of polarization as well as over the Stokes parameters that characterize the state. Furthermore, we explore the possibility of reproducing the same results with incoherent superposition. We present theoretical and experimental results. Our experimental results were obtained by using a HeNe laser as a primary source of light. However, the method could also be applied using quantum light as a primary source. Only slight modifications of our present setup would be required.

7. Excited-state phase transitions in the Dicke model: comparative quantum and semiclassical analysis

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We study the nonintegrable Dicke model and its integrable approximation, the Tavis-Cummings model, as functions of both the coupling constant and the excitation energy. We distinguish between two different Excited-state quantum phase transitions (ESQPT) by analyzing the density of states (DoS) in the semiclassical limit and comparing it with numerical results for the quantum case, taking advantage of efficient methods developed recently. Also, employing the semiclassical DoS we study the statistical properties of the quantum fluctuations in the energy spectrum and their relation with the ESQPT. The presence of chaos for different energies and couplings is exhibited, employing Poincaré sections and Peres lattices in the classical and quantum versions, respectively.

8. Quantum correlations from classically correlated states

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Consider a bipartite quantum system with at least one of its two components being itself a composite system. By tracing over part of one (or both) of these two subsystems it is possible to obtain a reduced (separable) state that exhibits quantum correlations even if the original state of the full system is endowed only with classical correlations. This effect, first pointed out by Li and Luo in (2008), is of considerable interest because there is a growing body of evidence suggesting that quantum correlations in non-entangled, mixed states may constitute a useful resource to implement non trivial information related tasks. Here we conduct a systematic exploration of the aforementioned effect for particular families of states of quantum systems of low dimensionality (three qubits states). In order to assess the non-classicality of the correlations of the reduced states we use an indicator of quantum correlations based upon the state disturbances generated by the measurement of local observables. We show, for a three-qubit system, that there exists a relationship between the classical mutual information of the original classically correlated states and the maximum quantum correlation exhibited by the reduced states.

9. From local to global Loschmidt echo in many-body systems

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Inspired in Nuclear Magnetic Resonance, the Loschmidt Echo (LE) has become an important dynamical witness to assess quantum chaos, decoherence and the emergence of classicality [1]. The study of the LE in interacting many-body systems is still a major and stimulating theoretical challenge, since it provides a sort of order parameter for novel dynamical transitions [2]. Here, we evaluate numerically the LE in an interacting spin system, where uncontrolled degrees of freedom involve polarization non-conserving interactions, which as in NMR experiments are truncated by the effective Zeeman splitting induced by rf irradiation. We find that these interactions yield polarization conserving virtual processes that proliferate as a function of the number of spins involved. We also assess the role of different dynamically prepared states. Our results confirm that the more "prepared" (i.e. correlated or entangled) the states are, the more fragile they become under perturbations [3]. Moreover, it is observed that the dynamical preparation saturates at a finite time-scale and thereafter the local LE can be mimicked by a global LE of a random superposition state [4]. Since these states already exhibit thermal properties [5], our results confirms that LE dynamics is a privileged witness of the onset of thermalization in closed quantum systems.

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10. Light scattering of an NV center

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Nitrogen-vacancy (NV) centers in diamond are single defects formed by a substitutional nitrogen atom and a neighboring vacancy site. They are promising candidates for single photon sources in quantum networks. As solid-state emitters they underlie a spectral broadening of the emission line due to the coupling to bulk phonons thereby limiting their applicability. Several approaches have been made to describe the vibronic sidebands of the absorbed and emitted light, ranging from models solely based on the Franck-Condon principle over multilevel models to non-Markovian master equations. Nevertheless, they either oversimplify, lack a clear picture of the underlying physical processes, or are too involved to allow a straightforward application to systems such as an NV center coupled to an optical cavity. To fill this gap, we develop a pragmatic model that reproduces the vibronic sidebands and can easily be extended to hybrid systems. We exploit the fact that NV centers only exhibit a strong coupling to a small number of local vibration modes of the surrounding crystal and focus on a single one of these modes that is damped by the phononic background. The dynamics of this system is governed by a Markovian master equation. A full analytic solution in terms of the damping basis is presented, i.e. the spectral decomposition of the Liouvillian that generates the time evolution of the density operator, thereby giving an example for a completely solvable non-trivial open quantum system. We apply this solution to a detailed analysis of the light scattering of the NV center, namely its absorption and fluorescence spectrum. Our model renders the main features of the vibronic sidebands and can be employed to analyze NV centers coupled to photonic crystal cavities, a setup that has been proposed to narrow the linewidth of the emitted single photons.

11. Generalized entropic uncertainty relations for positive operator-valued measures

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We present entropic formulations of the uncertainty principle for arbitrary pairs of positive operator-valued measures (POVM) A and B acting on N-dimensional Hilbert space. We introduce a generalized entropy to measure the lack of information associated to the probability distributions of the POVM depending on the state of the quantum system, and we find a non trivial bound for the sum of generalized entropies. To obtain our bound, we proceed in two steps: (i) evaluation of the minimal entropy of a distribution subject to maximal probability and (ii) minimization of the sum of the minimal entropies, subject to the Landau-Pollak inequality, which links the maximum of the distributions associated to the POVM. As a consequence, our bound depends on the triplet overlap (c_A, c_B, c_{AB}), where c_A and c_B are the intrinsic overlaps of each POVM whereas c_{AB} is the overlap between both POVM that quantifies the degree of incompatibility between them. In the case of nondegenerate observables $[(1, 1, c)]$, the bound appears to be optimum for given $c > 1/\sqrt{2}$ and improves all c-dependent bounds that exists in the literature such as Deutsch and Maassen-Uffink ones.

12. Thermal light cannot be represented as a mixture of random pulses

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The application of ultrafast non-linear spectroscopy to the study of photosynthesis raises an important methodological question: what relevance do these experiments have to the natural function of photosynthetic systems excited by sunlight? Sometimes a connection is posited by considering sunlight as "a series of random ultrashort spikes with a duration as short as the bandwidth allows" [1], but the link between natural sunlight and laboratory-generated ultrafast pulses has never been formally investigated, and continues to be a subject of ongoing debate. We ask whether or not thermal light can be understood as a mixture of broadband coherent pulses. We find that it cannot.

We demonstrate that no unit-trace density operator consisting of a mixture of pulses can equal the density operator for thermal light. Nonetheless, it is possible to construct a trace-improper mixture of coherent pulses that does yield a g(1) that matches that of thermal light. However, we further demonstrate that such a trace-improper mixture cannot even reproduce the simplest g(2) of thermal light. Our research highlights the very particular properties of thermal light and gives the limitations of broadband mixtures in understanding similar light-matter interactions. It suggests that our intuition of such states of light may be limited to linear interactions, and perhaps requires further development when it comes to making connections between nonlinear optical experiments involving broadband coherent, and those involving multi-mode incoherent, light.

References:

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13. Optimised shaping of optical nonlinearities in poled crystals

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Photon sources based on spontaneous parametric downconversion are an ubiquitous tool for quantum computation, quantum communication and quantum metrology. As these experiments evolve, more stringent requirements are placed on the characteristics of the created quantum light states. In particular, to produce high-purity heralded, or even near deterministic single photons, the spectral shape and correlations of the created photon pairs must be carefully engineered. Spectral properties of downconverted photons can be tailored by modulating the nonlinearity profile of a downconversion crystal. A discretized approximation to the desired nonlinearity profile can be achieved using higher-order poling [1]. We improve on this rudimentary method by directly manipulating the poling pattern. We present an algorithm that uses simulated annealing to find an optimized poling pattern corresponding to the desired effective nonlinearity profile. This has direct application in attaining one of the most prevalent goals of single-photon quantum optics – the creation of pure single Photons without spectral correlations. Our technique differs from [2], where the domain width is modulated while the grating period is fixed.

References

[1] A. Branczyk, A. Fedrizzi, T. Stace, T. Ralph, and A. White, Engineered optical Nonlinearity for quantum light sources, Opt. Express **19**, 55-65 (2011).

[2] P. Ben Dixon, J. Shapiro, and F. Wong, Spectral engineering by Gaussian phase-matching for quantum photonics, Opt. Express **21**, 5879-5890 (2013)

14. Double-herald single-photon absorption by a single atom

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We present a single-photon to single-atom interface, where a heralded single photon generated by Spontaneous Parametric Conversion is absorbed by a single trapped ion, subsequently generating a single Raman-scattered photon that heralds the absorption event.

15. Charge state conversion dynamics in nitrogen-vacancy centre ensembles

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In the past decades the negative nitrogen-vacancy (NV-) centre in diamond has demonstrated its versatility as a sensor for temperature, electrical and magnetic fields, and as a promising solid-state system for quantum information processing. The negative charge state is photochemically not stable and loses the essential properties for the mentioned applications as soon as it converts to the neutral charge state, NV0. Thus, the charge state conversion dynamics of the NV centre play a key role in the understanding and application of the color centre. In this work, we show measurements of the charge state dynamics for NV centre ensembles close to the surface of an artificial diamond. We implanted $10^{10} - 10^{13}/\mathrm{cm}^2$ nitrogen ions 14N4+ (8 keV) into a CVD diamond with initially ¡100ppb nitrogen content. As a result we created 25 different NV centre densities within a thin layer, just 12nm below the diamond surface. Through two-color laser excitation pulse sequences we explored the time dependence of ionization (NV- $\rightarrow$ NV0) and recombination (NV0 $\rightarrow$ NV-). This allowed us to measure laser-induced as well as spontaneous conversion processes, and we find that the charge conversion characteristics depend strongly on the density of the colour centres.

16. Experimental demonstration of computational speed-up with a single ququart

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Quantum algorithms are known for presenting more efficient solutions to certain computational tasks than any corresponding classical algorithm. It has been thought that the origin of the power of quantum computation has its roots in non-classical correlations such as entanglement or quantum discord. However, it has been recently shown that even a single pure qudit is sufficient to design a quantum circuit which solves a black-box problem faster than any classical approach to the same problem. In particular, the algorithm that we consider determines whether eight permutation functions defined on a set of four elements is positive or negative cyclic. While any classical solution to this problem requires two evaluations of the function, quantum mechanics allows us to perform the same task with only a single evaluation. Here, we present the first experimental demonstration of the considered quantum algorithm with a quadrupolar nuclear magnetic resonance setup using a single four-level quantum system, i.e., a ququart.

17. Coupling Different Degrees of Freedom of a Single Photon

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To couple continuous degrees of freedom, space or frequency, with the polarization variable of photons produced by spontaneous parametric down conversion (SPDC) process permits us to explore experimentally the behavior of quantum systems in the context of both open quantum systems and measurement theory. In this work, we report an experimental method to couple the different degrees of freedom mentioned before. We present our results in two sections: First, we reconstruct the density matrix which represents polarization state both for a single photon and for paired photons that pass through a birefringent material and exhibit therefore decoherence in the polarization state. Additionally, we report a method to control decoherence degree and the existence of decoherence-free states. In the second part, we report the coupling of the spatial and polarization variables to study weak and strong measurements and the implications of the correlations between the results obtained from successive measurements in fundamental quantum mechanics.

18. Evolution of entanglement between two harmonic modes in stable and unstable regimes

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The exact evolution of the entanglement between two harmonic modes generated by an angular momentum coupling is examined. Such system arises when considering a particle in a rotating anisotropic harmonic trap or a charged particle in a fixed harmonic potential in a magnetic field, and exhibits a rich dynamical structure, with stable, unstable and critical regimes according to the values of the rotational frequency or field and trap parameters. Consequently, it is shown that the entanglement generated from an initially separable gaussian state can exhibit quite distinct evolutions, ranging from quasiperiodic behavior in stable sectors to different types of unbounded increase in critical and unstable regions. The latter lead respectively to a logarithmic and linear growth of the entanglement entropy with time. It is also shown that entanglement can be controlled by tuning the frequency, such that it can be increased, kept constant or returned to a vanishing value just with stepwise frequency variations. Exact analytic expressions for the entanglement entropy in the different dynamical regimes are provided.

19. Experimental implementation of an eight-dimensional Kochen-Specker set and observation of its connection with the Greenberger-Horne-Zeilinger theorem

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For eight-dimensional quantum systems there is a Kochen-Specker (KS) set of 40 quantum yes-no tets that is related to Greenberger-Horne-Zeilinger (GHZ) proof of Bell's theorem. Here we experimentally implement this KS set using an eight-dimensional Hilbert space spanned by the transverse momentum of single photons. We show that the experimental results of these tests violate a state-independent noncontextuality inequality. In addition, we show that, if the system is prepared in a state that is formally equivalent to a three-qubit GHZ state, then the results of a subset of 16 tests violate another noncontextuality inequality that is formally equivalent to the three-party Mermin's Bell inequality, but for single eight-dimensional quantum systems. These experimental results highlight the connection between quantum contextuality and nonlocality for eight-dimensional quantum systems.

20. Work as a POVM

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We present a new method to measure work and to efficiently sample its probability distribution with fixed precision. The method can be used to estimate free energies on a quantum computer. It is based on three facts: (*i*) The probability to detect work w in the state ρ is $P(w) = \mathrm{Tr}[\rho\, W(w)]$, where $W(w)$ are positive operators satisfying $\int dw\, W(w) = I$. As $W(w)$ define a POVM (positive operator valued measure), work measurement always reduces to a projective measurement performed at a single time on an enlarged system. (*ii*) Work can be estimated using a variant of the "phase estimation algorithm" which is such that work w is detected as the outcome of the single time measurement with probability $P(w)$. (*iii*) The efficient sampling of $P(w)$ can be combined with fluctuation theorems to estimate differences between the free energy of quantum states.

21. Study of the evolution of the spectral profile of light propagating in a resonant atomic vapor

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Radiation propagating in an atomic vapor can undergo several processes of absorption and emission before the photons leave the vapor volume. As a result of these scattering events, the spectral profile of the radiation evolves under frequency redistribution mechanisms, which can be divided into two types, Partial Frequency Redistribution (PFR) and Complete Frequency Redistribution (CFR). Any correlation between the incident and emission frequencies characterizes PFR. No correlation leads to CFR. The frequency redistribution in a resonant vapor originates in the inhomogeneity of the spectral profiles of the incident radiation and of the response of the resonant vapor. Moreover, this inhomogeneity also determines the distribution of the photons steps length in the atomic vapor. The photons propagation in the atomic medium consists in a random walk between successive processes of absorption and emission, with steps lengths r described by a long tail probability distribution $P(r)$. The superdiffusive behavior of the photons is characterized by $P(r)$ decaying asymptotically as a power law $P(r) \sim r$ light propagating in a thermal vapor of rubidium atoms excited around the frequency of the Rb D2 transition, and we analyze the exponent of the power law for the probability distribution of the lengths of individual steps of photons. Several configurations of typical (Voigt, Lorentz and Doppler) and engineered spectral profiles for the incident light and for the atomic absorption are explored.

22. Detuning-control of Exciton Entanglement in two Quantum Dots coupled to a Photonic Mode

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The dynamical evolution of the entanglement of a two-exciton system, each of them confined to a single quantum dot (QD), is studied. The excitons, assumed to be coupled to a single electromagnetic mode of a semiconductor cavity, interact between them through a dipole-dipole potential. We explain why resonant exciton configurations favor relatively long coherent times for some two-qubit (exciton) states, using a Tavis-Cummings Hamiltonian to describe the exciton-photon system. Additionally, we show that exciton entanglement can be manipulated using either Foerster direct exciton-exciton interaction or the electrical control of the cavity-QDs detuning. The effect of photon dissipation on the time evolution of entanglement, is discussed. We also assess the consequences of having disparate exciton-electromagnetic field coupling constants.

23. New definition of the polariton ladder operators leads to interesting detuning dependent effects.

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Dressed Statesor Polaritons have proved to be an important resource for quantum information, especially because this hybrid light-matter state sometimes simplify the time evolution of the system. For a many body systems, like a cavity QED array, we derive a different hopping energy for the polaritons. This is because a complete formulation of the ladder operators for these states is missing. In this work, we present a new de?nition for the polariton ladder operators, which satisfy the boson commutation relations, including transitions between higher levels beyond the ground and 1^{st} excited state. Finally, for a three cavity system, we show how this new insight can affect the entanglement and the Mott-Superfluid quantum phase transition.

24. Coherence and dephasing spectroscopy through single-photon absorption in molecular matter-wave interferometry

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Wave-particle duality and the superposition principle lie at the heart of quantum mechanics. Kapitza-Dirac-Talbot-Lau interferometry [1] enables us to probe these phenomena with the most massive matter waves to date [2]. High contrast interference has recently been seen with functionalized organic molecules with masses exceeding 10,000 amu and consisting of more than 800 atoms per particle. Despite the numerous internal degrees of freedom in these complex, many-body systems, and despite their many possible couplings to the environment, quantum coherence can be maintained and interference can be observed over mesoscopic times and distances. Inside our interferometer molecules interact with the standing wave of an intense laser beam, through their optical polarizabillity, to create a phase grating. At high laser powers some species can additionally absorb a photon from the grating and store it for a time exceeding that of the experiment. The photons in the standing light wave are in a superposition of momentum states which can be transferred to the absorbing molecules. The resulting interference patterns are extremely sensitive to the number of photons absorbed, which is on average much less than one per molecule. By implementing a time-of-flight technique to produce velocity resolved molecular interferograms we have observed the superposition of momentum states in the molecular density after diffraction. If molecules absorb light from an additional laser, instead of in the grating, the well-defined momentum kick dephases them with respect to the rest of the molecular ensemble. We can deliberately exploit this sensitivity to demonstrate decoherence spectroscopy. Here the absolute absorption cross section is determined by observing the reduction in fringe visibility under the influence of an additional probe laser[3]. This new kind of absorption spectroscopy does not require any prior knowledge of the vapour pressure and avoids many of the challenges related to photon cycling in fluorescence spectroscopy. We achieve a fractional uncertainty of 3% and expect this method to be particularly useful for large bio molecules where gas phase spectra are often poorly known.

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25. Entanglement between cavity and detector in Dynamical Casimir Effect

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We study the effect of the parametric amplification in the entanglement dynamics in the context of photon generation due the so called Dynamical Casimir Effect (DCE). For this purpose we consider a coupled quantum system describing the interaction between a photon detector and a field mode in a quantum cavity modelled by two coupled quantum harmonic oscillators when the frequency of one of them (describing the field mode) is modulated at exactly twice the unperturbed eigenfrequency (the case of 'unshifted resonance'). This model appears as the simplest one associated with the MIR experiment where generated photons can be detected by means of an inductive loop in the antenna inside the cavity. By neglecting the dissipation in the cavity wall, we analyze both case of an ideal antenna described by a LC-circuit and a damped one modeled by a LRC-circuit. We exactly solve the dynamics for the LC-circuit with the aid of the method of multiple scales in the framework of quantum invariant for initial Gaussian states. We have the parameters ϵ as the amplitude of the cavity frequency modulation and ξ meaning the cavity-detector coupling strength. In the case of LRC-circuit we use the approach for the standard master equation which can be reduced to an explicit time independent form by means of some canonical transformation removing fast oscillations with an additional parameter γ representing the detector damping coefficient. This simplification allows us to determine exact explicit analytical solutions of the dynamical equations and determine precisely the entanglement behavior in time by means of the so called 'logarithmic negativity'. We suppose the field and detector mode initially in thermal states with different temperatures and analyse the entanglement dynamics depending on the relative strength of coupling coefficient and the parametric modulation amplitude $\alpha = \xi/\epsilon$ as well as on the damping rate γ. We find the conditions on the parameters of the initial thermal states and on the coupled system when initially separable states can go to permanently entangled states. In the case of LRC antenna, partial results indicate that we can choose appropriated values of damping coefficient that imply in a regime of stationary entanglement between the cavity mode and detector verified the condition $\alpha < 1$. In the regime $\alpha > 1$ the undamped detector model shows periodical appearance and disappearance of entanglement. We did not find any correlation between the entanglement measures and the mean energies of the modes.

26. Driving at the maximal speed limit with dynamic Landau-Zener Hamiltonians

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The geometry of the space of quantum states imposes limits on the interval of time that is necessary for changing the configuration of a quantum system. The total interval of time is a function of the quantum process that generates the dynamical evolution of the quantum system. The determination of optimal trajectories that minimize the interval of time of driving, subject to some constraints, is a challenging task in the field of optimal quantum control. The non-triviality arises mainly because of the connection between the velocity of the evolution and the path that are both generated by quantum processes. It may imply that the fastest route is not given by a geodesic trajectory. We show a variational approach that allows us to find optimal trajectories, which minimize the total time of evolution, for dynamical processes generated by Landau-Zener Hamiltonians acting in two-level quantum systems. Our approach provides the possibility of avoiding some trajectories for calculating the total time of evolution in the regime of constrained energy, and does not require the formal solution of the equations of movement. Also the expression for total time of evolution, in the regime of unconstrained energy, emerges naturally from our results. Furthermore, we show general and necessary conditions such that the optimal control function is given through or the bang-off-bang strategy or the bang-bang strategy, generalizing previous results in the literature. We present examples that the best strategy is neither given by the bang-off-bang strategy nor by the bang-bang strategy. These last results, interestingly, were not captured previously in numerical calculations.

27. Post-selection induced Entanglement is at the origin of the quantum Cheshire cat

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Recently, it has been proposed that a quantum system and its physical properties may, in some sense, be witnessed jointly at different locations, as the grin of the Cheshire cat could be seen by Alice even in absence of the cat itself. Here, it is argued that this phenomenon is a consequence of entanglement between the meters, detecting respectively the particle and its property, induced by both preparing and post-selecting the quantum system in a coherent superposition of states present at both locations.

28. Initial entanglement between detectors allows violating Heisenberg's uncertainty relations

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Physics textbooks introduce an inequality derived by Kennard that concerns the impossibility of preparing a quantum state with well defined momentum and position. However, Heisenberg had formulated two different inequalities: one stating the impossibility of a simultaneous detection of position and momentum with arbitrary precision, and another one imposing a tradeoff between the precision on the measurement of a variable and the backaction on a subsequent measurement of a conjugated variable. Here, we explore the connections among these three inequalities, and we show that the latter can be violated, if the detectors are initially entangled. The results, besides being of fundamental interest, can be useful for building up an ideal momentum, or position, detector (i.e. one that introduces no noise in the measurement, besides the intrinsic statistical noise of the input state).

29. Irreversible decoherence of dipole interacting nuclear spins coupled with a phonon bath

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We report a theoretical derivation of the adiabatic decoherence process, when the microscopic observed system is a chain of dipole coupled nuclear spins considered as an open quantum system in contact with a bosonic heat bath. The model is inspired on an experimentally accessible problem: the irreversible attenuation of coherences in solid state Nuclear Magnetic Resonance experiments. Nuclear spins are valuable for observing the time scale in which the phase factors of the quantum state have not yet dissapeared, allowing the experimenter to monitor the whole process which leads an arbitrary coherent initial state to a thermalized form. Particularly we are interested on samples where the spins of the observed species display an anisotropic dipolar network, like in crystalline hydrated salts. These systems are shown to reach quasi-equilibrium states (QE), long before thermal equilibrium. Formally, these states can be represented by a reduced density operator diagonal-in-blocks in the eigenbasis of the spin-environment Hamiltonian. The aim of this work is to inquire if the spin-boson interaction mediated by dipole couplings can act as an effective source of decoherence, able to bring an out-of-equilibrium system of weakly coupled pairs to a diagonal QE state, without energy exchange with the lattice. The strategy is based on calculating the exact quantum dynamics of an initial state of the observed system to derive the adiabatic decoherence function of this model. In order to confront with the experiment we estimate the characteristic times of decoherence under different scenarios of the dipolar network. We find that some of them yield decoherence time scales consistent with NMR experiments. Besides, we corroborate that the measured decoherence rate is parameterized by the eigenvalues of the spin part of the interaction Hamiltonian.

30. Quantum emission and control on circuit cavity electrodynamics

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Superconducting circuits made of Josephson junctions coupled to resonators are promising candidates for developing strong and ultra-strong interacting quantum electrodynamics devices since their fabrication is more reliable than in the quantum dot micro-cavity system (semiconductor analogue), and also the coupling strength reached is almost three magnitude orders greater. They are mainly used in the development of one atom radio-frequency lasers and in the quantum information processing/transmission, due their remarkable dynamical properties. Here, we present a simple effective model, according with the microscopic BCS model, that describes the interaction between Josephson junctions (superconducting qubit) and a coplanar waveguide resonator. Besides, the open quantum system is studied with the Lindblad master equation approach, and it is accomplished optical control of the emission and dynamical properties of the system.

31. One atom laser via phonon assisted cavity feeding

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We analyse theoretically the possibility to achieve no threshold lasing in a microcavity with a single quantum dot, incoherently pumped, without a direct coherent coupling between them. Instead, population is incoherently transferred from the dot to an off-resonance cavity mode via phonon-assisted cavity feeding. We find a Poissonian distribution for the cavity photon number with a high average population and narrowing of the cavity spectral line which indeed evidence a coherence build-up. Such properties are developed for sufficiently high dot excitation, when the phonon emission process is more efficient than the cavity decay. The system regimes (quantum, thermal, lasing), are contrasted with the usual one-emitter laser in the strong coupling regime. We solve the full quantum master equation of the system but also simple rate equations that provide some analytical insights.

32. Effects of the one-photon and two-photon cavity losses on quantum correlations of two-qubit system

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We study a system composed by a cavity with two atoms (qubits) which can absorb or emit pairs of correlated photons. This atom-field interaction is achieved when the one-photon transitions in the atoms are forbidden by the selection rule, and the cavity stimulate the two-photon processes. The photon pairs are correlated in frequency and this correlation is expected to have influence on the atom-atom Entanglement, Quantum Discord, and Geometric Discord. Our aim is to study the mechanisms of the correlation sharing. Hence, in this model we put special interest in the effect of the cavity losses on the transference of quantum correlations from the photon pairs to the atoms. As it is shown in literature, the nonlinear losses in a quantum system can have a positive effect on the correlations and to go further in the understanding of this effect, we investigate three different types of losses occurring by single photons, pairs of photons or both. We expect some losses to enhance correlations, while others should have a negative effect on them. The engineering of the losses could be a very efficient tool in diverse applications, where for example the generation, transmission and distribution of the quantum correlations are necessary.

33. Many-particle entanglement and phase coherence in mesoscopic Bose-Einstein condensates

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Atomic Bose-Einstein condensates (BECs) are highly controllable isolated quantum systems with long coherence times, and offer applications to metrology and quantum information processing. We experimentally prepare non- classical many-body spin states, analyze them by tomographic state reconstruction, and study their decoherence dynamics. Our system consists of a two-component Rubidium-87 Bose-Einstein condensate, consisting of a few hundred atoms, created on an atom-chip [1]. A state-selective potential tunes the collisional interactions (one-axis twisting dynamics [2]), which allows us to prepare many-particle entangled states [3]. We present our recent results on the preparation of strongly oversqueezed states. In finite-temperature BECs, interactions with the non-condensed fraction intrinsically limit the phase coherence [4]. We experimentally study these fundamental limits by performing Ramsey spectroscopy with BECs of different temperature and densities.

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34. Quantum friction: a microscopic approach based on the effective action

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We use a functional approach in Minkowski space to study the dissipative effects due to relative parallel motion of two flat, parallel, imperfect mirrors in vacuum. The integration over the mirrors' degrees of freedom results in a nonlocal term in the vacuum field effective action. The presence of quantum friction strongly depends on the analytical structure of this nonlocal term. In particular, we propose a simple model for the microscopic degrees of freedom on the plates, conformed by a set of uncoupled quantum harmonic oscillators, coupled to a scalar vacuum field, and we show explicitly that there is a nonvanishing frictional force, that depends on the parameters of the system.

35. Quantum vampire: action at a distance of the photon annihilation operator

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We consider a situation in which the photon annihilation operator is applied to an optical mode that has a partial overlap with another mode prepared in a certain optical state. For example, a single photon is extracted from a laser beam by a cloud of weakly absorbing atoms occupying only a part of the beam's cross-section. Surprisingly, such intervention will not create any 'shadow' in the beam. The energy will be drawn out of the whole mode, leaving its spatial and temporal structure undisturbed, regardless of the mode to which the annihilation operator is applied. In the experiment, we demonstrate the above effect in application to the 1- and 2-photon Fock states of an optical field, distributed over the two arms of the Mach-Zehnder interferometer. When photon annihilation is realized in one of its arms, it affects the quantum state in the other arm – so that, when recombined at the output of the interferometer, the resulting state is, respectively, a pure 0- or 1-photon Fock state. We verify this experimentally via homodyne tomography. The phenomenon of non-locality is known since early days of quantum mechanics. However, the only quantum operator whose nonlocal action has been tested to date, has been the projection (measurement) operator. Our results show that the photon annihilation operator is capable of quantum action-at-a-distance as well one remarkable feature of this action is teleportation of energy between parties of an entangled optical state.

36. Quantum Drift Model for Decoherence in Dynamical Transport: a wave function approach.

Lucas Fernández

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We develop and implement a model for including decoherent processes in the quantum dynamics underlying time-dependent transport. The model is inspired in a dynamical formulation of the Landauer-Büttiker equations and boils down into a form of wave function that undergoes a smooth stochastic drift. Thus, decoherence arises from a random perturbation of the environment in a local basis. This is, by construction, more efficient than density matrix approaches. Using numerical calculations, we probe the equivalence among our dynamical model and the decoherent steady state transport through the resonant state $|0\rangle$ of a quantum dot that undergoes decoherence through contact with a voltage probe. We also apply this model to a two level system (TLS) that oscillates among $|0\rangle \equiv |\uparrow\downarrow\rangle$ and $|1\rangle \equiv |\downarrow\uparrow\rangle$. We show that our model recovers not only the exponential damping of the oscillations in the low perturbation regime, but also the bifurcation of the decoherence rates at a critical perturbation. Thus, our Quantum Drift model is able to show the quantum dynamical phase transition produced by the interaction with the environment. We perform Loschmidt echo (LE) calculations to evaluate the decoherence in the TLS. We find that the pure states $|0\rangle \equiv |\uparrow\downarrow\rangle$ and $|1\rangle \equiv |\downarrow\uparrow\rangle$ are quite robust against the local perturbation. In contrast, the LE decays faster when the system is in a superposition state $(|\uparrow\downarrow\rangle \pm |\downarrow\uparrow\rangle)/\sqrt{2}$. These results are in agreement with the general trend recently observed in spin systems through NMR.

37. Interface between path and OAM entanglement for high-dimensional photonic quantum information

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Path encoding on integrated optical quantum circuits offer a way to scale the complexity of the setup as well as the dimensionality of the quantum state. To distribute high-dimensional quantum states over large distances, transverse spatial modes, like orbital angular momentum (OAM) possessing Laguerre Gauss modes, might be used as flying information carriers. We create three-dimensional path entanglement between two photons in a non-linear crystal and use a mode sorter as the quantum interface to transfer the entanglement to the OAM degree of freedom. Thus our results pave the way to implement broad complex quantum networks where high-dimensionally entangled states could be distributed over distant photonic chips.

38. Device-Independent Certification of High-Dimensional Quantum Systems

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An important problem in quantum information processing is the certification of the dimension of quantum systems without making assumptions about the devices used to prepare and measure them, that is, in a device-independent manner. A crucial question is whether such certification is experimentally feasible for high-dimensional quantum systems. Here we experimentally witness in a device-independent manner the generation of six-dimensional quantum systems encoded in the orbital angular momentum of single photons and show that the same method can be scaled, at least, up to dimension 13.

39. Open harmonic networks and the cubic eigenvalue problem

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Several approximations are commonly applied in order to study the dynamics and thermodynamics of open quantum systems, for example the weak coupling and the Markovian aproximations. Here we present a method to solve the dynamics and asymptotic state of an arbitrary network of quantum harmonic oscillators coupled linearly to a number of thermal baths with Ohmic spectral densities. This new method is based on an analytic expression for the exact non-equilibrium Green's function of the open system in terms of the eigenvalues and eigenvectors of a cubic eigenvalue problem, and enables us to study phenomena well beyond the weak coupling or Markovian approximations.

40. Experimental sequential discrimination of quantum states for multi-party communications

Pablo Gonzaléz

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The fact that two non-orthogonal states cannot be always perfectly distinguishable can be exploited for quantum communications and quantum cryptography. A recent strategy named Sequential State Discrimination [Phys. Rev. Lett. **111**, 100501 (2013)] proposed an alternative protocol for quantum communications: Alice delivers a qubit whose state can be one from a set of two nonorthogonal states and the aim is to send information to two different parties through this qubit resorting to neither classical communication among them nor additional qubits. In this work, we show an experimental proof-of-principle of this protocol using freedom degrees of single-photons. Sequential measurements were successfully performed and a fair agreement between theory and experiment was achieved.

41. Tunable photon statistics: a new approach for mixed light consisting of semiconductor-based ultra-broadband amplified spontaneous emission and coherent laser light

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We demonstrate experimentally the tunability of the photon statistics via mixing light from a single-mode laser diode with that from a superluminescent diode which exhibits an ultra-broadband optical spectrum originating from amplified spontaneous emission. By exploiting a recently demonstrated second-order correlation measurement technique we are able to resolve second order correlations $g_2(\tau)$ on the corresponding ultrashort timescales. Our results unveil for the first time the continuous change from Poissonian to Bose-Einstein statistics for this spectrally ultra-broadband mixed light. We support our experimental findings with a theoretical model for the second order coherence of a superposition of highly multimode Gaussian light states and a coherent light state.

42. Quantum and Classical Nonlinear Optics in Waveguides in the Presence of Scattering Loss

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While quantum field theory is required to fully explain the interaction of light with matter, the standard description of nonlinear optical interactions is grounded in classical electromagnetic theory. For example, sum frequency generation can be thought of as a kind of photon fusion, which proceeds efficiently if the momenta of the three photons involved are appropriately matched, but it is more commonly thought of as a three-wave mixing process for which phase matching is required to be efficient. In fact, a deep connection between the two pictures allows us to interpret quantum nonlinear optical processes as the spontaneous counterparts of corresponding stimulated (or classical) nonlinear optical processes. It has previously been shown theoretically that a difference frequency generation (DFG) experiment enables a prediction of the efficiency of a spontaneous parametric downconversion (SPDC) experiment in the same device [1]. Furthermore, the biphoton wave function [2] associated with photon pairs generated via SPDC is, in fact, also the response function for a generated DFG signal due to input pump and idler pulses [3]. However, these results have relied on calculations performed in the limit of no photon loss, and it is not known that they will remain valid if waveguide sidewall roughness were included. Such roughness is inherent in current waveguide fabrication processes and leads to scattering loss, often the largest source of loss in modern integrated waveguides [4]. Yet, as experiments have already proven some of these results [5,6], it would be distressing if a close link between quantum and classical nonlinear optical processes did not persist in the presence of loss. In this work we extend the initial theory to include scattering loss, and demonstrate that a strong connection exists between quantum and classical nonlinear optical waveguides whether scattering loss is present or not. We further show that the lossless biphoton wave function is modified by the inclusion of loss, and that these modifications have implications for time-energy entanglement as characterised by the Schmidt number, K [7]. In particular, large losses at the second harmonic but not the second fundamental frequency tend to reduce the expected (lossless) frequency correlations and therefore increase heralded photon purity, and low-loss features at the fundamental frequency may provide a new pathway to engineering frequency correlations.

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43. Long coherence times for Rydberg qubits on a superconcducting atom chip

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Rydberg atoms and superconducting cavities are remarkable tools for the exploration of basic quantum phenomena and of quantum information processing. These giant atoms are blessed with remarkable properties. They undergo a distance-dependent strong dipole-dipole interaction that gives rise to the dipole blockade mechanism. In the Van der Waals regime, this energy shift scales as n11, where n is the principal quantum number. By tuning the excitation laser at the frequency of the isolated atomic transition, we expect to excite at most one atom within a blockade volume of $\sim (8\ \mu\mathrm{m})^3$, provided that the atomic line is not widened by laser noise or stray inhomogeneous electric fields. In order to assess these stray fields, we work with a small cloud of ground state Rubidium 87 atoms magnetically trapped in a superconducting atom-chip at 4K. Once a Rydberg atom has been excited to our target state —60S1/2¿ we explore the narrow millimeter-wave transitions between Rydberg. With a front gold surface for the chip, we observe as other groups large field gradients due to deposited rubidium atoms. We have circumvented this problem by coating the chip with a metallic rubidium layer. The gradients are an order of magnitude smaller. This improvement allowed us to observe extremely high coherence times, in the millisecond range, for Rydberg atoms near a superconducting atom.

44. Classicalization and Lyapunov Exponents

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There has been much speculation about the possibility of classicalization of a quantum system through a time-dependent Hamiltonian. It is known that it is no possible to increase the system's entropy using a purely Hamiltonian evolution. However, if we have two coupled systems, entropy of just one of them would increase. In fact, coupled systems, governed by quadratic systems, have been found in which the classicalization actually occurs. In particular, it has been observed that in these systems classicalization seems to be related to Lyapunov exponents, found by solving classical dynamics. The objective of this work is to study the possible relationship between classicalization and Lyapunov exponents in the light of some particular cases.

45. Smallest set for non-Markovian dynamics in collisional models

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The dynamics of open quantum systems is characterized for continuous Markov processes in terms of master equations in the so-called Lindblad form. However, the required assumption of a memoryless environment is in reality, in most of the cases, an approximation. In general, the environment presents memory effects that may lead to non-Markovian dynamics. Understanding these effects is an important fundamental question with potential applications in the engineering of reservoirs for quantum computation and as a resource for quantum information processing such as quantum key distribution, quantum metrology, quantum teleportation, and quantum communication. We present in this work a new collisional model for the study of open quantum systems [1]. The smallest set of requirements for inducing non-Markovian dynamics in this model is investigated. This is done by introducing correlations in the state of the environment and analyzing the divisibility of the quantum maps from consecutive time steps. Our model and results serve as a platform for the microscopic study of non-Markovian behavior as well as an example of a simple scenario of non-Markovianity with purely contractive maps, i.e. with no back-flow of information between system and environment.

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46. Wigner-Yanase skew information in quantum critical spin chains

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We study the quantum coherence and the local quantum uncertainty, based on Wigner-Yanase skew information, in the thermal ground state of the anisotropic spin-1/2 XY chain in transverse magnetic field. Our results demonstrate that adopting the skew information as a figure of merit provides us the necessary information to reveal the occurrence of the second order phase transition and the completely factorized ground state in the XY chain in transverse field. We discuss the consequences of a simplification in the definition of the coherence measure, which is employed to make it experimentally accessible, in the context of the examined model. Furthermore, we demonstrate how the connection between the appearance of non-analyticities in the ground state correlations and the quantum phase transitions does not hold in general, by providing clear examples of the situation. Lastly, we discuss the ability of the coherence measure to accurately estimate the critical point of the phase transition, and explore the robustness of the factorization phenomena at sufficiently low temperatures.

47. Noisy Quantum Teleportation

Laura Knoll

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We present the experimental results of the influence of quantum noise on a photonic implementation of the quantum teleportation algorithm, where we use a pair of polarization entangled photons as quantum resource and we encode the state to be teleported in the phase or linear momentum of one of the photons. The arrangement designed allows us to prepare and teleport any state on the Bloch sphere with fidelities above 90%, with a resolution of the degree of mixture given by the coherence length of the photon pair. We study the interaction of the system with noisy environments adding an amplitude damping channel and a phase damping channel over each photon path. In particular, we study the fidelity of teleportation over a controlled environment.

48. Generation and confirmation of a (100×100)-dimensional entangled quantum system

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Entangled quantum systems have properties that have fundamentally overthrown the classical worldview. By increasing the size of the entangled quantum system, a wider variety of fundamental tests as well as more realistic applications can be performed. The size of the entangled quantum state can increase with the number of particles or, as it will be presented here, with the number of involved dimensions. We explore a quantum system that consists of two photons which are 100-dimensionally entangled, using spatial modes of photons. For its verification we develop a novel nonlinear criterion which infers entanglement dimensionality of a global state by using only information about its subspace correlations. This allows very practical experimental implementation as well as highly efficient extraction of entanglement dimensionality information. The result may have potential applications in quantum cryptography and other quantum information tasks.

49. Synchronizing Photons with a Binary Division Strategy

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We present a scheme to produce clock synchronized photons from a single parametric downconversion source with a binary division strategy. The time dierence between a clock and detections of the herald photons determine the amount of delay that must be imposed to a photon by actively switching different temporal segments, so that all photons emerge from the output with their wavepackets temporally synchronized with the temporal reference. We extend this scheme to the production of many synchronized photons and find expressions for the optimal amount of correction stages as a function of the pair generation rate and the target coherence time. For multiple photon generation at an optimized input photon rate, the output rate of our scheme scales essentially with the reciprocal of the number of photons produced, which is an improvement on the inherent exponential scaling of multi-photon parametric downconversion.

50. Solitons in PT-symmetric nonlinear dissipative gratings

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We investigate the solitary behavior in PT-symmetric dissipative gratings with periodic spatial modulation of gain/loss coefficient which is described by a set of time-dependent Schrodinger equations. At the same time, the effects of periodic coupled coefficients are also analyzed. In order to analyze the stability of soliton solutions, variational approximation and numerical simulation are adopted. Our results show that oscillatory and standard solitons can propagate stably in these systems over a wild range of modulation parameters. It is interested that there exists a wider parameter region for the case with periodic coupled coefficients.

51. Quantum limit for estimation of weak classical forces via a noisy harmonic oscillator.

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With the development of technologies and experiments designed to get deeper into the fundings of physics, the needs of high precision parameter estimation protocol are each time more pressing. The limits of precision imposed by quantum mechanics are still being questioned, and the influence of the noise is an important feature difficult to take into account. A related problem is to find out a precise experimental protocol able to reach these limits, which includes the initial state of the probe and the measurement procedure. In this work [1], we establish an exact analytical expression for the quantum limit to the precision estimation of weak classical force probed by an harmonic oscillator, taking into account a Markovian source of noise. This expression shows the interplay between the quantum enhancement and the thermal noise, corresponding to the transition between the so-called Heisenberg limit and the shot-noise (classical limit). In order to reduce the disturbance due to the thermal noise, we investigate the precision limit reached by sequential measurement. We show that in the regime of rapid sequential measurement (assuming reinitialization of the probe state between each measurement), the same precision limit as the one given by continuous measurement [2] is reached. Further more, we show that the initial state of the probe that yields the best estimation precision of the force amplitude is a squeezed state. This work applies directly to pulsed optomechnics [3] and could find applications in gravitational wave detection, atomic force microscopy, and experiments or devices designed to detect weak forces, etc...

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52. A fiber-based and polarization encoded Quantum Key Distribution practical device

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We present the characterization and performance of a polarization stabilization scheme for a fiber-based Quantum Key Distribution device. The setup is based on two commercial electro-optic polarization controllers and a detection scheme prepared to work within a classical (intense light) or photon counting regime. We show how to control the state of polarization of light, in particular we demonstrate a method to generate the set of polarization states that defines two MUBs needed for a standard BB84 protocol. In practical fiber implementations of QKD the sender (Alice) and receiver (Bob) are typically separated by kilometer distances. Due to unavoidable external perturbations, the rotation induced by the fiber connecting the parties varies randomly with time. Therefore, a mismatch between the input and output states of polarization naturally arises. The channel is stabilized by maximizing the overlap between the emitted and detected states. The optimization process is implemented with Arduino

microcontrollers and additional 12-bit Digital to Analog converters. The performance of the device is evaluated by forcing sudden changes of the polarization on the fiber spool that connects the sender and receiver stations.

53. Low cost ECDL and control toolkit for Rb hyperfine interaction

Marcelo Luda

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High coherence tunable laser are a fundamental tool for several techniques used often on atomic physics, laser spectroscopy and quantum optics. Most of these techniques include mode-hop-free frequency tunning, locking laser to hyperfine transition frequency and laser cooling on MOTs devices. In this work we present an ECDL built from low cost components and from a diode laser extracted from a CD-RW, suitable for Rb hyperfine interaction. Frequency selectivity is obtained with a diffraction grating feedback, which is mounted on a piezoelectric transducer (PZT) for position/angle control, and controlling diode temperature and current supply. We developed specific electronic circuits for current, temperature and PZT drivers, which are controlled from an Ardunio microcontroller connected to a PC. The simultaneous tunning of these three variables enabled the possibility to make large mode-hop-free frequency tunning (∼40 GHz) on frequencies near the Rb 5^2 $P_{3/2} \rightarrow 5^2$ $S_{1/2}$ transition (780 ± 2 nm). This toolkit was tested on a saturated absorption spectroscopy setup used to measure the hyperfine structure of 85,87Rb. We used a Rb vapor cell with natural isotope abundance (70% 85Rb - 30% 87Rb) for analysis. The spectra acquired let us estimate the isotope composition and identify all the hyperfine transitions of the D2-line and the cross-over peaks. Also, we tested an algorithm for digital locking to one of the spectra peaks and could reach frequency stabilization around 40 MHz line-width.

54. A three-particle, three-dimensonal GHZ state using twisted photons

Mehul Malik

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Initially proposed as a two-particle problem, the concept of entanglement was extended to three particles by Greenberger, Horne, and Zeilinger in 1989. Commonly referred to as GHZ states, these entangled multipartite systems have allowed for a non-statistical, all or nothing violation of local realism. To date, experimental realizations of GHZ states have been limited to two dimensions due to the use of polarization-entangled photons. Alternatively, the orbital angular momentum (OAM) of photons offers a discrete, infinite-dimensional Hilbert space. Many recent techniques have been developed to manipulate the OAM of light in a manner similar to that of polarization. We describe an experiment that uses these techniques to realize a three-dimensional, three-particle GHZ state using the OAM photonic degree of freedom. In this talk, I will present recent progress our group has made towards achieving this goal.

55. Correlation spectroscopy in Cold Atoms: Dynamical regime and detecting sidebands-carrier correlation in EIT condition

Hans Marin Florez

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In this work we explore the features of the correlation spectroscopy between two noisy lasers under electromagnetically induced transparency condition in cold Rubidium atoms, for different one-photon detuning of the Λ configuration. We report the dynamical regime of the correlation when the one-photon detuning of the Λ system is resonant to the atomic transition. In such regime an hysteresis effect in the correlation profile was observed with respect to the two-photon detuning between the two light fields. The time scale on which the correlation reaches the steady condition is ∼ 100 times slower than the one in conventional theoretical prediction for a three level system. Considering optical pumping with different levels, a five-level atomic system was proposed to describe our system. Also we explore the correlation spectroscopy for different values of one-photon detuning. Since our detection system is in the frequency domain, we show that for one-photon detuning of the order of the natural linewidth, the sideband-carrier correlation is spectrally independent from the carrier-carrier correlation. Moreover, the steep profile of the correlation induced by the atomic medium under non-zero one-photon detuning suggests that the correlation between two fields can be controlled by switching the two-photon detuning between the fields. The theoretical model based on a three-level system in Λ configuration, is enough to describe the spectral independence of the sideband-carrier correlation and the steep correlation profile as well.

56. Scalable Source of Multipartite Continuous Variable Entangled Beams of Light

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The development of efficient and scalable sources of multipartite entanglement is required for the further development of quantum information. We propose a scalable configuration based on cascaded four-wave mixing (FWM) processes for the generation of multipartite CV entanglement. The FWM process is based on a double-lambda configuration in rubidium vapor and has been previously used to generate highly entangled twin beams. In the proposed configuration, one of the twin beams is used to seed another FWM process. We have experimentally verified that two cascaded FWM processes lead to the generation of three beams that contain quantum correlations in the form of intensity-difference squeezing and show that the level of squeezing produced by the first FWM process is increased by the second one. We derive a necessary criterion for the presence of multipartite entanglement that shows that one should expect the beams generated by the cascaded FWM processes to be entangled even in the presence of losses.

57. Quantum computations on a topologically encoded qubit

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The construction of a quantum computer remains a fundamental scientific and technological challenge because of the influence of unavoidable noise. Quantum states and operations can be protected from errors through the use of protocols for quantum computing with faulty components. We present a quantum error-correcting code in which one qubit is encoded in entangled states distributed over seven trapped-ion qubits. The code can detect one bit flip error, one phase flip error, or a combined error of both, regardless on which of the qubits they occur. We applied sequences of gate operations on the encoded qubit to explore its computational capabilities. This seven-qubit code represents a fully functional instance of a topologically encoded qubit, or color code, and opens a route toward fault-tolerant quantum computing.

58. Estimating Quantum Correlations in Dimerized Spin Systems Through a Correlated Mean Field Approach

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In many-body physics, the Mean Field Theory (MFT) provides an intuitive starting point for the evaluation of local observables and some correlations. When systems develop just weak quantum correlations, a linear response theory built over this approximation allows us to recover many of the main features of their quantum correlations. However, due the fact that the approximation is based on fully factorized states, this method is not able to deal with systems which develop a large amount of entanglement among its components. In this contribution we shall employ a Correlated Mean Field scheme to study quantum correlations for the case of systems which presents strong but localized quantum correlations. Applications to the estimation of pairwise, bipartite and multipartite entanglement in the zig-zag ladders and other dimerized chains are discussed. Besides, analytical results from both a linear response theory and a perturbative approach over this correlated mean field state are presented, as well as their comparison with numerical results.

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59. Continuous-Variable Bicolor Entanglement for Quantum Teleportation

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Bicolor quantum teleportation emerges in the context of quantum communication as a powerful technique to link e.g. two quantum systems constituting a quantum computer and interacting with different optical wavelengths. Sending the quantum state of a beam at a given wavelength to a beam at another wavelength through teleportation requires a bicolor entangled state. In this work, we report the generation of such a state using a doubly-resonant, frequency-non-degenerate optical parametric oscillator operating above threshold. A complete characterization of the state is achieved via a resonator-detection scheme.

60. Quantum Characterizations of Photon Number Resolving Detectors

Griselda Mingolla

INTI.

Single-Photon detectors are a fundamental tool in many different fields of optical science and technology such as quantum metrology (e.g. redefinition of the SI candela unit), quantum imaging and quantum information. Unfortunately, most conventional (commercial) single-photon detectors can only distinguish between zero photons detected ("no-click") and one or more photons detected ("click"), thus they are not photon-number-resolving (PNR). In this case the PNR-ability can be obtained by spatially or temporally multiplexing this kind of on/off detectors. The most promising true PNR detectors (i.e. detectors intrinsically able to produce a pulse proportional to the number of absorbed photons) are the visible light photon counters and transition edge sensors. For a practical application of these detectors it is crucial to achieve precise characterization of both this kind of PNR detectors. We present some innovative measurement techniques providing the full characterization of the detection process. Here, the detection process is represented by its POVM, thus these techniques realize the tomography of the POVM. One of the two techniques discussed exploits the photon number entanglement of a twin beam obtained from parametric down conversion, while the other one exploits the over-completeness of the coherent states.

61. Distributing entanglement with separable states

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Entanglement can be distributed without sending entanglement. The counterintuitive phenomenon that one can entangle two quantum systems by transmission of a third separable quantum system between them has been first recognized for qubits by T. S. Cubitt et al. [1]. We propose a continuous-variable analogy of the protocol working solely with Gaussian states and operations [2] and we demonstrate it experimentally [3] using Stokes polarization observables of light. The protocol is possible due to the existence of bipartite separable states, which can be turned into a delocalized entanglement shared by a sender and a receiver by a beam splitter on sender's part of the state. We further explore theoretically [4] and experimentally this property on a more simple class of states enabling a weaker form of entanglement distribution by a separable system. The states underlying the performance of the protocols are mixed, partially entangled, and they contain bound or nonlocalizable entanglement which are indispensable ingredients for the protocols to work. Our results thus demonstrate the applicability of quantum states with properties normally perceived as detrimental for quantum information processing.

62. A Rydberg Probe for Short-Range BEC Density Correlations

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We describe a scheme to measure short-range density correlations in the ground state of a Bose-Einstein condensate (BEC), by using a single electron confined in a highly excited Rydberg state as a probe. We demonstrate that such a device is sensitive to the anti-bunching of the BEC atoms at distances much smaller than the healing length. This behaviour has never been measured, despite its theoretical prediction more than 50 years ago. Interestingly, the existence of these correlations directly contradicts the standard Gross-Pitaevskii description of the BEC ground state as a static, coherent mean field, with all atoms condensed into the same single-particle orbital.

63. Engineered atom-light interactions in 1D photonic crystals

Juan Andrés Muniz

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The integration of ultracold atomic systems with nanoscale photonic crystal devices provides new tools for creating strong atom-photon interactions [1]. The photonic band structure of one-dimensional photonic crystal waveguides can be engineered for both stable trapping and strong atom-photon interactions [2], enabling novel cavity QED systems [3] and exploration of quantum many-body physics [4]. Achieving the desired atom-photon interactions require that we align the optical bands of the photonic crystal waveguides with selected atomic transitions. We present the experimental realization of a nanophotonic quantum interface based on a nanoscale photonic crystal waveguide, demonstrating that the atomic spontaneous emission rate into the guided mode represents a fractional value 0.32 ± 0.08 of the total decay rate in all other channels, a value unprecedented in all current atom-photon interfaces [5, 6]. We also discuss progress towards stable trapping of Cesium atoms within the nanophotonic structure and its possible experimental implications.

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64. Entanglement characteristics of few-particle trapped systems

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The recent progress in nanoscale technology made it possible to fabricate single quantum systems composed of a small number of interacting elements. Small clusters containing down to a few atoms or ions can be isolated in various kinds of electromagnetic or optical traps at ultracold temperatures. Another example are quasi-zero-dimensional semiconductor heterostructures known as quantum dots. The correlation effects that are crucial for determining the properties of such systems are well characterised by their entanglement content. I will review several entropic measures that are being used to quantify entanglement in few-body systems and discuss their behavior for simple models with harmonic confinement. Dependence on the number of constituents and the interaction strength will be studied in the case of contact and Coulombic inter-particle interactions.

65. Quantum memory based on electromagnetically induced transparency in optical cavities

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Here we studied a quantum memory based on the phenomenon of electromagnetically induced transparency in optical cavities. Our main goal was to study the mechanisms through which it is possible to optimize the efficiency and fidelity of the process. For this purpose we used two different approaches: a master equation formalism, traditional method for including dissipation in open quantum systems, and an input-output theory. We compared the results for when the input state is a weak coherent field and a single photon wave packet.

66. Optomechanical description of Dynamical Casimir effect

Belter Ernesto Ordaz Mendoza

University of Connecticut.

Dynamical Casimir Effect (DCE) is the reconstruction of the quantum state of field due to a time dependence of the geometrical configuration hence photons are generated due to interaction between vacuum fluctuations and time-dependent boundary conditions. In order to understand its effect in optomechanical systems, we consider a Fabry-Perot cavity with one heavy, fixed mirror and one light, movable mirror this is the simplest configuration in optomechanical setups. For adiabatically slow motion of the mirror no photons could be created, however for nonadiabatic regimes the coupling between the mirror and light field can become significant, therefore rapidly oscillating terms must be kept. These terms have been overlooked so far in the construction of the system Hamiltonian. Here starting with the nonadiabatic optomechanical Hamiltonian, we study the contribution of DCE on quadratically coupled optomechanical systems providing us with the basis for studying vacuum fluctuations in optomechanical steups this is a higher-order photon contribution in the Hamiltonian. Additionally, for and easy estimate we solve the equations of motion using linear stability analysis and numerical simulation of the master equation. Then we consider the quantum Langevin formalism for the full treatment and compare both results.

67. Eigenvalue density phases of a two dimensional quantum spin system

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For the first time we show evidence of both integrability together with an ergodic regime in which the correlation functions vanish, in 2 dimensional spin models. The correspondence with the spectral statistics is clear, and a distinct phases appear in the spectral density of the model. Large systems are studied using graphical cards, obtaining evolution speeds up to 240 faster. The details and the flexibility of such a model is discussed in some detail.

68. Spin conservation in bicircular high harmonic generation

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We study the generation of high-order harmonics by atoms driven by a pair of strong, counter-rotating, circularly polarized laser pulses at different frequencies, which were shown recently to produce circularly polarized harmonics in the XUV range using tabletop setups. This provides a sensitive probe for the conservation of spin angular momentum in high-harmonic generation (HHG), as the process can be understood as the transfer of energy and angular momentum between the drivers and the harmonics. To that end, we present a photon-exchange model of HHG as a parametric process which is consistent with experimental observations. Alternatively, the harmonic generation can be understood in terms of the classical trajectories of ionized electrons which recollide with their parent ions, and we investigate the conservation law in terms of these classical trajectories and their corresponding quantum orbits.

69. Proposed application of the neutral Nitrogen-Vacancy center in diamond as an optically controllable quantum light-matter interface

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It is proposed that the neutral Nitrogen-Vacancy center in diamond (NV0) could be used as an optically controllable quantum two-level system, as well as a broad-band, low-noise quantum-optical memory. Both applications are based on the Lambda-type three level system created between the two E orbital ground states and the A1 orbital excited state, and the cross-linear polarization selection rules obtained with the application of transverse electric field or uniaxial stress. It will be shown how existing diamond samples could be used for these applications.

70. Maximum population transfer in a periodically driven quantum system

Pablo Poggi

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We show that the evolution of a two-level quantum system in a sinusoidal driving field is remarkably regular for specific combinations of the field parameters. At these points, identified through analysis of the Floquet quasienergy spectrum, population transfer is optimal and takes place through a series of well defined steps of fixed duration. We also show how the corresponding evolution operator can be approximated at all times by a very simple analytical expression. Finally, we apply these results to designing a control protocol in a realistic molecular model, characterized by a complex multilevel structure.

71. Control of open quantum systems and the quantum speed limit

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Departamento de Física Juan José Giambiagi & IFIBA CONICET - UBA.

Unitary control and decoherence appear to be irreconcilable in quantum mechanics. When a quantum system interacts with an environment, control strategies usually fail due to decoherence. Recently, we propose a time-optimal unitary control protocol suitable for quantum open systems. The method is based on the succesive diabatic and sudden switch transitions in the avoided crossings of the energy spectra of the closed systems. We show that the speed of this control protocol meets the fundamental bounds imposed by the quantum speed limit, thus making this scheme ideal for application where decoherence needs to be avoided. We show that our method can achieve complex control strategies with high accuracy in open quantum systems.

72. Scalable Quantum State Engineering wit Trapped Ions

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Microstructured, segmented Paul traps offer the perspective to realize scalable quantum information protocols. This requires shuttling of trapped ion qubits within the trap structure. These shuttling operations have to be performed rapidly, but without significant excitation of motion. We demostrate shuttling of single ions at negligible energy transfer with a few trap oscillation cycles [1]. A more sophisiticated operation is the separation of trapped ions from a single-well to a double well-configuration. We point out why this process is substantially more difficult to control [2], and show results for separation of two ions within 80 microseconds at energy transfers of a few phonons [3]. We show how these operations can be combined with single- and two-qubit gate operations. In particular, we present results for the separation of entangled qubits, where a tomographical reconstruction of the quantum state is performed, where separation and shuttling operations provide the required single-qubit addressing. Additionally, we show results on the decoherence properties of physically separated entangled qubits.

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73. Time ordering effects in the generation of entangled photons using nonlinear optical processes

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We study the effects of time ordering in photon generation processes like spontaneous parametric down-conversion (SPDC) and four wave mixing (SFWM) and in photon conversion processes like frequency conversion (FC). We provide an intuitive picture that allows to predict when time ordering effects modify the joint spectral amplitude of the photons generated in SPDC and SFWM. These effects become important only when the photons generated in previous instants of time co propagate with the pump beam that travels through the non-linear material. This immediately implies that for sources of very entangled photons the effects of time ordering are negligible unless the nonlinearity takes extremely high values.

74. Quantum Interference of N photons in a Mach-Zehnder Interferometer

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Possible applications to quantum communications and quantum computing has motivated the study of the behavior of multi-photon quantum states in quantum information networks. A more general is to study the probability distribution of N phtons entering an optical communication network of N_i input ports and N_o output port. In this work we present a description of the interference of N photons on a Mach-Zhender interferometer through analyzing the probability as a function of the number of photons and the phase in one arm, as well as the density matrix and the average photon number standard deviation, in order to discern the type of statistics.

75. Properties and control of an hybrid qubit based on a double quantum dot.

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Since the original proposal of DiVincenzo and Loss [Phys. Rev. A **57**, 120 (1998)] to use the spin of an electron trapped in a quantum dot as qubit, a lot of work has been done to circumvent the huge difficulties associated to the implementation. One of the major problems associated to spin qubits is the long time required to implement quantum logical gates or other control operations. This is so because the low strength of the coupling between the spin and the external magnetic fields applied to the quantum dot. This low strength causes that the operation times are too long allowing that different coherence mechanisms change the state of interest. To solve such problem, i.e. to have shorter time operations, hybrid qubits have been proposed, so the information is effectively stored in the spin degrees of freedom, but the operations are implemented through the application of electric fields. In this poster, we analyze the performance of the hybrid qubit proposed by Tokura et al. [Phys. Rev. Lett. **96**, 047202 (2006)], which is based in a double quantum dot with external magnetic fields applied to it and driven by a time dependent electric field. To model the quantum dot we use the Effective Mass Approximation, with a quartic well potential. We considered the complete magnetic field dependence, in both the orbital and spinorial parts.

76. Non-Gaussianity for the two-photon spatial state of SPDC using Hermite-Gaussian pump beams

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One of the goals in the area of Quantum Information (QI) is to identify and develop quantum resources. All the knowledge that was obtained in the last years for the characterization, measurement and control of entanglement and non-locality is a good example of this effort. In this context, non-Gaussianity of states and operations has been considered a resource in the Continuous Variable (CV) domain, since it became clear that it is either necessary or desirable for a lot of tasks. A method to generate non-Gaussian quantum states is the non-linear optical process known as spontaneous parametric down-conversion (SPDC). Recently, the non-Gaussian feature of the two photon spatial state (TPSS) generated by SPDC was put in evidence [1, 2]. In this sense, since it was demonstrated that the spatial information of the pump laser field is transferred to TPSS [3], it is possible to prepare different non-Gaussian TPSS by the control of the angular spectrum of the laser field. Here, we present the quantification of the non-Gaussianity of a TPSS when the pump beam field that is used in the SPDC process is a Hermite-Gaussian (HG) mode. The measure that we use is based on a statistical quantity called negentropy. The measure of the non-Gaussianity is defined as the sum of negentropies for the far- and near-fields, and it is called total negentropy (nGT). This measure was recently introduced in [2] and was used to quantify the TPSS when the pump beam field is a Gaussian mode. It appears to be operationally practical, and experimentally accessible, since it can be obtained from the results of the measurements in two well-known geometries, which are largely used in experiments related to TPSS. In fact, while other non-Gaussian measures require the knowledge of the full density matrix [4], nGT only requires the knowledge of near and far-field joint probability distributions. The explicitly analytical expression for nGT was obtained and its behavior was compared with the non-Gaussian measure known as quantum relative entropy (QRE), showing the same behavior. Also, both quantities show dependence only on the shape of the pump beam, but not on the experimental parameters as the width of the laser profile, wave number of the pump beam and thickness of the crystal. Since QRE is becoming the standard quantifier of non-Gaussianity, those facts suggests that nGT is a good quantifier for the non-Gaussianity of a TPSS. Finally, as Hermite-Gaussian laser modes constitute a basis for describing any laser mode, our results can be used for the research of non-Gaussianity of the TPSS when Laguerre-Gaussian pump beams are used. (rebon@fisica.unlp.edu.ar).

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77. Theoretical study of the interaction between two polariton condensates in the presence of a magnetic field

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In this work we present the theoretical study of the interaction between two polariton condensates in the presence of a constant magnetic field. We take into account Coulomb's potential between electrons and holes, and the light matter interaction of the particles inside each condensate. Interaction between condensates takes into account only interaction with a single shared cavity electromagnetic mode. The effects of the magnetic field in the critical temperature and number of photons are determined, as well as the dependence of the latter on the number of polaritons.

78. Generalized conditional entropy in quantum systems

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We analyze, for a general concave entropic form, the conditional entropy of a quantum system A + B, obtained as a result of a local measurement on one of the systems (B). This quantity measures the average mixedness of A after such measurement, and its minimum over all local measurements is he associated entanglement of formation between A and a purifying third system C. In the case of the von Neumann entropy, this minimum determines also the quantum discord. For classically correlated states and mixtures of a pure state with the maximally mixed state, we show that the minimizing measurement can be determined analytically and is universal, i.e., the same for all concave forms. While these properties no longer hold for general states, we also show that in the special case of the linear entropy, an explicit expression for the associated conditional entropy can be obtained, whose minimum among projective measurements in a general qudit-qubit state can be determined analytically in terms of the largest eigenvalue of a 3×3 correlation matrix. Such minimum determines the maximum conditional purity of A, and the associated minimizing measurement is shown to be also universal in the vicinity of maximal mixedness. Results for X states, including reduced states of spin pairs in XY chains at weak and strong transverse fields, are also discussed.

79. Open Quantum System Approach for the Non-Equilibrium Casimir Effect

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We studied the fully non-equilibrium aspects of the Casimir force between real material boundaries. For this purpose, we employed the Schwinger-Keldysh formalism or closed time path (CTP) functional approach in an open quantum system framework, implementing the Feynman-Vernon influence functionals. Real media are modeled as continuous distributions of Brownian particles representing the polarization degrees of freedom (DOFs) in each point of space. Each DOF is both coupled to a local thermal bath through a linear coupling, and to the electromagnetic (EM) field through the appropriate real current-type coupling. We computed the coarse-graining effective action for the for the EM field, by tracing out the baths and the DOFs successively. Then, we finally integrated over the EM field to calculate the generating functional and computed the field correlation in a general inhomogeneous and anisotropic media, having arbitrary initial temperature states for the bath and DOF in each point of space and setting the field initially at a thermal state too. Therefore, we employed these results to study the non-equilibrium Casimir steady situation by solving the time evolution for the Lifshitz problem and obtaining the behavior, in the long-time limit, analitically.

80. Optimal Control of Effective Hamiltonians

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I will present a framework for optimization of quantum simulations by pulse shaping techniques, which relies on accurate treatment of driving-induced effective dynamics, together with suppression of undesired fluctuations. For polychromatic driving we provide analytic and numerical solutions which significantly improve the simulation of Raman transitions in the Lambda-like systems, and decrease the population of the excited states involved. [arXiv:1401.7446].

81. Image Formation and Angular Spectrum Transfer in Non-degenerate Stimulated Down-conversion

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It is known that the stimulated light beam produced in the process of stimulated parametric down-conversion carries some transverse propagation properties of the pump and auxiliary laser beams. In this work, we experimentally investigate the transfer of angular spectrum and image formation in stimulated down-conversion with nondegenerate twin beams, signal and idler. We use pump and auxiliary lasers at the wavelengths of λ_p=532nm and λ_a=1550nm, respecively, giving rise to a stimulated twin down-converted beam at λ_s=810nm. We chose these wavelengths as 1550nm because it is interesting from the point of view of telecomunications, whereas 810nm is a wavelength suitable for optical imaging applications. We observe phase conjugation and interference patterns that are transferred from the auxiliary to the stimulated down-converted beam. This transfer of information from the auxiliary to the stimulated beam allows us to use a 1550nm laser as illumination whereas the image or diffraction pattern is observed with an ordinary CCD camera that is able to detect the wavelength of the stimulated beam at 810nm.

82. Testing magnetic a decoherence-free subspace and its limits

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We present experimental results benchmarking the decoherence-free subspace formed by the ground magnetic Zeeman levels of two 40Ca+ ions. The odd entangled states of a pair of qubits can form a decoherence-free subspace if both qubits are close enough to fell the same external fluctuations. However, if the two physical systems carrying the qubits are far enough, they will no longer feel the same external fluctuations and the decoherence subspace breaks. We show how far this decoherence free subspace holds for the magnetic Zeeman sub-levels of two trapped calcium ions by bringing them apart in a segmented linear Paul trap. We do so by preparing different entangled states of an ion crystal which we then separate by distances from a few um to up to a few mm, wait and finally tomograph.

83. Projection operators in the theory of open quantum systems

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The variety of projection operators is considered for application to open quantum systems. Particularly, we study a formalism, which differs from the widespread Nakajima-Zwanzig projection operators and is based on the extremality of some functional, such as, the informational entropy. The master equations derived in this formalism are nonlinear and rigidly coupled to the chosen functional. The last feature allows to extract additional information from the dynamical equations, for example, to find an explicit form of the information entropy for an open system. All studied methods are illustrated by a simple open quantum system, namely, the damped harmonic oscillator.

84. Non-Gaussian state generation certified by the EPR-steering inequality

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Due to practical reasons, experimental and theoretical continuous-variable (CV) quantum information (QI) has been heavily based on Gaussian states. Nevertheless, many CV-QI protocols require the use of non-Gaussian states and operations. Here, we show that the Einstein-Podolsky-Rosen steering inequality can be used as a practical witness for the generation of pure bipartite non-Gaussian states. While the scenario require pure states, we show its broad relevance by reporting the experimental observation of the non-Gaussianity of the CV two-photon state generated in the process of spontaneous parametric down-conversion (SPDC). The observed non-Gaussianity is due only to the intrinsic phase-matching conditions of SPDC.

85. Observing non-equilibrium quantum thermodynamics features in a reliable way.

Roberto Serra

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Research on the out-of-equilibrium dynamics of quantum systems has so far produced important statements on the thermodynamics of small systems undergoing quantum mechanical evolutions. The Crooks and Jarzynski relations provide key examples. Taking into account fluctuations in non-equilibrium dynamics, such relations connect equilibrium properties of thermodynamic relevance with explicit non-equilibrium features. Although the experimental verification of such fundamental relations in the classical domain has encountered some success, their quantum mechanical version requires the assessment of the statistics of work performed by or onto an evolving quantum system, a step that has so far encountered considerable difficulties in its implementation due to the practical difficulty to perform reliable projective measurements of instantaneous energy states. By exploiting

a radical change in the characterization of the work distribution at the quantum level, we report the first experimental verification of the quantum Jarzynski identity and the Tasaki-Crooks relation following a quantum process implemented in a Nuclear Magnetic Resonance (NMR) system. Our experimental approach has enabled the full characterization of the out-of-equilibrium dynamics of a quantum spin in a statistically significant way, thus embodying a key step towards the grounding of quantum-systems thermodynamics. This approach is also applied to build and optimize a quantum thermal machine in a single molecule driven by fast field quenches. An NMR experimental implementation of such a quantum thermal machine will also be discussed.

86. Universal definition of Markovianity for open systems.

Ilya Sinayskiy

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A universal definition of Markovianity for the dynamics of open quantum and classical systems is proposed. The key to distinguish Markov and non-Markov processes is the comparison between measured correlation functions and those constructed from the results of quantum process tomography. The suggested definition is based on the fact that the knowledge of both the initial state of the system and the solution of the quantum master equation for the density matrix is not enough to fully characterize the system. Using examples of the spontaneous emission and pure dephasing it is shown explicitly that the proposed definition is essential for an adequate description of the typical observables. It is demonstrated that existing non-Markovianity measures based on the analysis of the properties of dynamical maps lead to inconclusive results.

87. Multipartite quantum eraser in cavity QED

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We propose a feasible experiment in the context of cavity QED as follows: The initial state is a maximally entangled two cavity mode (MA, MB). Next a sequence of atoms are sent, one at a time, and interact with mode MB. We show that the which-way information is initially stored only in MB is now distributed among the parties of the global system. The results realize known complementarity relations derived in the context of arbitrary qubits. We show that this dynamics may lead to a quantum eraser phenomenon provided that measurements of the probe atoms are performed in a basis which maximizes the visibility.

88. Study of the entanglement properties of a system of interacting quantum dots embedded in an optical microcavity

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We study a system of three quantum dots embedded in an optical microcavity. The model used takes into account two interactions, the matter-light interaction under the dipole and rotating wave approximations, and the dot-dot interaction (with first neighbors) by adding a Foerster term in the Hamiltonian. In particular, we study the light-matter entanglement by calculating numerically the negativity of the density matrix, and its dependence with the spatial distribution of the quantum dots by varying the geometry of the system. We also make a comparative analysis, by using the fidelity criteria, of triangular and linear quantum dots distributions. We found that if the dot-dot interaction is much greater than the matter-light interaction, the three quantum dots present a collective behavior, but if the two energies are comparable, the individual efects dominate the behavior of the full system. For the two geometric distributions mentioned above, we study how collective behavior and individual behavior affect the entanglement properties of the system.

89. Generation of geometric phases in polarization-path entangled states

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We propose an all-optical array to generate geometric phases in a bipartite system displaying polarization-path entangled states. These entangled states describe prescribed curves on the Schmidt sphere, thereby accumulating geometric phases that mirror the case of pure polarization states on the Poincaré sphere. We nullify the dynamical contribution to the total (Pancharatnam) phase by choosing appropriate U(1) local transformations, so as to generate pure geometric phases along prescribed paths. The Mach-Zender-like array we propose is technically viable and should exhibit great versatility. Different configurations are shown that could be adapted to be employed with either classical or quantum sources of light.

90. Accessing multi-dimensional entanglement via discrete measurements on mutually unbiased bases of a bipartite continuous variable system

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We explore spatial correlations of photon pairs from spontaneous parametric down-conversion in transverse linear position and momentum domain to experimentally investigate bipartite multi-dimensional entanglement. Position and momentum constitute a pair of conjugate observables with continuum outcome. We discretize our position and momentum measurements into a d-outcome measurement by employing a set of binary masks as our mode analyzers. We choose a complete set comprising d masks with the shape of a periodic square wave, each of which selecting a given region of the detection plane that is orthogonal to each other. Using this set of masks, we characterize the multi-dimensional spatial correlations by the joint detection probability for the photon pair to fall within a given pair os masks. We analyze bipartite d-dimensional entanglement as a function of of the spatial frequency of the masks, where a cut-off spatial frequency above which entanglement is not detected is connected with the spatial mode content of the biphoton.

91. Homodyne vs Heterodyne for Gaussian States

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A comparison between homodyne and heterodyne tomography for Gaussian states is presented here.

92. Atomic squeezing in CQE systems.

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We study the problem of three (and two)-level atoms systems interacting with a radiation field in a quantum cavity. The exact eigenstates of the Hamiltonian are calculated in order to study the time evolution of spin observables like the spin squeezing factor, and the total spin alignment. It was found for the two-level systems that entanglement between atoms could be obtained depending on the initial conditions. For the three level systems we use a coherent spin state as initial conditions and determined the occurrence of atomic squeezing as a result of the initial coherent state parameters.

93. Quantum interference with SPDC photons: The roles of pump beam waist, detection mode, and longitudinal crystal position

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Spontaneous parametric down-conversion (SPDC) is a widely used process for creating photon pairs and heralded single photons. One of its advantages is its versatility as a source of quantum light, which stems from the fact that many properties of the downconverted biphoton wavefunction are amenable to experimental control. We experimentally and theoretically study an SPDC source where type II collinear down-conversion in a ppKTP crystal is used to create photon pairs from a 404 nm, focused Gaussian pump beam. One of the fascinating properties of photon pairs is their potential for quantum interference. This is one of the signature phenomena of quantum optics, observable in a Hong-Ou-Mandel (HOM) type experiment. Quantum interference manifests itself as photon bunching or antibunching at the output arms of a beam splitter when one photon is incident in each input arm. We examine the quantum interference of SPDC photons as a joint function of crystal temperature and path length difference, and pay close attention to the roles of the pump beam waist and detection mode. Numerous works can be found in the literature on how to optimise photon counts by appropriate choice of the detection mode. We, however, observe that the detection mode also strongly influences the quantum interference. This strong dependence on the detection mode is a result of spatiotemporal correlations. We furthermore study what happens as we move the crystal along the optical axis of the beam in an otherwise fixed set up. In particular, such a movement has a noteworthy effect on the path length difference required to reach the minimum of the HOM dip. The path length difference reflects the delay between signal and idler photons acquired due to the birefringence of the nonlinear crystal. Our results show that there is a significant change in the optimal path length difference when moving the crystal. This result is somewhat surprising, given that the SPDC is a process which occurs coherently over the crystal volume, with linear dependence on the pump power.

94. Achieving single-photon nonlinearities with an intracavity Rydberg medium

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The realization of a strong deterministic photon-photon interaction is a challenging task, but could enable the implementation of two-photon phase gates or the generation of non-classical states of light. The nonlinearities in standard media are however too weak to induce such effects. One approach to create single-photon nonlinearities is to temporally convert the photons into dark-state polaritons involving Rydberg atoms. The principle is that a single Rydberg excitation may modify strongly the susceptibility of a small region, thanks to Rydberg blockade. Recent experiments have demonstrated a Rydberg medium with a nonlinearity strong enough so that it can be used as a single photon source. Our setup consists of a cold atomic cloud of Rubidium trapped in the mode of a low finesse Fabry-Perrot cavity, which should allow to observe nonlinearities at the single photon level with a smaller Kerr effect than in a free-space configuration. For now, we could observe strong nonlinearities in the dispersive regime for a weak probe beam (1 nW). We will present our current efforts to observe nonlinearities for single-photons. This includes the implementation of a dipole trap to increase the atomic density, or increasing the cavity finesse and its concentricity. An interesting approach would be to work in resonance with a one-ended cavity. From our -under progress- theoretical models, we expect the reflected field should present non classical behaviors, such as phase jumps or anti-bunching.

95. Entanglement distribution in decoherence channels

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By letting an initially entangled pair of qubit systems to interact with their local environments through a decoherence process, we are able to observe the phenomena of Entanglement Sudden Death (ESD) and Entanglement Sudden Birth (ESB). Using an all optical experimental set-up, we monitor the dynamics and distribution of entanglement and observe the transition bipartite $\leftrightarrow$ multipartite entanglement, showing how such transition is intimately related to ESD and ESB. We further present a novel decomposition of the residual entanglement, that allows us to analyze the multipartite entanglement in terms of well-identified 3- and 4- partite entanglement contributions. The results represent a step towards a deeper understanding of the dynamics and distribution of entanglement in multi-qubit systems.

96. Polarization entanglement generation by interference of two squeezed states using Rubidium vapor

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We present a scheme for polarization entanglement production based on the interference of two squeezed beams that are provided by interaction of two laser light beams with one atomic Rb vapor cell in a single passage configuration. The squeezed states are reached through polarization self rotation, providing squeezing of one Stokes parameter in the (S_2 and S_3) plane. We observed a violation of Duan's inequality of 1.5 (2 for a coherent state) that indicates entanglement between the fields by their Stokes parameters (S_2 and S_3).

97. Efficient generation of high dimension photonic states

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Quantum information processing and computing protocols employ quantum systems as information carriers. The two-level quantum bit (qbit) is the most basic system normally used to transport or store information. Nevertheless qudits [D-level quantum systems (D > 2)] have attracted growing interest due to their greater potential for much of those applications. One way of creating qudits is achieved when the photons pass through an aperture with D slits, which sets the number of possible paths taken by the photon, creating spatial qudits. The information is then encoded in the discredited transverse position and momentum of individual photons. Although amplitude and phase masks have been used for this purpose, programmable spatial light modulators (SLMs), allows real-time manipulations of the photon state without movable parts in the optical paths, which simplifies the alignment process and also allows obtaining greater number of possible states. Previous works had shown, by means of using two SLMs, the possibility of preparing the most arbitrary quantum state, provided of full control of its amplitude and

phase. This had been done by programming D slits in one SLM and the phase changes in the other one. In this work we present a new method for preparing arbitrary pure states of spatial qudits by using a single phase-only SLM and a spatial filtering. The method relies in codifying in the SLM a transmission complex function, which is composed by D slits, each one containing a diffraction grating. Then, a spatial filter selects a diffraction order. The D slits determine the transversal momentum. The diffraction grating allows the complete control of the phase and amplitude of the state. With this encoding method is possible not only prepare the state but also realize projective measurements over arbitrary bases that contribute in the reconstruction process. We have implemented the method for a big number of states of dimension D=2 and analyzed its quality using the fidelity of preparation as figure of merit. We show the flexibility of the method for implementing higher dimension qudits in the cases D=3 and D=7. This new configuration, besides being simpler, more compact and less costly, uses the photons 10 times more efficiently than previous methods, which is relevant when working with individual photons that are generated by parametric down-conversion. Additionally, we propose a variation of the phase codification method, based in lateral displacements of the diffraction grating. This method is robust against the temporal phase fluctuations in the SLM, and allows a complete 2pi phase modulation independent on the wavelength.

98. Quantum Speed Limit for relativistic electron in an uniform magnetic field

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How fast a physical system can process information? It is an extremely important question in the field of computation. The answer to this question is the central focus of this study, to investigate the minimum time required for a relativistic quantum system changes to an orthogonal state respected to the initial one. In the present study we analysed the relativistic dynamics according to the Dirac equation an electron in the presence of an uniform magnetic field. The initial state of the system was chosen as a superposition of two states with equal weight, each of them being associated with a different Landau levels. Analysing the speed in which the electron moves from its initial mean position to its mean final position, it was found that in the case relativistic electron description never reach a speed greater than the speed of light. On the other hand, in non-relativistic description obtained by the Schrödinger equation, the electron will reach a higher rate of displacement greater than c when it is in a very strong magnetic field. Therefore, to realize a correct description of this problem of quantum speed limit is necessary to treat it according to the relativistic quantum mechanics.

99. Joint estimation of phase and phase diffusion for quantum metrology

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Phase estimation, at the heart of many quantum metrology and communication schemes, can be strongly affected by noise, whose amplitude may not be known, or might be subject to drift. We investigate the joint estimation of a phase shift and the amplitude of phase diffusion at the quantum limit. For several relevant instances, this multiparameter estimation problem can be effectively reshaped as a two-dimensional Hilbert space model, encompassing the description of an interferometer phase probed with relevant quantum states – split single-photons, coherent states or N00N states. For these cases, we obtain a trade-off bound on the statistical variances for the joint estimation of phase and phase diffusion, as well as optimum measurement schemes. We use this bound to quantify the effectiveness of an actual experimental set-up for joint parameter estimation for polarimetry. We conclude by discussing the form of the trade-off relations for more general states and measurements.

100. Nonlinear optics with atomic mercury vapor inside a hollow-core photonic crystal fiber

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We demonstrate high atomic mercury vapor pressure in a kagomé-style hollow-core photonic crystal fiber at room temperature. The use of mercury vapor in quasi one-dimensional confinement may be advantageous compared to chemically more active alkali vapor, while offering strong optical nonlinearities in the ultraviolet region of the optical spectrum.

101. Entangling mechanical oscillators: measurement-based and coherent feedback approaches

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The generation and verification of a macroscopic, all-mechanical entangled state is a major goal and (at present) outstanding task in the study of mechanical systems in the quantum regime. The canonical continuous-variable entangled state is the two-mode squeezed state. Here we describe how to prepare and detect all-mechanical two-mode squeezed states in optomechanical systems. In one approach we show how one can prepare such states using a two-mode back-action-evading (BAE) measurement and feedback, implemented via a coupled driven cavity [1]. We show how the same system can be used for force sensing beyond conventional quantum limits. By perturbing such a BAE measurement interaction, one can prepare a mechanical two-mode squeezed state without the need for any explicit measurement [2]. This may be regarded as either a reservoir engineering scheme or as a form of coherent feedback. It is, from an experimental perspective, a less demanding proposal than the measurement-based scheme and the generated mechanical steady-state is of higher purity. The experimental realisation of these proposals would involve relatively minor modifications of existing experiments.

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102. Quantum Speed-Up of Field Evolution by Atomic Number in an Optical Cavity QED System

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The quantum speed of the evolution of a state is an important parameter in quantum information. We are studying the quantum speed in an optical cavity QED system. We measure the second order correlation function of the intensity escaping the cavity. We focus on the cavity field coupled to an atomic polarization (N two-level atoms), which we treat as a tunable environment. Changing the number of atoms changes the quantum speed of the cavity field as it returns to steady state. Our results open the possibility to control and manipulate the quantum speed by tailoring the environment. Work supported by the NSF of USA.

103. Storage and manipulation of light by higher order nonlinearities in an atomic medium

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104. A scheme for efficient generation of mesoscopic field states superposition in cavity QED

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Theoretically, we present a simple scheme for the fast and efficient generation of quantum superpositions of two coherent fields with different classical amplitudes in a cavity. It relies on the simultaneous interaction of two two-level systems with the field. The work is done in the context of cavity QED, hence the two-level system are circular Rydberg atoms which lifetime may reach

milliseconds. Their final detection with a high probability in the proper state projects the field onto the desired mesoscopic field state superposition (MFSS). We show that the scheme is notably more efficient than those using a single atom. We discuss the method in the context of microwave cavity quantum electrodynamics (CQED), but it is also highly relevant for the thriving field of circuit-QED. It may lead to interesting experimental studies of decoherence at the quantum-classical boundary.

105. Quantum metrological bounds for weak-value measurements

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Weak-value amplification [1] requires the pre-and post-selection of states of a quantum system, followed by a measurement on the meter. We found, using quantum metrological methods, a best post-selection procedure that leads to the value of the Quantum Fischer information, under conditions fulfilled by most experiments reported so far. This implies that weak-value measurements, using a proper post-selection scheme, is as good as standard quantum protocols of measurements for parameter estimation.

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106. Distribution of multipartite correlations

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Using the relative entropy of total correlation, we derive an expression relating the mutual information of n-partite pure states to the sum of the mutual informations and entropies of its marginals and analyze some of its implications. Besides, by utilizing the extended strong subadditivity of von Neumann entropy, we obtain generalized monogamy relations for the total correlation in three-partite mixed states. These inequalities lead to a tight lower bound for this correlation in terms of the sum of the bipartite mutual informations. We use this bound to propose a measure for residual three-partite total correlation and discuss the non-applicability of this kind of quantifier to measure genuine multiparty correlations.

107. Distribution of multipartite correlations

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Quantum mechanical tunneling is one of the most fruitful concepts in modern physics. While the study of linear microscopic quantum tunneling has a very long history going back to the first days of quantum mechanics, the field of nonlinear (soliton-like) macroscopic quantum tunneling is relatively young and was born only after two discoveries - solitons and BEC. Nonlinear wave excitations and solitons – self-localized robust and long-lived solitary waves that do not disperse and preserve their identity as they travel through a medium – are ubiquitous in Nature, they arise in many fundamental areas of physics and technology: from nonlinear optics and ultrafast photonics, condensed matter and plasma physics to elementary particle physics, cosmology and monster (rogue) waves in oceans and Bose-Einstein condensates. Owing to their remarkable features solitons might appear as the idealized structures for the description of extended "elementary" particles. Consequently, general questions naturally arise: To what extent the soliton can be regarded as a classical point-like particle which is governed by Newton's equations of motion? As to whether the wave-particle duality and intrinsic ("hidden") degrees of freedom can show up in the soliton tunneling through potential barriers and wells? Previously, it was demonstrated that so-called nonautonomous solitons in the exactly integrable nonautonomous and nonlinear systems can be adapted to both the external potentials and the dispersion and nonlinearity changes and generally move with varying amplitudes, speeds and spectra. We stress that in this Report, we consider the soliton dynamics in the frameworks of exclusively nonintegrable models with arbitrary localized external potentials. Our main purpose is to present the conceptual consideration of the underlying physical principles involved into the soliton tunneling efect. We prove that scaling symmetry breaking in soliton scattering reveals the hidden role of the soliton self-interaction ("binding") energy and its dramatic impact on the wave-particle duality of solitons. Deep analogies between nonlinear Schrödinger solitons scattering on external potentials and the Gamow model for alpha particles tunneling are demonstrated. Based on these analogies, the hidden features of the nonlinear Ehrenfest theorem and the leading role of the soliton binding energy in the soliton tunneling through classically forbidden potential barriers are revealed. Simple physical criteria for classical Newtonian like and quantum mechanical like dynamics of the Schrödinger solitons in external potentials are obtained and confirmed by direct computer experiments. Main experimentally accessible strategies to reveal the hidden role of the soliton binding energy are presented. The results obtained can find different applications in the developing basically novel all-optical soliton logic and switching devices, in soliton lasers design, soliton supercontinuum generation and formation of matter wave solitons in Bose-Einstein condensates.

108. Probing Macroscopic Realism via Ramsey Correlation measurements

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We describe a new and experimentally feasible protocol for performing fundamental tests of quantum mechanics with massive objects. In our approach a single two level system is used to probe the motion of a nanomechanical resonator via multiple Ramsey interference measurements. This scheme enables the measurement of modular variables of macroscopic continuous variable systems and we show that correlations thereof violate a Leggett-Garg inequality and can be applied for tests of quantum contextuality. Our method can be implemented with a variety of different solid state or photonic qubit-resonator systems and provides a clear experimental signature to distinguish the predictions of quantum mechanics from those of other alternative theories at a macroscopic scale.

109. Separable Schmidt modes of a non-separable state

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The development of quantum information protocols is one of the most promising applications of the intrinsic properties of quantum mechanics such as quantum superposition and entanglement [1,2]. Two-photon states entangled in continuous variables such as wavevector or frequency represent a powerful resource for quantum information protocols in higher-dimensional Hilbert spaces [3,4,5,6]. At the same time, there is a problem of addressing separately the corresponding Schmidt modes. For wavevector variables, a single Schmidt mode can be filtered out with the help of a single-mode fibre [7], but no similar procedure exists for the frequencies. This filtering, in principle, can be lossless, which is crucial for experiments with twin-beam squeezing [8–14]. Here we propose a method of engineering two-photon spectral amplitude in such a way that it contains several non-overlapping Schmidt modes, each of which can be filtered losslessly [15]. The method is based on using a pump with a comb-like spectrum, which can be obtained, in particular, by passing a laser beam through a Fabry-Perot interferometer. For the two-photon amplitude to consist of non-overlapping Schmidt modes, the crystal dispersion dependence, the length of the crystal and the width of a single Fabry-Perot transmission peak should satisfy a certain condition. We experimentally demonstrate the control of Schmidt modes structure through these parameters.

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