Italian Quantum Information Science Conference 2009

Thursday 05 November 2009 - Sunday 08 November 2009

Scuola Normale Superiore, Pisa, Italy

Programme

Table of contents

Thursday 05 November 2009

Registration (14:00-14:50)

Opening (05 November 14:50-15:00)

Session 1 (05 November 15:00-16:30)

time	title
15:00	**New horizons for quantum information science: topology, formal languages, living matter** *Speaker: RASETTI, Mario* A review will be presented exploring novel efficient applications of quantum algorithms and quantum information concepts to diverse areas of science, from the evaluation of topological invariants of manifolds, to the classification of grammatical structures in the theory of formal languages, to the conceptual realization of consistent schemata and models for the representation of the features of living matter.
15:30	**Control of Many Body Quantum Systems** *Speaker: MONTANGERO, Simone* We explore the ultimate limits of optimal control of many body quantum systems studying different cases ranging from the information transfer along a chain to the creations of defects across a quantum phase transition. We introduce a new technique to control the time evolution of many body quantum systems combining tensor network methods (tDMRG, TEBD) and optimization techniques.
16:00	**Experimental realization of operator superpositions by single-photon interference** *Speaker: ZAVATTA, Alessandro* The successful experimental implementation of the single-photon addition and subtraction operations has permitted for the first time the realization of alternated sequences of the creation and annihilation operators [1]. The states resulting from the application of these sequences to a thermal state depend on the order in which the two operations are combined. Here a single-photon interferometer is used to create coherent superpositions of the two alternated sequences of operators. The sign of the superposition depends on the destructive or constructive character of the single-photon interference, thus the commutation relation can be directly proven or a novel nonclassical state can be produced [2]. The resulting states are analyzed by mean of homodyne detection and the non-commutativity of the bosonic operators is directly verified. [1] V. Parigi, A. Zavatta, M. S. Kim and M. Bellini, Science 317, 1890 (2007). [2] M. S. Kim, H. Jeong, A. Zavatta, V. Parigi and M. Bellini, Phys. Rev. Lett. 101, 260401 (2008).

Coffee Break (16:30-17:00)

Session 2 (05 November 17:00-19:00)

time	title
17:00	**Frames and fusion frames in stroboscopic tomography** *Speaker: JAMIOLKOWSKI, Andrzej* The main purpose of this presentation is to show that the notions of frames and fusion frames introduced in non-harmonic Fourier analysis are also very natural in discussion of some basic problems in theory of open quantum systems and, in particular, in quantum optics. Frames are collections of vectors in a Hilbert space which assure a natural representation of each vector in the space, but may have infinitely many different representations for any given vector. For a given quantum system represented in a Hilbert space $\mathcal{H}$, the question of minimal number η of observables $Q_1,\ldots,Q_{\eta}$, whose expectation values at some instants $t_1,\ldots,t_p$ determine the statistical state of the system is discussed. We assume that the time evolution of the system in question is governed by a semigroup of linear transformations with generator $\mathbb{L}$
17:30	**Multipartite entanglement detection via structure factors** *Speaker: MACCHIAVELLO, Chiara* We present a novel method to detect multipartite entanglement, based on a relation between entanglement of a many-body system and its diffractive properties. The link is given by structure factors. Based on these, we provide a general analytical construction of multi-qubit entanglement witnesses, that contain two-point correlations. They could be either measured in a scattering experiment or via local measurements, depending on the underlying physical system. For some explicit examples of witnesses we analyze the properties of the states that are detected by them. We further study the robustness of these witnesses with respect to noise.

18:00	**Sub-Shot-Noise Quntum Imaging** *Speaker: RUO BERCHERA, Ivano* We exploited spatial quantum correlation between twin beams generated by Parametric Down Conversion (PDC) for realizing sub-shot -noise quantum imaging of weak absorbing objects. The idea of quantum imaging consists in measuring the intensity pattern on one branch of PDC, where an object has been inserted, and then subtracting the correlated noise pattern measured in the other branch that does not interact with the object. The image of the object, previously hidden in the noise, can be restored because the noise has been washed away by the subtraction. The method, proposed theoretically few years ago, has never been realized before, because of the difficulties of measuring a level of spatial correlation under the standard quantum limit. In Phys. Rev. Lett. 102, 213620(2009) we showed that this limit can be achieved, by using a low noise CCD array, loss-limited optical channel and a control of the coherence area of PDC. Moreover, very recently we realized a real sub-shot noise imaging experiment showing an improvement of the signal to noise ratio from 30% to 70% with respect to the classical imaging schemes operating at the same illumination level.
18:30	**2D topological phases, duality and 3D state sum models** *Speaker: MARZUOLI, Annalisa* Kitaev and Levin-Wen doubled topological phases are shown to correspond to Hamiltonian versions of topological quantum field theories described by Turaev-Viro state sum models for decorated triangulated 3D manifolds. REF: Z. Kadar, A. Marzuoli, M. Rasetti, arXiv:0907.3724

Friday 06 November 2009

Session 3 (06 November 09:00-10:30)

time	title
09:00	**Quantum computation with two-photon six-qubit cluster states** *Speaker: MATALONI, Paolo* A six-qubit linear cluster state has been created by transforming a two-photon hyper-entangled state in which three qubits are encoded in each particle, one in the polarization and two in the linear momentum degrees of freedom. We have completely characterized this state, demonstrating genuine six-qubit entanglement, persistency of entanglement against the loss of qubits, and higher violation than in previous experiments on Bell inequalities of the Mermin type. The two-photon six-qubit cluster state has been adopted in the framework of the one-way quantum computation model to perform and test the correct functioning of a CNOT gate (allowing for different input states). Other quantum computation applications of this state will be discussed.
09:30	**Random Quantum Satisfiability** *Speaker: SCARDICCHIO, Antonello* Quantum SAT is a natural generalization of k-Satisfiability and has been proven to be QMA-complete, hence among the most difficult problems for a quantum computer. We introduce a natural measure for defining a random ensemble and find a SAT and UNSAT phases separated by a phase transition. The nature and the precise location of the transition are under current investigation.
10:00	**Trace-Norm Isometries in Quantum Information Encoding and Protection** *Speaker: TICOZZI, Francesco* We illustrate how the problems of faithful encoding and correction of quantum information in physical systems can be investigated by embracing the operational notion of "distinguishability preservation". A measure of distinguishability of quantum states is given by the trace-norm distance. In fact, by using trace-norm isometries, we derive a "subsystem principle" for quantum information encoding, as well as necessary and sufficient conditions for error correction. A robustness analysis of the same issuess can also be developed by considering approximate isometries. Work in collaboration with L. Viola (Dartmouth College).

Coffee Break (10:30-11:00)

Session 4 (06 November 11:00-12:30)

time	title
11:00	**Quantum traffic jam in far from equilibrium quantum systems** *Speaker: BENENTI, Giuliano* Low-dimensional systems are interesting for theoretical investigations, as they admit ordering tendencies, leading to collective quantum states that are difficult to realize in three-dimensional systems. Understanding the transport properties of such low-dimensional strongly correlated systems is a challenging open problem. So far, most of the theoretical studies concentrated on the close-to-equilibrium situation by using the linear response, while very little is known about the physics of such systems far from equilibrium. On the other hand, new quantum phases and interesting physical phenomena may appear in the far from equilibrium regime. It is shown that, when a finite anisotropic Heisenberg spin-1/2 chain in the gapped regime is driven far from equilibrium, oppositely polarized ferromagnetic domains build up at the edges of the chain, thus suppressing quantum spin transport. As a consequence, a negative differential conductivity regime arises, where increasing the driving decreases the current. This phenomenon arises as an outcome of the interplay between coherent quantum dynamics of the spin chain and incoherent spin pumping. Finally, the negative differential conductivity phenomenon is discussed in the context of charge transport in strongly correlated electron systems, i.e., for the Hubbard model. References: [1] G. Benenti, G. Casati, T. Prosen and D. Rossini, "Negative differential conductivity in far-from-equilibrium quantum spin chains", Europhys. Lett. 85, 37001 (2009). [2] G. Benenti, G. Casati, T. Prosen, D. Rossini and M. Znidaric, "Charge and spin transport in strongly correlated one-dimensional quantum systems driven far from equilibrium", Phys. Rev. B 80, 035110 (2009).

11:30	**Collective decoherence of cold atoms coupled to a Bose-Einstein condensate** *Speaker: PALMA, Massimo* We examine the time evolution of cold atoms (impurities) interacting with an environment consisting of a degenerate bosonic quantum gas. The impurity atoms differ from the environment atoms, being of a different species. This allows one to superimpose two independent trapping potentials, each being effective only on one atomic kind, while transparent to the other. When the environment is homogeneous and the impurities are confined in a potential consisting of a set of double wells, the system can be described in terms of an effective spin-boson model, where the occupation of the left or right well of each site represents the two (pseudo)-spin states. The irreversible dynamics of such system is here studied exactly, i.e., not in terms of a Markovian master equation. The dynamics of one and two impurities is remarkably different in respect of the standard decoherence of the spin - boson system. In particular we show: ({\em i}) the appearance of coherence oscillations, ({\em ii}) the presence of super and sub decoherent states which differ from the standard ones of the spin boson model, and ({\em iii}) the persistence of coherence in the system at long times. We show that this behaviour is due to the fact that the pseudospins have an internal spatial structure. We argue that collective decoherence also prompts information about the correlation length of the environment. In a one dimensional configuration one can change even stronger the qualitative behaviour of the dephasing just by tuning the interaction of the bath.
12:00	**Quantumness without the quantum world?** *Speaker: PATERNOSTRO, Mauro* Among the goals that modern quantum science aims at achieving, one of the most elusive and yet intriguing and fascinating is a full understanding of the quantum-to-classical transition and the role that "microscopicity" plays in the occurrence of genuinely non-classical phenomena. This talk deals exactly with all this. I will show that failure of local realism can be revealed to observers for whom only extremelycoarsegrained measurements are available. In the instances I will treat, a Bell's inequality is violated even up to the maximum limit while both the local measurements and the initial local states under scrutiny approach the classical limit. Furthermore, one can observe failure of local realism when an inequality enforced by non-local realistic theories is satisfied. This suggests that locality alone may be violated while realism cannot be excluded for specific observables and states. Smallscale opto-mechanical and alloptical experimental demonstrations of such examples are described in some details. The "Holy Grail" may still be missing but, certainly, we are having fun!

Lunch (12:30-15:00)

Session 5 (06 November 15:00-16:30)

time	title
15:00	**Entanglement and Fisher Information: Indistinguishable two-mode systems versus distinguishable qubits** *Speaker: BENATTI, Fabio* After introducing an algebraic notion of separability suited to N indistinguishable two-mode particles, we re-examine a class of inequalities that have been derived for N distinguishable qubits and show that some of them are violated. We discuss the relevance of such differences for the Fisher information and its application to entanglement based high accuracy experiments.
15:30	**Quantum teamwork for unconditional multiparty communication with Gaussian states** *Speaker: ADESSO, Gerardo* We demonstrate the capability of continuous variable Gaussian states to communicate multipartite quantum information. A quantum teamwork protocol is presented according to which an arbitrary possibly entangled multimode state can be faithfully teleported between two teams each comprising many cooperative users. We prove that N-mode Gaussian weighted graph states exist for arbitrary N that enable unconditional quantum teamwork implementations for any arrangement of the teams. These perfect continuous variable maximally multipartite entangled resources are typical among pure Gaussian states and are unaffected by the entanglement frustration occurring in multiqubit states. [J. Zhang, G. Adesso, C. Xie, and K. Peng, Phys. Rev. Lett. 103, 070501 (2009)]
16:00	**Entanglement in quantum spin chains with no reflection symmetry** *Speaker: ZIMBORAS, Zoltan* Understanding the entanglement properties of systems with many degrees of freedom, such as quantum spin chains, has been one of the main recent research topics connecting quantum information science and statistical physics. Huge amount of results has been accumulated about translation-invariant systems. However, the results almost exclusively correspond to models with reflection symmetry, despite that non-reflection-invariant systems also play a prominent role in statistical mechanics (e.g. in describing non-equilibrium steady states, or in case of spin models with Dzyaloshinskii-Moriya interactions). In this talk we will present some new results, both analytical and numerical, about the entanglement properties of non-reflection-invariant spin chains, and discuss how these differ from the reflection-invariant case.

Coffee Break (16:30-17:00)

POSTER SESSION (06 November 17:00-19:00)

title	board
Mapping between Kitaev's quantum double and the Levin-Wen spin net *Speaker: KADAR, Zoltan* Duality in lattice gauge theory is an equivalence of different descriptions of states living on the lattice. Kitaev's model is the description in terms of the (gauge) group algebra basis, the Levin-Wen spin net is that in the Fourier (a.k.a. spin network) basis. The construction is explicit for the ground state, whereas matching excitations is an open problem.	
Not all pure entangled states are useful for sub shot-noise interferometry *Speaker: HYLLUS, Philipp* We consider the usefulness for sub shot-noise interferometry of pure entangled states of fixed particle number N quantified by the quantum Fisher information F_Q under (i) collective and (ii) general local unitary operations. We show that in case (i) there is a simple way to compute the optimal transformation while in case (ii) an upper bound can be easily obtained which is tight in many important cases. We use these results to show that for $N=2$ all pure entangled are useful in the sense above while for $N>2$, there are entangled states cannot be made useful even in case (ii). Further, we completely characterize all pure symmetric states regarding the usefulness. We compute the optimal F_Q for several prominent examples of symmetric states as well as for a non-trivial family of singlet states and for all cluster states, showing that the latter are practically of no more use than product states.	
On the difference between a quantum computer and a quantum mind *Speaker: ZIZZI, Paola* We formulate a no-go theorem which states that an autonoumous quantum computer, that is one which is not controlled by a human (quantum) mind, cannot develop a quantum metalanguage and therefore will not be able to program its own mind or that of any other quantum machine.	
Quantum estimation of non-observable quantities *Speaker: GENONI, Marco G* Several quantities of interest in quantum information are nonlinear functions of the density matrix and cannot, even in principle, correspond to proper quantum observables. Any method aimed to determine the value of these quantities should resort to indirect measurements and thus corresponds to a parameter estimation problem whose solution, i.e the determination of the most precise estimator, unavoidably involves an optimization procedure. We review local quantum estimation theory and apply it to different non-observable quantities: entanglement and displacement/squeezing parameters. As concern entanglement estimation, we evaluate quantum Fisher information for discrete and continuous variable systems and for different entanglement measures. Our results indicate that entanglement may be efficiently estimated when it is large, while the estimation of weakly entangled states is, in most cases, an inherently inefficient procedure. As concern displacement and squeezing parameters, we address their estimation by the class of probes made of Gaussian states undergoing Kerr interaction. At fixed overall energy, Gaussian squeezed vacuum states represents the optimal resource for parameter estimation. In the more realistic case, where the amount of Gaussian squeezing is fixed or even absent, Kerr interaction turns out to be useful to improve estimation, especially for probe states with large amplitude. Our results indicate that precision achievable with current technology Gaussian squeezing may be attained and surpassed for realistic values of the Kerr coupling. References: [1] Marco G. Genoni, Paolo Giorda and Matteo G.A. Paris, Phys. Rev. A 78, 032303 (2008). [2] Marco G. Genoni, Carmen Invernizzi and Matteo G.A. Paris, arXiv:0906.0710 [quant-ph].	

Quantum information transmission across a memory amplitude damping channel

Speaker: D'ARRIGO, Antonio

Quantum communication channels use quantum systems as carriers for information. A key problem is the determination of the classical and quantum capacities of noisy quantum channels, which give upper bounds to the channel efficiency per use. In any realistic implementation, errors occur due to the unavoidable coupling of the transmitted quantum systems with an uncontrollable environment. Noise can have significant low frequency components, which traduce themselves in memory effects, leading to relevant correlations in the errors affecting successive transmissions. Memory effects become unavoidably relevant when trying to increase the transmission rate [1], that is, to reduce the time interval that separates two consecutive channel uses. Our aim is to study a memory amplitude damping channel [2]. We model it as a damped harmonic oscillator, and we consider transfer of quantum information through it. A train of N qubits is sent down the channel, so that they interact with the harmonic oscillator, initially prepared in its ground state, during the transit time. If the state of the oscillator is not reset after each channel use, then the action of the channel on the k -th qubit depends on the previous k 1 channel uses. The oscillator acts as a local environment, coupled to a memoryless reservoir damping both its phases and populations, which mimics any cooling process resetting the oscillator to its ground state. The model is visualized by a qubit-micromaser [3] system, the qubit train being a stream of two-level Rydberg atoms injected at low rate into the cavity; it also describes the dynamics of a quantum memory, which may be implemented by coupling N superconducting qubits to a microstrip cavity, in a circuit-QED [4] architecture We will show that the quantum information transmission worsens with increasing transmission frequency due to the increase of memory effects [2]. However, the decrease is found to be only moderate, so that the quantum transmission rate increases with increasing transmission frequency. Therefore, operating the memory channel at high transmission frequency, thus accepting prima facie deleterious memory effects, will be more beneficial than using low frequency. These results are relevant also for the secure transmission of classical information, then for cryptographic purposes. [1] V. Giovannetti, J. Phys. A 38, 10 989 (2005). [2] G. Benenti, A. D'Arrigo, and G. Falci., Phys. Rev. Lett. 103, 020502 (2009). [3] P. Meystre and M. Sargent, III, Elements of Quantum Optics (Springer□Verlag, Berlin, 2007), 4th ed. [4] A. Wallraff et al., Nature (London) 431, 162 (2004); J. M. Fink et al., Nature (London) 454, 315 (2008).

Quantum teleportation of electrons in quantum wires with surface acoustic waves

Speaker: BUSCEMI, Francesco

We propose and numerically simulate a model of a deterministic quantum teleportation protocol based on the single-electron transport assisted by surface acoustic waves (SAW) in semiconductor quantum wires. The three qubits are each defined by a single electron carried by SAW along one of two coupled quantum wires. We show that, due to the Coulomb interaction between carriers in different channels, first a highly entangled pair of electrons is created and then a complete Bell-state measurement involving one electron from this pair and a third electron can be performed. Finally the state reconstruction depending upon such a measurement is realized by means of local one-qubit operations on the other half of the entangled pair. The estimated fidelity ranging from 0.95 to 0.99 explicitely suggests that a high-efficiency of the teleportation process could be reached in an experimental setup. The realization of the proposed model should be on the borderline of the present semiconductor technology.

Representing fuzzy structure in quantum computation wuth mixed states

Speaker: SERGIOLI, Giuseppe

In the usual representation of quantum computational processes, a quantum circuit is identified with an appropriate composition of quantum gates, i.e. unitary operators acting on pure states (qubits or quregisters) of a convenient (n-fold tensor product) Hilbert space. Consequently, quantum gates represent reversible time evolution of the system. According to [1], however, such a representation is unduly restrictive insomuch it does not encompass open systems where coupling with environment and measurement processes may occur. In this case, time evolution is no longer reversible. In [1], the authors formulate a more general model of quantum computational processes, where pure states and unitary operators are replaced by density operators and quantum operations, respectively. Let H be a Hilbert space, L(H) the vector space of all linear operators of H and D(H) the set of density operators in H. A quantum operation [2] is a linear and completely positive operator from L(H1) to L(H2) . Clearly, a quantum operation maps density operators into density operators. It can be seen that every unitary operator U in a Hilbert space H gives rise to a quantum operation Ou called unitary embedding. However, not every quantum operation is a unitary embedding. In this framework, some irreversible transformations of density operators into density operators emerge. In particular, in [2] the authors introduce a kind of irreversible conjunction (IAND) and a Lukasiewicz- style truncated sum. The question naturally arises whether these fuzzy-like transformations of density operators into density operators can be represented or probabilistically approximated by means of quantum operations. In the present work we provide a quantum operational representation of the irreversible conjunction via the first Krause representation theorem [3] and we introduce a particular kind of quantum operation, the so called polynomial quantum operation. We finally show a polynomial quantum operation that approximates the Lukasiewicz truncated sum with a very good accuracy (2x10^-8) . REFERENCES [1] Aharonov, D., Kitaev, A. and Nisan, N. (1998), Quantum circuits with mixed states. STOC □98: Proceedings of the thirtieth annual ACM symposium on Theory of computing, pp. 20□30. ACM press. [2] G.S., M. L. Dalla Chiara, R. Giuntini, H. Freytes, A. Ledda (2009): The algebraic structure of an approximately universal system of quantum computational gates. Foundations of Physics. [3] Kraus, K. (1983), States, effects and operations. Springer-Verlag, Berlin.

Spin-boson--like quantum phase transition in systems of trapped ions

Speaker: GIORGI, Gian Luca

A model representing a spin chain interacting with bosons is introduced which is exactly solvable. This model shows a quantum phase transition when the coupling between spins and bosons reaches a critical value which corresponds to a level crossing in the energy spectrum. In the critical region, a coherent emission in the bosonic modes is present which would be forbidden by the Hamiltonian symmetry. We show how this model can be efficiently simulated using trapped ions.

Sub-wavelength interference as a tool for identifying entanglement

Speaker: D'ANGELO, Milena

Both entangled two-photon systems and thermal light have been shown to give rise to sub-wavelength interference patterns which overcome the Rayleigh diffraction limit by a factor of 2, provided adequate coincidence detection is performed. A natural question arises: Which is the role of entanglement in such interferometric phenomenon? By answering this question we underline both fundamentally intriguing aspects and practically useful peculiarities of entanglement-based sub-wavelength interference. In particular, we show that, different from classical interference phenomena, high-contrast sub-wavelength interference is completely independent of the source spectrum, provided entangled photons are employed; in fact, broadband entangled-photon sources give rise to high-contrast sub-wavelength interference patterns as good as narrowband sources (whether entangled or thermal) do. Besides the practical advantages offered by such macroscopic light levels for quantum lithography applications, this effect comes out to be a useful and esay-to-implement tool for identifying and quantifying entanglement.

The algebraic structure of an approximately universal system of quantum computational gates

Speaker: LEDDA, Antonio

As is well known, the classical circuit-model of computation, both in its reversible and in its irreversible version, can be formulated by using a very small set of gates, called universal set of gates. This property amounts to saying that every gate can be mathematically simulated by means of a convenient composition of gates belonging to the universal set. For instance, in the irreversible case, the system consisting of the two gates AND and NOT turn out to be functionally universal. In the reversible case, such a role is played by a single gate: the Toffoli gate T. Unlike the classical circuit model, quantum computation ``originates'' in a naturally reversible way, because quantum gates are interpreted as unitary operators acting on pure states (qubits or quregisters) of the Hilbert space associated with the quantum circuit at issue. Being unitary, quantum gates represent reversible time-evolution of the circuit in question. Since there are uncountably many unitary operators, there is no hope to find any finite functionally universal set of quantum gates. The best we can do is having recourse to the notion of finite approximate universality ([Sh02]): a finite set of gates is said to be approximately universal iff any quantum gate can be approximated up to an arbitrary accuracy by a quantum circuit that consists of elements of this set. Finding simpler and simpler sets of universal gates represents a crucial step in order to try and realize concrete quantum computers. Interestingly enough, this does not involve any serious loss in computational power; in fact, as proved by Solovay and Kitaev ([NC00]), shifting from a universal set to another one only causes a polylogarithmic overhead. The existence of a three-element (approximately) universal set of quantum gates has been proved by Deutsch in [De89]. Many other universal sets were discovered afterwards, culminating in the result obtained by Shi ([Sh02]) and further investigated by Aharonov ([Ah03]). These authors found a two-element universal set consisting of the (three-qubit) Toffoli gate, T, and of the one-qubit Hadamard gate, I (also called the squareroot of the identity). Unlike the classical reversible case, the Toffoli gate alone is not sufficient to reproduce the behavior of all quantum gates. A gate exhibiting a ``genuine'' quantum behavior needs to be added: a ``good'' example is represented by the operator I. From a foundational point of view, we can say that I is just all that the Toffoli gate needs in order to reach quantum (approximate) universality, starting from classical (functional) universality. The results we have mentioned so far are formulated in the framework of the usual approach to quantum computation, which is essentially based on quregisters and unitary operators of convenient Hilbert spaces. However, such a representation is unduly restrictive, since it does not encompass open systems, where interactions with an environment and some measurement-processes may occur. In this case, the time-evolution of quantum objects is no longer reversible. One can formulate a more general model of quantum computational processes, where quregisters and unitary operators are replaced by density operators (qumixes) and by unitary quantum operations, respectively (see [AKN98] and [Gu03]). From a physical point of view, using qumixes instead of quregisters has plenty of advantages. In fact, physical systems are never completely isolated and are always somehow interacting with the rest of the Universe. Hence, quantum states are better represented by qumixes (mixed states) instead of quregisters (pure states). Moreover (as shown by Aharonov, Kitaev and Nisan [AKN98]), taking into account quantum circuits with qumixes allows us to treat some critical problems (such as measurements in the middle of a computation, decoherence, noise, and so on), which cannot be adequately represented in the framework of the usual approach. It should be noticed, however, that the Aharonov-Kitaev-Nisan model and the standard model are polynomially equivalent in computational power ([AKN98]). In this work we will investigate some algebraic properties of the Shi-Aharonov universal set of gates (in their quantum operational form). To this aim we will equip the set of all qumixes with two quantum operations representing an appropriate generalization of the Toffoli gate T and of the Hadamard gate I. We will show that the main algebraic properties of this structure can be also captured by restricting the action of the two quantum operations to qumixes ``living'' in the simplest Hilbert space, C^2. In this way, the dimension of the Hilbert space associated with a reversible quantum circuit is dramatically reduced. The price to pay is the loss of the reversible nature of the two quantum operations. REFERENCES [Ah03] D. Aharonov, D, ``A simple proof that Toffoli and Hadamard are quantum universal'', [arXiv:quant-ph/0301040], 2003. [AKN98] D. Aharonov, A. Kitaev, and N. Nisan, ``Quantum circuits with mixed states'', STOC '98: Proceedings of the thirtieth annual ACM symposium on Theory of computing, ACM Press, 1998, pp. 20--30. [De89] D. Deutsch, ``Quantum computational networks'', Proceedings of the Royal Society of London A, 425, 1989, pp. 73--90. [Gu03] G. Gudder, ``Quantum computational logics'', International Journal of Theoretical Physics, 42, 2003, pp. 39--47. [NC00] M. Nielsen, I. Chuang, Quantum Computation and Quantum Information, Cambridge University Press, Cambridge, 2000. [Sh02]Y. Shi, ``Both Toffoli and controlled-Not need little help to do universal quantum computation'', [arXiv:quant-ph/0205115], 2002.

Atomic color superfluid via three-body loss

Speaker: DALMONTE, Marcello

Large three-body losses in a three-component Fermi gas confined in an optical lattice can prevent the occupation of a lattice site by three atoms. This effective constraint not only gives rise to a suppression of actual three-body loss, but stabilises BCS pairing phases by suppressing the formation of trions. We study the effects of the constraint using bosonisation and density matrix renormalisation group techniques (DMRG). We discuss the case of Lithium experiments, and study the dissipative dynamics including loss using time-dependent DMRG with quantum trajectories methods.

Entanglement and Fisher information: indistinguishable two-mode systems versus distinguishable qubits

Speaker: MARZOLINO, Ugo

fter introducing an algebraic notion of separability suited to N indistinguishable two-mode particles, we re-examine a class of inequalities that have been derived for N distinguishable qubits and show that some of them are violated. We discuss the relavance of such differences for the Fisher information and its application to entanglement based high accuracy experiments.

Landau-Zener Decay of a Bose-Einstein Condensate in the Presence of Stochastic Noises

Speaker: TAYEBIRAD, Ghazal

A comprehensive study of tunneling dynamics of a Bose□Einstein condensate (BEC) in a tilted quasiperiodic potential is presented. Since no real system is defect□less, the study of quasiperiodic or stochastic systems enjoys a continuing popularity in theoretical as well as experimental groups. A variety of phenomena is expected to occur in these systems, such as Anderson localization and the quantum transition to the Bose glass phase originating from the interplay of interaction and disorder [1]. Our theoretical calculations, based on a mean□eld effective theory for many□particle condensate, explain the temporal behavior of the Landau□Zener tunneling. The step□like structure in the survival probability as a function of time which is achieved for a periodic system (resembling the periodic Bloch oscillation) are gradually washed out either in the presence of static and time□dependent incommensurable optical lattices together with increasing atom□atom interaction. The main idea is to search for possibilities of coherent quantum control of the transport and decay of Bose-Einstein condensates by stochastically time-dependent potentials. [1] Salger et al., Phys. Rev. Lett. 99, 190405 (2007); Fallani et al., Phys. Rev. Lett. 98, 130404 (2007); Schulte et al., Phys. Rev. A 77, 023610 (2008); Roati et al., Nature 453, 895 (2008)

Saturday 07 November 2009

Session 6 (07 November 09:00-10:30)

time	title
09:00	**How far can you push optimal control of quantum operations?** *Speaker: CALARCO, Tommaso* Quantum optimal control theory is a well established set of methods that can be applied to systematically improve the fidelity of quantum logical operations. They have been shown to be robust with respect to a broad range of experimental imperfections. Their ultimate limits, in particular concerning gate speeds, will be discussed in this talk in the light of examples from quantum computation and quantum communication.
09:30	**A statistical approach to bipartite entanglement** *Speaker: DE PASQUALE, Antonella* We introduce a statistical approach to the study of bipartite entanglement for large quantum systems; in particular our approach is based on a random matrix model that describes the purity of a party. We write the expression of a partition function, with a fictitious temperature and determine the spectrum of the reduced density matrix that maximize it. In the case of pure states the presence of phase transitions has been unveiled. We can also generalize and discuss this approach to the case of mixed states.
10:00	**Minimal output entropy problem for Gaussian Channels** *Speaker: GIOVANNETTI, Vittorio* We show that the minimum output entropy for all single-mode Gaussian channels is additive and is attained for Gaussian inputs. This allows the derivation of the channel capacity for a number of Gaussian channels, including that of the channel with linear loss, thermal noise, and linear amplification.

Coffee Break (10:30-11:00)

Session 7 (07 November 11:00-12:30)

time	title
11:00	**Multipartite Entanglement and Frustration** *Speaker: PASCAZIO, Saverio* A part of the global entanglement of a composed quantum system can be quantified by computing the purity of a balanced bipartition, made up of half of its subsystems. For the given bipartition, purity can always be minimized by taking a suitable (pure) state. When many bipartitions are considered, the requirement that purity be minimal for all bipartitions can engender conflicts and frustration arises. This unearths an interesting link between frustration and multipartite entanglement, defined as the average purity over all possible (balanced) bipartitions.
11:30	**Optimal fidelity of teleportation of coherent states and entanglement** *Speaker: VITALI, David* We study the Braunstein-Kimble protocol for the continuous variable teleportation of a coherent state. We determine lower and upper bounds for the optimal fidelity of teleportation, maximized over all local Gaussian operations for a given entanglement of the two-mode Gaussian state shared by the sender (Alice) and the receiver (Bob). We also determine the optimal local transformations at Alice and Bob sites and the corresponding maximum fidelity when one restricts to local trace-preserving Gaussian completely positive maps.
12:00	**Thermalization and ergodicity in many-body open quantum systems** *Speaker: ROSSINI, Davide* Recent experiments with ultracold atomic gases have raised an intense theoretical activity focused on some fundamental aspects of nonequilibrium physics in strongly correlated quantum systems. In particular, the observation of absence of thermalization in closed integrable systems put forward some questions related to the integrability issue in such systems. For closed many-body systems, integrability plays a crucial role in the relaxation to the steady state. The nonequilibrium dynamics of a chaotic system is expected to thermalize at the level of individual eigenstates; by contrast, for systems with non trivial integrals of motion, steady states usually carry memory of the initial conditions and are not canonical. Much less is known about the relaxation to the steady state for open quantum systems. We have performed extensive numerical investigations in many-body quantum systems locally coupled via Lindblad equation to an external bath. We provide evidence of the fact that quantum chaotic systems do thermalize, that is, after long time they reach an invariant ergodic state which is in the bulk well approximated by the grandcanonical state. Moreover, the resulting ergodic state does not depend on the details of the baths. On the other hand, for integrable systems the invariant ergodic state does depend on the bath and is in general different from the grandcanonical state.

Lunch (12:30-15:00)

Session 8 (07 November 15:00-16:30)

time title

15:00 **Entanglement generation and perfect state transfer in qubit chains**

Speaker: MARZOLI, Irene

We prove that long-range interacting qubit chains are working equally well as quantum channels for information transfer and entanglement generation. Our scheme relies on designing an effective two-qubit dynamics restricted to sender and receiver. Neither ancillary systems nor carefully engineered couplings are required. Our approach is fully scalable and straightforward to implement with arrays of trapped particles.

15:30 **Few-Qubit Lasing in Circuit QED**

Speaker: BROSCO, Valentina

Motivated by recent experiments [1], which demonstrated lasing and cooling of the electromagnetic modes in a resonator coupled to a superconducting qubit, we describe the specific mechanisms creating the population inversion, and we study the spectral properties of these systems in the lasing state [2]. Different levels of the theoretical description, i.e., the semi-classical and the semi-quantum approximation, as well as an analysis based on the full Liouville equation are compared. We extend the usual quantum optics description to account for strong qubit-resonator coupling and include the effects of low-frequency noise. We focus in particular on the phase coherence and diffusion of the electromagnetic field in the lasing state proving that in the strong coupling regime the phase diffusion rate depends non-monotonically on the qubit-resonator detuning. Due to this non-monotonic behaviour, in single-qubit lasers, the optimal lasing conditions are generally realized out of resonance, an effect which may lead to a double peak structure in the maser spectrum. Finally, in order to clarify the peculiar properties of single qubit lasers, we discuss the modifications occurring in the lasing state when many qubits are coupled to the resonator and the scaling of the diffusion rate with the number of qubits. [1] O. Astafiev et al., Nature 449, 588 (2007); M. Grajcar et al., Nature Physics 4, 612 (2008). [2] S. Andr\□e, V. Brosco, A. Shnirman, and G. Sch\□on Phys. Rev. A 79 053848 (2009); S. Andr\□e, V. Brosco, M. Marthaler, A. Shnirman, and G. Sch\□on, arxiv:0908.4227 (2009).

16:00 **Bayesian qubit phase estimation in the presence of phase diffusion: theory and experiment**

Speaker: OLIVARES, Stefano

We address Bayesian estimation of a phase shift imposed to a qubit when non-dissipative phase noise affects its propagation. The comparison with the ultimate quantum limit to precision, the quantum Cramer-Rao bound, is given. In our analysis we also take into account the biased nature of the Bayes estimator in the non-asymptotic regime. The experimental demonstration of our scheme relates on a setup based on a KDP crystal, that allows both to manipulate the optical qubit polarization and to simulate the noise affecting the propagation. An adaptive method to always achieve the optimal estimation, i.e., the Cramer-Rao bound, is also analyzed in some detail.

Coffee Break (16:30-17:00)

Session 9 (07 November 17:00-18:30)

time title

17:00 **Optimal tuning of solid state quantum gates: a i-SWAP^1/2 gate**

Speaker: PALADINO, Elisabetta

We present a general route to reduce inhomogeneous broadening in nanodevices due to $1/f$ noise. We apply this method to a universal two-qubit gate and demonstrate that for selected optimal couplings, a high-efficient gate can be implemented even in the presence of $1/f$ noise. Entanglement degradation due to interplay of $1/f$ and quantum noise is quantified via the concurrence. A charge-phase $\sqrt{{\rm i-SWAP}}$ gate for spectra extrapolated from single qubit experiments is analysed.

17:30 **Block entropy of the XYZ model: Exact results and numerical study**

Speaker: DEGLI ESPOSTI BOSCHI, Cristian

In the first part of this contribution we review the recent analytical results obtained by Ercolessi, Evangelisti and Ravanini (arXiv:0905.4000) regarding the block entropy of the XYZ spin-1/2 model. Using the corner transfer matrix formalism the exact value of the von Neumann entropy for a semi-infinite block whitin an infinite chain is obtained for all possible choices of the exchange couplings, including the fully anisotropic case. Remarkably, it is also possible to compute the block entropy for the quantum sine-Gordon model by taking a suitable scaling limit of the XYZ spin chain. The second part is devoted to a numerical investigation of these results, using the density-matrix renormalisation group algorithm. We discuss the even/odd finite-size effects and argue that the expected asymptotic values are correctly reproduced provided that the ground-state (quasi-)degeneracy is properly taken into account. In fact we show how the amount of entanglement is related to an interplay of the chain length and the symmetry breaking fields.

18:00 **Quantum cooperative effects in cavity**

Speaker: PLASTINA, Francesco

Two kinds of cooperative effects are discussed for qubits interacting with an off-resonance electromagnetic cavity, both of them concerning the Dicke super-radiance. The first is a static, critical phenomenon: the so called super-radiant phase transition, occurring when a large number of qubits is coupled to a single cavity mode giving rise to a quantum phase transition for a critical value of the interaction strength. The second is a dynamic phenomenon, producing (among other effects) the generation and/or preservation of entanglement between qubits even in the presence of cavity losses.

Sunday 08 November 2009

Session 10 (08 November 09:00-10:30)

time	title
09:00	**Quantum entanglement in many-body systems: Some recent results on fundamental aspects and applications to quantum information science** *Speaker: ILLUMINATI, Fabrizio* In this talk I will review some recent results by the Salerno quantum theory group on entanglement in many-body systems. First, I will discuss the phenomenon of long-distance entanglement in quantum spin models, some schemes for its implementation in optical lattices and coupled cavity arrays, and its use in protocols of long-distance, high-fidelity quantum communication. I will then review the general theory of ground-state factorization and illustrate how this property can be exploited as a tool to extract information on the phase diagram of frustrated quantum spin models. Finally, I will discuss a recently introduced generalization of the Wei-Goldbart geometric measure of entanglement and its applications to characterize and quantify multipartite quantum correlations.
09:30	**Optimized single-qubit gates for Josephson phase qubits** *Speaker: TADDEI, Fabio* In a Josephson phase qubit, the coherent manipulations of the computational states are achieved by modulating an applied ac current, typically in the microwave range. In this work, we show that it is possible to find optimal modulations of the bias current to achieve high-fidelity gates. We apply quantum optimal control theory to determine the form of the pulses and study in details the case of a NOT gate. To test the efficiency of the optimized pulses in an experimental setup, we also address the effect of possible imperfections in the pulses shapes, the role of off-resonance elements in the Hamiltonian, and the effect of capacitive interaction with a second qubit.
10:00	**Entanglement, Non-linear Dynamics and Heisenberg Limit** *Speaker: SMERZI, Augusto* We show that the quantum Fisher information provides a sufficient condition to recognize multi-particle entanglement in a N qubit state. The same criterion gives a necessary and sufficient condition for sub shot-noise phase sensitivity in the estimation of a collective rotation angle θ. The analysis therefore singles out the class of entangled states which are {\it useful} to overcome classical phase sensitivity in metrology and sensors. We apply our results to study the creation of useful entangled states by the non-linear dynamical evolution of two decoupled Bose-Einstein condensates or with ions trapped in periodic potentials. reference: Luca Pezzé and Augusto Smerzi, Phys. Rev. Lett. 102, 100401 (2009)

Coffee Break (10:30-11:00)

Session 11 (08 November 11:00-12:30)

time	title
11:00	**Quantum information processing by exploiting the orbital angular momentum of photons** *Speaker: SCIARRINO, Fabio* The orbital angular momentum (OAM) of light, associated with a helical structure of the wavefunction, has a great potential for quantum photonics, as it allows attaching a higher dimensional quantum space to each photon. Unlikespin angular momentum, however, OAM is yet to be widely exploited in the quantum information field, owing to its difficult manipulation. By exploiting the recently demonstrated spin-OAM information transfer tools, we report the first observation of the Hong-Ou-Mandel coalescence of two incoming photons having nonzero OAM into the same outgoingmode of a beam-splitter. Such effect has been then exploited to carry out the 1 2 universal optimal quantum cloning of OAM-encoded qubits, using the symmetrization technique already developed for polarization. These results are finally shown to be scalable to quantum spaces of arbitrary dimension, even combining different degrees of freedom of the photons.
11:30	**Networks of interacting qubits: mathematical perspective** *Speaker: SEVERINI, Simone* Networks of interacting qubits are a generalization of spin chains. These are of theoretical importance for the study of many-body quantum systems and could constitute a good test ground for technologies spanning from quantum key distribution in multi-user networks to various nano-scale devices. Networks of interacting qubits are also considered to be good candidates for engineering good quantum channels and allow information transfer between distant particles therefore covering the role of quantum buses. I shall review the mathematical perspective on these topics, with particular attention to design of networks for perfect state transfer. The technical tools include algebraic and spectral graph theory, combinatorial number theory, etc.
12:00	**A new class of Decoherence-Free Macroscopic Quantum Superpositions** *Speaker: DE MARTINI, Francesco*