Meeting on
Quantum Information Processing and Applications
02-08 December, 2013

QIPA-2013

Harish-Chandra Research Institute
Chhatnag Road, Jhunsi, Allahabad-211019, India

Information for Participants of QIPA – 2013

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Accommodation: Your stay has been arranged at one of the following places (1) HRI guest house **"**Pratisthanpur**"**, (2) apartments within the campus, (3) IGM guest house (about 3km from the campus), and (4) Hotel Grand Continental (in the city). You can contact HRI guest house reception (0532-227-4080, 0532-227-4109, 0532-2569303) for any help/query regarding accommodation. If you are staying outside the campus, we shall arrange transport from your place of accommodation to HRI and back. The details of such pick up and drop shall be mentioned separately.

Venue: The venue of the conference will be HRI auditorium which is located in the main building inside the campus.

Registration: 02.12.2013 from 8.00 AM to 8.45 AM outside the auditorium.

Poster session: The contributed posters can be displayed from day one till the end of the workshop at the lobby outside the auditorium. However there will be a slot allotted for the poster session during the workshop.

Food: Food arrangements are made at the HRI guest house **"**Pratisthanpur**".** The timings are:

For Breakfast	:	7:30 - 9:00 AM
For Lunch	:	12.30 - 2:30 PM
For Dinner	:	7.30 - 9:30 PM

(on Dec 6, there will be a conference banquet which will be from 7.00PM)

Refreshments: Beverages and some snacks are available at the guest house and institute pantry. Guest house services are round the clock whereas pantry works from 8.00 AM to 8.00 PM. Payment at the guest house has to be done to the respective staffs. At the pantry, the payment has to be done through coupons which can be bought from the reception during office hours.

Internet facility: Wireless is available in the entire main building of the institute, the auditorium, the guest house seminar rooms, and the pantry. You can also access the internet on your laptop from your respective places of accommodation within the campus via LAN (for which you need to have a LAN/patch cord with you). In addition, you can access the internet on desktops in the conference computer room, which is on the first floor of the building where the conference is taking place. Your login and password is inside your bag.

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Proxy	Port	Availability
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Library facility: You can use the library for references. However, you may not be allowed to borrow books. Please enter your name and address in the register kept at the entrance, before entering the library. Photo copying facility in library is available only during working hours. The library is open during 08.00 AM (day 1) – 02.00 AM (day 2) from Monday to Saturday and during 08.00 AM to 6.00 PM on Sundays.

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ABSTRACTS FOR INVITED SPEAKERS

Local Response of Topological Order to an External Perturbation

Luigi Amico
Dipartimento di Fisica, Univ. Catania, Italy and Centre for Quantum Technologies, NUS, Singapore

I elaborate on the idea that topologically ordered ground states can be distinguished through a specific property related to the notion of LOCC, known as differential local convertibility. Such a property can be expressed in terms of the response of the Renyi entropies to an external perturbation. I will present results for one and two dimensional spin systems. Using analytical and numerical methods, we show that while a subset of these entropies increase with the correlation length, others decrease in the topologically ordered phase; compared to the response in the trivial phase where all entropies increase with increasing correlation length. We conjecture that this characteristic perturbative response should hold for a wider class of states such as quantum double models, cluster states and other quantum spin liquids. The findings here hold experimental promise because the subsystem size can be independent of the correlation length, in addition we discuss their implication s for quantum information processing tasks using topologically ordered states. Finally, I will discuss the results in the context of universal quantum simulators.

Quantum Simulations by NMR: (a) Mirror Inversion of Quantum States in an XY spin-chain and (b) Dzyaloshinsky-Moriya (DM) Interaction in presence of Heisenberg XY interaction: optimized by Genetic Algorithm

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Feynman in 1982 suggested that Quantum Simulations using a Quantum device will be “efficient”. This has lead to an explosion of Quantum Simulations by NMR in recent years. Many quantum calculations have been performed including “calculation of the ground state of Hydrogen Molecule up to 45 bit accuracy using a 2-qubit NMR system by Du et al (PRL **104**, 030502, 2010). We have also performed Quantum Simulations of entanglement in a 3-spin Heisenberg XY chain using nearest neighbour interaction and simulated the quantum transverse Ising spin system in a triangular configurations and studied the frustrated and non-frustrated phases in the ground state of such a system.

Here we report an experimental quantum simulation of the unitary dynamics of an XY spin chain and demonstrate “mirror” inversion of the quantum states of the system using a 5-qubit NMR system. Further it is demonstrated that entangled states can be transferred from one end of the spin chain to the other, using “mirror” inversion. In another study we have performed Entanglement preservation of Bell States in presence of Heisenberg XY interaction and DM interaction, using Genetic algorithm.

State Tomography with Weak Measurements

Arvind
Indian Institute of Science Education and Research (IISER) Mohali, India

Measurement in quantum physics has a very different connotation as compared to that in classical physics. Measurement invariably disturbs the quantum system, and we say that information comes at a certain cost. The most commonly encountered quantum measurements are projective measurements, where the state collapses into one of the eigenvectors of the observable being measured. There is no further information that one can obtain by making a repeated measurement on this collapsed state. Alternatively, one could conceive of ``weak'' measurements, where the coupling of the apparatus with the system is weak, and only a limited amount of noise is introduced. Consequently, the information obtained from this weak measurement is also limited. However, there is a possibility of recycling the state and making further measurements on it, which may reveal more

information about the state. In this way, weak measurements are distinct from projective measurements. We have explored state reconstruction using weak measurements and compared their efficacy with state tomography by projective measurements. Since state tomography requires an ensemble of identically prepared states, we have assumed finite ensembles and calculated the dependence of the fidelity of the tomography scheme as a function of ensemble size in both cases. We have shown that in certain circumstances, weak measurements with state recycling can be a better tool for state reconstruction. This we believe, extends the scope of extracting information from quantum systems at a reduced cost. The work is in progress to optimize these measurement schemes.

Power-law Random Banded Unitary Matrices: A new random matrix ensemble

Jayendra N Bandyopadhyay
Physics Department, BITS-Pilani, India

Power-law random banded unitary matrices (PRBUM), whose matrix elements decay in a power-law fashion, were recently proposed to model the critical statistics of the periodically driven quantum systems. In this talk, we discuss the statistical properties of the PRBUM ensemble. We also discuss its recent application in ocean acoustic propagation or underwater sound propagation in ocean.

Quantum Information: From the perspective of Quantum Optics

Subhashish Banerjee
Indian Institute of Technology Jodhpur, India

Here I will talk about some aspects of quantum information from the perspective of quantum optics. The systems used are, usually, subject to damping and dephasing: naturally treated within the ambit of Open Quantum Systems. After a brief discussion of open quantum systems and some measures of quantum information, I will talk about the dynamics of quantum correlations and holonomic quantum computation in a number of models motivated from quantum optics. In the end, diverting somewhat from the main theme, I will briefly talk about geometric phase in a frustrated spin system which also brings out an interesting connection with Parrondo's effect.

Inseparability Inequalities for Multi-Spin Systems based on Bipartition

Asoka Biswas
Indian Institute of Technology Ropar, India

The detection and measurement of multipartite entanglement has always been of basic importance in the field of quantum computation and information. Though the entanglement in two-spin systems is well understood, detection of entanglement in many-spin systems is still an open issue. We propose a new set of inequalities, based on the Peres PPT criterion, to detect and quantify different classes of multipartite entanglement in spin systems. This is based on the prescription of Shchukin and Vogel that was originally proposed to detect entanglement in bipartite continuous variable systems. We consider different forms of bipartitions in a multi-spin system and identify inequalities in terms of collective spin operators on each partition. Two inequivalent sets of inequalities are obtained for GHZ-like and W-like entangled states. The entanglement in these states can be quantified on the basis of extent of violation of these inequalities. Our proposal uniquely explores the entanglement between different partitions of a multipartite system, unlike the proposals based on spin-squeezing, covariance matrix, and Schrodinger-Robertson uncertainty. Further, as the inequalities involve the expectation values of collective spin operators, it does not require addressing of individual spin and can be demonstrated in experiments.

Retrieving and Routing Quantum Information in a Quantum Network

Indranil Chakrabarty
IIIT Hyderabad, India

In quantum secret sharing protocols, once the secret is shared in a quantum network (qnet) it can not be retrieved back, even if the dealer wishes that her secret no longer be available in the network. For instance, if the dealer is part of two qnets, say Q1 and Q2 and she subsequently finds that Q2 is more reliable than Q1, the dealer may wish to transfer all her secrets from Q1 to Q2. Extant protocols are inadequate to address such a revocation. In this work we address this problem by designing a protocol that enables the source/dealer to bring back the information shared in the network, if desired. Unlike classical revocation, no-cloning-theorem automatically ensures that the secret is no longer shared in the network. The implications of our results are multi-fold. One interesting implication of our technique is the possibility of routing qubits in asynchronous qnets. By asynchrony we mean that the requisite data/resources are intermittently available (but not necessarily simultaneously) in the qnet. For example, we show that a source A can send quantum information to a destination R even though (a) A and R share no quantum resource, (b) R's identity is unknown to A at the time of sending the message, but is subsequently decided, (c) A herself can be R at a later date and/or in a different location to bequeath her information (`backed-up' in the qnet) and (d) importantly, the path chosen for routing the secret may hit a dead-end due to resource constraints, congestion etc. (therefore the information needs to be back-tracked and sent along an alternate path). Another implication of our technique is the possibility of using insecure resources. For instance, if the quantum memory within an organization is insufficient, it may safely store (using our protocol) its private information with a neighboring organization without (a) revealing critical data to the host and (b) losing control over retrieving the data. Putting the two implications together, namely routing and secure storage, it is possible to envision applications like quantum mail (qmail) as an outsourced service.

A quantum dynamical framework for Brownian heat engines

Subhash Chaturvedi
University of Hyderabad, India

Motivated by recent experimental works, we present a self contained microscopic framework modelled after the Brownian motion of a quantum harmonic oscillator for describing the performance of microscopic Brownian heat engines such as Carnot, Stirling and Otto engines. Our work, besides reproducing the standard thermodynamics results in the steady state enables permits us to study the role dissipation plays in determining the efficiency of Brownian heat engines under actual laboratory conditions. This work though of great topical interest falls more in the category of `quantum thermodynamics' than quantum information processing.

Quantum Interference Between a Single Spin Excitation and a Macroscopic Atomic Ensemble

S. L. Christensen, J.-B. Béguin, E. Bookjans, H. L. Sørensen, J. H. Müller, J. Appel, E. S. Polzik
QUANTOP, Niels Bohr Institute, University of Copenhagen, Denmark

We report on the observation of quantum interference of a collective single spin excitation with a macroscopic spin ensemble of 10^5 atoms. Detection of a single photon scattered from the atoms via a Raman process creates a collective single spin excitation [1]. This is a Fock state directly embedded in the spin of the ensemble. The state of the atomic ensemble is then detected by tomography via a quantum non-demolition measurement of the collective spin [2, 3]. To characterize the created state we measure the population difference and compare the statistics of these measurement outcomes in the presence and absence of a spin flip. Due to the quantum interference between the single excited atom and the remaining ground state atoms this difference is much larger than a single atom effect [4, 5]. The hybrid discrete-continuous processing of the collective spin paves the road towards generation of even more exotic states for quantum information processing, precision measurements and communication.

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Sensing and Imaging at the Quantum Limit

Animesh Datta
University of Oxford, UK

Quantum correlated probes have the potential of delivering enhanced precision in estimating individual parameters. Obtaining quantum enhancements in scenarios of wider appeal such as imaging require an understanding of the quantum limits of estimating several parameters across multiple modes simultaneously. The problem is made theoretically and well as practically interesting and non-trivial by the possible non-commutativity of the optimal measurements needed to attain the quantum limits for estimating individual parameters. We present developments on the quantum theory of estimating multiple parameters -- arising from both unitary dynamics as well as decoherence -- simultaneously in a few scenarios, and its ramifications in the imaging of real-world samples.

Quantum criticality, quenches and the Loschmidt echo

Amit Dutta
Indian Institute of Technology, Kanpur, India

I shall introduce the notion of the Loschmidt echo using the central spin model in which a central spin (qubit) is globally coupled to a spin chain. I shall indicate how does the Loschmidt echo behave close to a quantum critical point and how it is also related to the decoherence of the central spin which was initially in a pure state. Finally, I shall discuss at some length the behavior of the echo when the spin chain is driven across a quantum critical point suddenly or slowly.

Non-Markovianity Through Accessible Information

Felipe Fernandes Fanchini
U Estadual Paulista, Bauru, Brazil

We demonstrate how the entanglement-based measure of non-Markovianity [A. Rivas, S. F. Huelga, and M. B Plenio, Phys. Rev. Lett. 105, 050403 (2010)] is related with the flow of information between a quantum system and its environment using the concept of assisted knowledge, where a subsystem obtains information about other by means of a third party. Our approach is in the spirit of the decoherence program, in the sense that we consider a system that is correlated with a quantum measurement apparatus through which the environment learns about the system. We reveal that, the rate of change of the entanglement of formation between the system and the apparatus is directly linked with the rate of change of information that the environment can acquire about the system, namely the accessible information, which can be shown to monotonously increase for all Markovian quantum processes. We present an experimental realization of this scenario with the help of an optical-based setup that allows full access to the environmental degrees of freedom.

Entanglement in Classical Optics

Partha Ghose
Bose Institute, Kolkata, India

That entanglement, which has hitherto been regarded as an exclusively quantum feature of the world, also occurs in classical polarization optics, resulting in the violation of Bell-like inequalities, has been a major realization in recent years. It can even be shown that entangled classical light violates noncontextuality and that it can be used to simulate quantum information processing tasks. A short review of these developments will be sketched.

Towards a Universal Count of Resources Used in a Precision Measurement

Saikat Ghosh
Indian Institute of Technology Kanpur, India

A possible route to quantify resources (N) used in a general precision measurement is considered, independent of specific system dynamics or states. For any arbitrary measurement model with a discrete set of outcomes (M+1), we explicitly construct a probability distribution that minimizes the standard deviation and it is found that this distribution is unique i.e. any single parameter estimation strategy, classical or quantum, will have to yield to this distribution as the final measurement outcome. Furthermore, we show that the standard deviation for this distribution is bounded by 1/M. This motivates a simple ansatz equating resources (N) to the number of possible discrete outcomes (M+1). We justify the ansatz for measurements for all classically correlated as well as few quantum-mechanically correlated probe states. Accordingly, we conclude that 1/N is an absolute, information-theoretic limit for any general measurement of a single parameter and is independent of specific classical or quantum measurement strategies. Furthermore, it is argued that the bound is not achievable in practice.

Minimal State-Dependent Proof of Measurement Contextually for a Quit

Sibasish Ghosh
Institute of Mathematical Sciences, Chennai, India

We show that three unsharp dichotomic quit measurements are enough to violate a generalised non contextual inequality in a state-dependent manner. For the case of trine spin axes we calculate the optimal quantum mechanical violation of this inequality. We conjecture this to be the optimal quantum mechanical violation obtainable from quit measurements. Besides, we show that unsharp quit measurements do not allow a state-independent violation of this inequality. We thus provide a minimal state-dependent proof of measurement contextually requiring one quit and three unsharp measurements. This is a novel no-go theorem for generalised non contextual models of these measurements.

Experimental Quantum Correlations in Condensed Phase: Possibilities of Quantum Information Processing

Debabrata Goswami
Indian Institute of Technology Kanpur, India

We have recently observed femtosecond laser induced coherent oscillations in a large cyanine dye (IR775) in binary liquid mixture of methanol and chloroform illustrating micro-heterogeneity. However, these oscillations also provide information of the coherent correlations existing within the system. Earlier gas phase experiments on complex molecules at ultrafast timescales have shown coherent correlations that have also been connected to quantum information processing. Condensed phase experimental applications are more attractive due its

scalability and its ease of experimentation. In this talk I will show how our efforts on ultrafast optical quantum information processing with molecules have evolved over the years to finally get to a molecular system in the condensed phase that show coherent correlations.

Simple Method of Obtaining Bell Inequalities from Quantum Advantage in One Way-Communication Complexity

Andrzej Grudka
Adam Mickiewicz University in Poznan, Poland

We consider relations between communication complexity problems and detection of correlations (violation of local realism) with no local hidden variable model. We show first universal equivalence between characteristics of protocols used in that type of problems and non-signaling correlations. We provide simple method of obtaining Bell inequalities and show that existence of a gap between quantum and classical communication complexity classes leads to violation of these inequalities. In particular we construct non-linear bipartite Bell inequalities with binary observables and show their exponential violation.

On the Quantum Limits of Classical Communication and Secret-Key Generation over a Lossy Optical Channel

Saikat Guha
Raytheon BBN Tech, Cambridge, USA

This talk will address two closely inter-related topics: The quantum limit on the rate of reliable transmission of classical information over a lossy optical channel, and the quantum limit on the rate at which two distant parties separated by a lossy optical channel can generate information-theoretically-secure shared secret keys when an eavesdropper has access to the isometric extension of the channel, i.e., she gets to collect all the photons transmitted in either direction that do not reach the intended receiver. For the former problem, even though the quantum limit to the reliable communication rate--the `Holevo capacity'--is known [1, 8], and is known to be achievable using ideal laser-light modulation [1], structured optical receivers to attain this capacity, which must make collective measurements over long symbol blocks, are not as well understood [5]. I will present some of our recent results on explicit codes [4], structured joint-detection receivers [2, 3, 6, 7], and finite-blocklength performance bounds on such receivers [10] towards attaining the Holevo capacity. Unlike this forward-communication capacity, which increases unbounded with increasing input power, the secret-key-generation capacity of the lossy optical channel--with unlimited two-way authenticated public classical communication allowed between the sender and the receiver--has a tight upper bound that is solely a function of the channel loss [9]. I will present this new upper bound on the secret-key-generation capacity that stems from a recent result on the squashed entanglement of a quantum channel, which closes the gap between the best-known achievable secret-key-generation rate (the reverse-coherent-information bound) and our new upper bound, in the high loss regime. I will show secret-key-agreement rates achievable via several structured protocols against the squashed-entanglement upper bound.

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Probing Quantumness and its Macrolimit of the Schrödinger Coherent State for Harmonic Oscillator using Leggett-Garg inequality

Dipankar Home
Bose Institute, Kolkata, India

The Leggett-Garg inequality (LGI) as a temporal analogue of Bell's inequality (BI) has acquired considerable significance in recent years. The original motivation that led to LGI was to use it for probing the QM effects in the macroscopic regime, e.g., in the context of suitable experiments involving the rf-SQUID device. Of late, a variety of studies, both theoretical and experimental, have been made to investigate the extent to which LGI is violated by QM for different types of systems. In this talk, after explaining the basics of LGI, it will be applied to show testable non-classical feature of the Schrödinger Coherent State (minimum uncertainty non-spreading wave packet) which is usually regarded as providing quasi-classical quantum description of a linear harmonic oscillator. The macrolimit of quantumness of such a state will be discussed in terms of LGI. Conceptual implication of this study as regards the role of measurement in QM will be analyzed.

Nodal Domains of the Equilateral Triangle Billiard

Sudhir R. Jain
Bhabha Atomic Research Centre, Mumbai, India

We characterise the eigenfunctions of an equilateral triangle billiard in terms of its nodal domains. The number of nodal domains has a quadratic form in terms of the quantum numbers, with a non-trivial number-theoretic factor. The patterns of the eigenfunctions follow a group-theoretic connection in a way that makes them predictable as one goes from one state to another. Extensive numerical investigations bring out the distribution functions of the mode number and signed areas. Finally, the distribution functions of the nodal loop count and the nodal counting function are shown to contain information about the classical periodic orbits using the semiclassical trace formula. We believe that the results belong generically to non-separable systems, thus extending the previous works which are concentrated on separable and chaotic systems.

Two-Photon Fields: Coherence, Interference and Entanglement

Anand Kumar Jha
Indian Institute of Technology Kanpur, India

One of the most widely used processes for generating entangled two-photon fields is parametric down-conversion. It is a second-order nonlinear optical process in which a pump photon interacts with a nonlinear

crystal and breaks up into two separate photons known as the signal photon and the idler photon. The constraints of energy and momentum conservation render the two photons entangled in several different variables including time and energy, position and momentum, and angular position and orbital angular momentum. In this talk, I will present our studies of the coherence and entanglement properties of the down-converted two-photon field and will also discuss some of the practical implications of these studies for quantum information science.

Quantum Algorithm for Linear Programming (LP) Problems

Pramod S. Joag
University of Pune, India

We present a quantum algorithm for solving LP problems. This is done by transforming the given LP problem, using its dual, to the problem of solving a system of linear equations comprising

i. the equation representing the duality condition at optimality,
ii. equations representing constrints imposed on primal problem and
iii. equations representing constrints imposed on the corresponding dual problem,

whose non-negative solutions are sought. The non-negative solutions are obtained by Non-negative Least Squares method (NNLS) which is iterative and requires solving a system of linear equations in each iteration. We employ the quantum algorithm to solve the system of linear equations proposed by Seth Lloyd and collaborators [PRL 103, 150502 (2009)]. A classical implementation of the algorithm requires N^3 operations (N : number of variables in the problem, which can be as large as one million) while the quantum algorithm achieves exponential speed up as it requires operations linear in log(N). With a forty qubit quantum computer, an LP problem containing 10^12 variables can be solved, which is classically intractable.

The Triangle Principle: A New Approach to Non-Classical Correlations

Dagomir Kaszlikowski
National University of Singapore, Singapore

We study an application of an information distance between two measurements to investigate non-classical correlations. We postulate the triangle principle which states that any information distance is well defined on any pair of measurements, even if the two measurements cannot be jointly performed. As a consequence, the triangle inequality for this distance is obeyed for any three measurements. This simple principle is valid in any classical realistic theory, however it does not hold in quantum theory. It leads to derivation of certain inequalities whose violation is a new indicator of non-classicality. Some of these new inequalities formally look the same as those found in the literature but we also derive completely new inequalities. We also show that this principle can be applied to derive monogamy relations. The triangle principle is different than the assumption of non-contextuality and local realism, which is defined as a lack of existence of a joined probability distribution recovering all measurable data.

A Universal Framework for Entanglement Detection

Marek Kus
Center for Theoretical Physics, Polish Academy of Sciences, Poland

We construct nonlinear multiparty entanglement measures for distinguishable particles, bosons and fermions. In each case properties of an entanglement measures are related to the decomposition of the suitably chosen representation of the relevant symmetry group onto irreducible components. In the case of distinguishable particles considered entanglement measure reduces to the well-known many particle concurrence. We prove that our entanglement criterion is sufficient and necessary for pure states living in both finite and infinite dimensional spaces. We generalize our entanglement measures to mixed states by the convex roof extension and give non-trivial lower bounds of thus obtained generalized concurrence leading to effective criteria for discriminating multipartite mixed entangled states in various settings.

Local Unitary Invariants from Entanglement Detecting Maps and Applications to Dynamical Systems

Arul Lakshminarayan
Indian Institute of Technology Madras, India

Motivated by link transformations of lattice gauge theory, a method for generating local unitary invariants, especially for a system of qubits, has been pointed out in an earlier work. We show the equivalence of the so constructed transformations to the combined operations of partial transpose and realignment. This allows construction of local unitary invariants of any system, with subsystems of arbitrary dimensions. Some properties of the resulting operators and consequences for pure tripartite higher dimensional states are discussed and applied to a system of three rotors where interesting dynamical properties are reflected in these invariants.

Incompatible Local Hidden-Variable Models of Quantum Correlations

Wieslaw Laskowski
University of Gdansk, Gdansk, Poland

There exist correlations between quantum systems that cannot be explained by any local hidden-variable (LHV) theory. The simplest scenario that demonstrates this phenomenon involves bipartite entangled quantum states measured with one of two local observables [1,2]. This original approach of Bell was later extended to correlations between more parties [3–6] and to correlations between different numbers of subsystems [7–11]. A natural question arises if there is a correlation Bell inequality that can be violated although all inequalities involving correlations between a fixed number of observers are satisfied. Our main finding is that there exist multiparty states with explicit LHV models for correlations between any fixed number of subsystems in a Bell scenario with two settings per party. Nevertheless these models can be disqualified. It turns out that they are incompatible with each other and cannot be extended to model correlations between various numbers of subsystems. We present a Bell-like inequality that involves correlations between different numbers of subsystems which is satisfied by all LHV models and violated by the quantum correlations. We also show a stronger result, by exhibiting separable two-party reduced states A-B, A-C, and B-C, such that any three qubit state compatible with these marginals violate a Bell inequality. Hence, we obtain that nonclassicality of multipartite states can be certified from information only about separable marginals.

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Quantum Counting of Prime Numbers

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We propose a quantum circuit that creates a pure state corresponding to the quantum superposition of prime numbers. This {\em Prime} state can be built using an oracle which is a quantum implementation of the classical Miller-Rabin primality test. The {\em Prime} state is highly entangled, and its entanglement measures encode number theoretical functions such as the distribution of twin primes or the Chebyshev bias. This algorithm can be further combined with the quantum Fourier transform to yield an estimate of the prime counting function, more efficiently than any classical algorithm and with an error below the bound that allows for the verification of the Riemann hypothesis. Arithmetic properties of prime numbers are then, in principle, amenable to experimental verification on quantum systems.

Ancilla-Assisted Quantum Information Processing

T. S. Mahesh
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Ancillary qubits are used in various protocols of QIP. Often they are part of a quantum algorithm, but sometimes the presence of ancilla qubits, though not essential, assist in increasing the efficiency of experimental protocols. In this regard, we describe certain scenarios where additional qubits can be exploited, if available. For example, we explain how additional qubits allow complete state tomography with just one measurement. Presence of ancilla qubits can assist in single-shot process tomography. We then explain how ancilla qubits are exploited in quantum simulations with explicit example of single-particle Schrodinger dynamics. A single ancilla qubit can be used to emulate a quantum beam-splitter in a quantum delayed choice experiment. Ancilla qubits are also useful for non-invasive measurements required in certain experiments. We further describe how random kicks on ancilla qubits can be used to introduce controlled nonunitary dynamics on the system qubits. Finally we describe how a large number of ancilla qubits can be used for efficient phase encoding required in certain standard experiments in spectroscopy.

Fixing the Lower Limit of Entropic Uncertainty Using Quantum Memory

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The limitation on obtaining precise outcomes of measurements performed on two non-commuting observables of a particle as set by the uncertainty principle in its entropic form, can be reduced in the presence of quantum memory. We derive a new entropic uncertainty relation based on fine-graining, which leads to an ultimate limit on the precision achievable in measurements performed on two incompatible observables in the presence of quantum memory. The maximum possible reduction of uncertainty is shown to be related to classical information. We show that our derived uncertainty relation tightens the lower bound set by entropic uncertainty for members of the class of two-qubit states with maximally mixed marginals, while accounting for the experimental results using maximally entangled pure states and mixed Bell-diagonal states. An implication of our uncertainty relation on the security of quantum key generation protocols is pointed out.

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Flow of Information and Classical simulatability in MBQC and Adiabatic QC

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We present recent work on how flow and spread of information during a computation can be used bound classical simulatability of the computation in measurement based quantum computation (MBQC). The main tool utilised is the gflow - a causal structure for measurements guaranteeing deterministic computation for graph state resources. In the first instance we show how the size of the causal cone induced by gflow bounds the difficulty in classical simulation, and futhermore the same cone can be interpreted as an information forward cone. Secondly we show how gflow leads to natural bounds on the entanglement of the resource state, leading to another complementary approach to bounding the cost of classical simulation. Using the same tool, gflow, we present a general translation of MBQC to adiabatic quantum computation, through which these, and many other notions can be translated.

Experimental Quantification of Entanglement and Quantum Discord in Spin Chains

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We report the macroscopic entanglement properties of a low dimensional quantum spin system by investigating its magnetic properties at low temperatures and high magnetic fields. The temperature and magnetic field dependence of entanglement from the susceptibility and magnetization data is performed and comparison is made with corresponding theoretical estimates. Extraction of entanglement has been made possible through the macroscopic witness operator, magnetic susceptibility. The spin system studied is a chain, which exhibits dimerisation and yields fascinating entanglement properties when the temperature and magnetic field are varied. These spin systems exhibit quantum phase transition (QPT) at low temperatures, when the magnetic field is swept through a critical value. We show explicitly, using tools used in quantum information processing (QIP), that quantum phase transition (QPT) can be captured experimentally using quantum complementary observables. We also report heat capacity as an entanglement witness. Entanglement properties of the same quantum spin system has also been investigated by heat capacity measurements performed down to very low temperatures (400 mK), for various applied magnetic field values. The experimentally extracted results for the value of heat capacity at zero field matches perfectly with the theoretical estimates of entanglement from model Hamiltonians. We also report experimentally quantified quantum discord in the same spin system.

Ramp Dynamics for Entanglement Generation and Cooling

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Advancing from demonstrative quantum gates to real application requires scalable computing architecture. Considering the best performing demonstrative system, a chain of trapped ions, it needs to satisfy scalability either by qubit shuttling or by large scale entanglement and qubit processing. In either case lies the experimental challenge of motional state heating. Here I will discuss a possible way of achieving both many-body entanglement as well as non-invasive motional state cooling utilizing the non-equilibrium dynamics of the Bose-Hubbard model (BHM). A chain of ions in a linear trap can be shown to behave like coupled oscillators whose phonons are trapped at each site of the ions and can be fully described by an effective BHM. The time evolution of the BHM can be suitably utilized to perform both the above quantum manipulations using very similar protocols. The theoretical detail an experimental advancements will be discussed in details.

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A Mechanical Switch for Quantum State Transfer in Dual Cavity Optomechanical Systems

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Optomechanical systems are coupled cavity and spring systems. The radiation pressure force exerted by the field inside the cavity establishes coupling between the cavity and the spring. The coupling leads to cooling of the mechanical spring to its quantum mechanical ground state thus opening the possibility of quantum state transfer from the filed mode of the cavity to the mechanical mode of the spring. Dual cavity opto-electromechanical systems (OEMS), consists of two electromagnetic cavities connected by a common mechanical spring. These systems have been shown to facilitate high fidelity transfer of quantum states of light from one cavity to another using a dark mode in the system Hamiltonian [1]. In this talk I will explain the effects of additional mechanical modes on the fidelity of quantum state transfer in a dual cavity OEMS. I will outline how this can be used to create an efficient mechanical switch which will either inhibit or facilitate quantum state transfer between the cavities [2].

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Geometric Discord: Some Analytic Results

Preeti Parashar
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After a brief introduction to geoemtric discord as a correlation measure, I will discuss its anaylitical formulae and interrelation with entaglement. It will also be shown that there is a unique (up to LU) separable two qubit X state having maximum geometric discord 1/4.

Master-Key Controlled Quantum Key Distribution

Tabish Qureshi
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We analyze three entangled particles in a GHZ state and show that the concept of Quantum Disentanglement Eraser provides the possibility of a modified Quantum Key Distribution protocol. In this protocol, a 3-particle source is held by a third person, the Master, who sends two particles to Alice and Bob. The Master can control the key distribution in the sense that Alice and Bob cannot share a secret key unless he publicly provides them with a master-key, later in time. Another variant of the scheme has been proposed in which Alice holds a 3-particle source and sends two particles to Bob, keeping one with herself. Bob uses one particle to generate a secure key, and the other to generate a master-key. This scheme provides an additional level of complexity, in ideal situations, as compared to the standard protocols BB84 and Eckert.

Geometry and Operator Entanglement Of Two-Qubit Gates

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National Institute of Technology, Trichy, India

In the recent years, there has been much attention on the unitary operators, as they are responsible for the entanglement of quantum states. From the information view point, investigations on nonlocal features of these operators are fundamental in nature. In this direction, Cartan decomposition of SU(4) class for practical model of spin-1/2 systems is relevant [1]. The decomposition leads to an elegant geometrical perspective for the two-qubit gates [2]. An equivalent representation called operator-Schmidt decomposition, wherein nonlocal features of the gates are measured using Schmidt number and operator entanglement (Schmidt strength, linear entropy etc.). In this talk, the above measures in terms of the geometry will be discussed [3,4].

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Majorana Modes and Non-Abelian Statistics

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We give an introduction to Majorana modes in condensed matter systems. We then describe some of the systems which have Majorana states as non-local fractionalized quasi-particles and show how the exchange statistics of these states are non-abelian. Finally, we briefly describe some of the experimental setups looking for Majorana modes such as fractional Josephson effect and interferometry experiments.

Remote Tomography and Entanglement Swapping via von Neumann-Arthurs-Kelly Interaction

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Homi Bhabha Centre for Science Education,
Tata Institute of Fundamental Research, Mumbai, India

Abhinav Deshpande and Nitica Sakharwade,
Indian Institute of Technology Kanpur, India

We propose a novel interaction-based method for remote tomography and entanglement swapping. Alice arranges a von Neumann-Arthurs-Kelly interaction between a system particle P and two apparatus particles A_1, A_2, and then transports the latter to Bob. Bob can reconstruct the unknown initial state of particle P not received by him by measurements on A_1,A_2. Further, if another particle P' in Alice's hands is EPR-entangled with P, it will be EPR entangled with the distant pair A_1,A_2. This method will be contrasted with usual teleportation protocols.

Bipartite Versus Multipartite Entanglement in Strongly Correlated Systems

Anna Sanpera
Universitat Autonoma de Barcelona, Barcelona, Spain

In spin 1/2 systems, rotationally invariant states can be used to detect genuine tripartite entanglement beyond nearest-neighbour. In this talk I will review main properties of rotationally invariant states, and construct a very general entanglement witness independent on the details, geometry or dimensionality of the Hamilonian we are interested on. We will exemplarize the use of the witness operator by studying the XXZ chain and the breaking of the underlying symmetries.

Local Quantum Uncertainty and Bounds on Quantumness for $\mathcal{O} \otimes \mathcal{O}$ invariant class of states

Debasis Sarkar
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Quantum mechanics shows several counter-intuitive results when we are dealing with composite systems. There exist correlations between different parts of composite quantum systems commonly known as non-classical correlations. Entanglement is one of the most powerful non-classical correlation that establishes its importance in different information processing tasks. However, several post entanglement correlation measures have generated a lot of interests in recent years. Discord, quantum deficit, measurement-induced nonlocality (in short, MIN) are a few of them. Recently Girolami et. al. introduced the concept of local quantum uncertainty which quantifies the uncertainty in a quantum state due to measurement of a local observable. However, we could consider this quantifier as a faithful measure of quantumness in quantum states. Now, due to inherent optimization, finding closed formula is a difficult problem for most of the correlations measures. Local quantum uncertainty (LQU) has analytical form only for any qubit-qudit system. Here, we will consider orthogonal invariant class of states which is a larger class of symmetric states. It contains both Werner and Isotropic classes. We will derive bounds and closed form (for some specific cases) of LQU for this class of states in two qudit system. We will also evaluate bounds of geometric discord and MIN for this symmetric class of states and discuss some related issues.

Review of the Firewall Paradox

Ashoke Sen
Harish-Chandra Research Institute, Allahabad, India

In this talk I shall review some of the arguments and counter arguments to the hypothesis that for an old black hole the smooth horizon is replaced by a firewall where an infalling observer burns up.

Probing the Environment Using System Dynamics in Open Quantum Evolution

Anil Shaji
Indian Institute of Science Education and Research, Thiruvananthapuram, India

Modeling the environment of a single qubit as an N dimensional quantum system, we show that the dynamics of the qubit alone, if measured in sufficient detail, can reveal the parameters of the qubit-environment coupling Hamiltonian. We show that data from quantum process tomography experiments can be used to get information about the environment that can be used to minimize its deleterious effects on the state of the qubit.

Quantifying the Quantum

Urbashi Sinha
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In the first part of the talk, I will describe some theoretical investigations towards more precise understanding of certain features of Quantum Mechanics. This includes the Wave function hypothesis [1] as well as Sorkin's measure theory in the context of superluminal signalling [2]. We find that the commonly used text-book assumption that in a double slit interference experiment, the wave function at the screen with both slits open is exactly equal to the sum of the wave functions with the slits individually open one at a time called the Wave function hypothesis is only approximately true. We also find in a separate work that under certain assumptions, violation of higher sum rules (as defined in Sorkin's sum over histories approach to Quantum Mechanics) allows for superluminal signalling. In the second part of my talk, I will describe progress in some on-going collaborative

efforts between the Radio Astronomy lab and our Quantum Information lab at RRI towards experimental realization of the observation of non-classical paths in interference experiments and demonstration of the break-down of the wave function hypothesis in the microwave regime.

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Representation and Local Unitary Classification of Pure and Mixed Symmetric N-qubit States

Swarnamala Sirsi
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We develop a method of classifying local unitary (LU) equivalent classes of symmetric N-qubit or spin- j (j=N/2}) mixed states based on the geometrical multiaxial representation (MAR) of the density matrix. In addition to the two parameters defined for the entanglement classification of the symmetric pure states based on Majorana representation(MR) in the literature, namely, diversity degree and degeneracy configuration, we show that another parameter called rank needs to be introduced for symmetric mixed state classification. This scheme of classification based on the MAR is more general as it can be applied to both pure and mixed states. To bring out the similarities/ differences between the MA and MAR representation, N-qubit GHZ state is taken up for a detailed study. A recipe to identify the most general symmetric N-qubit pure separable state is also given. The power of our method is demonstrated using several well-known examples of symmetric two qubit pure and mixed states as well as three qubit pure states. Classification of uniaxial, biaxial and triaxial symmetric two qubit mixed states which can be produced in the laboratory is studied in detail.

Probing the Role of Leggett-Garg Inequality in Quantum Key Distribution

R. Srikanth
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It is generally believed that nonlocality is required to guarantee security of quantum key distribution (QKD) in the device-independent (DI) scenario. For prepare-and-measure cryptographic protocols (which may not involve quantum entanglement), a weaker scenario called semi-device-independence has been invoked. We report some progress towards DI-QKD without invoking nonlocality, based on the violation of the Leggett-Garg inequality (LGI), for protection against attacks that use higher dimensions but no communication. A crucial feature here is the use of LGI for entity authentication of the qubit transmitted, while the signaling property of temporal correlations can weaken the monogamy of the LGI violation. Finally, we consider more general attacks in the DI scenario and indicate the possibility of recovering device-independence for prepare-and-measure protocols.

Entanglement of Correlated Electron States and the Metal-Insulator Crossover Scaling Form

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We will discuss the entanglement in many-electron states using a global entanglement measure, viz. average site mixedness, and a bipartite entanglement measure, viz. the block entanglement entropy. We examine metallic

states of noninteracting electrons, and insulating Gutzwiller-projected states of strongly-correlated electrons in one dimension. Uncorrelated metallic states at half filling maximize the global entanglement, as these states optimize the number of holes and the number of doubly-occupied sites. Gutzwiller-projected many-electron states, viz. correlated electron states exhibit lower entanglement as double occupancy is inhibited in these states. The block entanglement entropy is investigated for small system sizes, which follows the conformal field theory prediction of a logarithmic divergence with the size of the block in both the insulating limit (central charge c = 1), and the metallic limit (c = 2). A scaling form is proposed for the metal-insulator crossover regime, in terms of the scaling variable that depends on the system size and the projection parameter.

Local Invariant Spin Squeezing Criteria for Multiqubit States

Sudha Shenoy
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Spin squeezing [1,2] has been originally defined for symmetric multiqubit states that are invariant under exchange of particles [3]. The possibility of extending the concept of spin squeezing to states that are not necessarily symmetric requires a criterion that is invariant under local unitary operations on the qubits [4]. The local invariant spin squeezing criterion has been proposed in [4,5] and the connection of spin squeezing with pairwise entanglement has been studied. Here we examine the local invariant spin squeezing criterion for symmetric as well as non-symmetric multiqubit states. We show that the local invariant analogue of Kitegawa-Ueda(KU) [2] and Wineland[1] spin squeezing parameters match with that of original KU and Wineland spin squeezing parameters when the states are symmetric. We make use of the expression for concurrence in terms of LU spin squeezing parameters to arrive at the pairwise entanglement of both symmetric and non-symmetric multiqubit states of interest.

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Quantum Measurement and Feedback with Superconducting Circuits

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Recent progress in ultra-low noise amplification techniques using superconducting devices has enabled fast and high-fidelity measurements of solid-state quantum devices. In this talk, I will focus on superconducting circuits which are engineered to behave like ‘artificial atoms’ when operated at dilution temperatures (~ 10 mK). These circuits have quantized energy levels which can be manipulated and measured using microwave frequency signals. We treat the two lowest quantum levels of the circuit as a quantum bit or qubit. The measurement signal is amplified using a near-noiseless superconducting parametric amplifier enabling high-fidelity monitoring of the quantum state. This paves the way to develop feedback protocols to prepare and stabilize various kinds of quantum states in these circuits. I will give an overview of different feedback protocols which have recently been implemented and discuss their applications for quantum information processing.

Strong Converse for the Classical Capacity of Entanglement-Breaking and Hadamard Channels

Andreas Winter
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A strong converse theorem for the classical capacity of a quantum channel states that the probability of correctly decoding a classical message converges exponentially fast to zero in the limit of many channel uses if the rate of communication exceeds the classical capacity of the channel. Along with a corresponding achievability statement for rates below the capacity, such a strong converse theorem enhances our understanding of the capacity as a very sharp dividing line between possible and impossible rates of communication. We will show that such a strong converse theorem holds for the classical capacity of all entanglement-breaking channels and all Hadamard channels (the complementary channels of the former). These results follow by bounding the success probability in terms of a "sandwiched" Renyi relative entropy, by showing that this quantity is subadditive for all entanglement-breaking and Hadamard channels, and by relating this quantity to the Holevo capacity. Prior results regarding strong converse theorems for cq-channels and certain covariant channels emerge as special cases. [Joint work with Mark M Wilde and Dong Yang, arXiv:1306.1586]

Polaron Dynamics and Decoherence in an Interacting Two-Spin System Coupled to Optical Phonon Environment

Sudhakar Yarlagadda
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We study two anisotropically interacting spins each of which is coupled to a different optical phonon bath; we restrict our analysis to the subspace with zero value for S^z_T (the z-component of the total spin). In the non-adiabatic regime and under strong coupling to the environment, by analyzing the polaron dynamics through non-Markovian quantum master equation, we find that the system manifests a small amount of decoherence that decreases both with increasing non-adiabaticity and with enhancing strength of coupling; whereas, under the Markovian approximation, the polaronic system exhibits a decoherence free behavior. For the situation where both spins are coupled to the same phonon bath, we also show that the system is decoherence free in the subspace where S^z_T is fixed. To suppress decoherence through quantum control, we employ a train of pi pulses and demonstrate that unitary evolution of the system can be retained.

ABSTRACTS FOR CONTRIBUTORY TALKS

Limit on Time-Energy Uncertainty with Multipartite Entanglement

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We establish a relation between the geometric time-energy uncertainty and multipartite entanglement. In particular, we show that the time-energy uncertainty relation is bounded below by the geometric measure of multipartite entanglement for an arbitrary quantum evolution of any multipartite system. The product of the time-averaged speed of the quantum evolution and the time interval of the evolution is bounded below by the multipartite entanglement of the target state. This relation holds for pure as well as for mixed states. We provide examples of physical systems for which the bound reaches close to saturation.

Reference:

Manabendra N. Bera, R. Prabhu, Arun Kumar Pati, Aditi Sen De, Ujjwal Sen, arXiv:1303.0706 [quant-ph].

Shared Purity of Multipartite Quantum States

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Fidelity plays an important role in measuring distances between pairs of quantum states, of single as well as multiparty systems. Based on the concept of fidelity, we introduce a physical quantity, shared purity, for arbitrary pure or mixed quantum states of shared systems of an arbitrary number of parties in arbitrary dimensions. We find that although it detects a quantum feature of the shared state, it is different from quantum correlations. We prove that a maximal shared purity between two parties excludes any shared purity of these parties with a third party, thus ensuring its quantum nature. Moreover, we show that all generalized GHZ states are monogamous, while all generalized W states are non-monogamous with respect to this measure. We apply the quantity to investigate the quantum XY spin-1/2 models, and observe that it can faithfully detect the quantum phase transition present in these models. We perform a finite-size scaling analysis and find the scaling exponent for this quantity.

Quantum Metrology in Realistic Scenarios

Janek Kolodynski
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Quantum metrology offers an enhanced performance in experiments such as gravitational wave-detection, magnetometry and atomic clocks frequency calibration. Under the idealistic assumption of no decoherence, it allows for an improvement of measurement precision over classical protocols that grows without restraint with the number of particles involved. Motivated by practical applications, we propose tools for quantifying the attainable quantum enhancement based on the geometry of quantum channels and semi-definite programming that account for the inevitable impact of the noise. As a result we obtain a simple and direct methods yielding bounds that interpolate between the quantum enhanced scaling characteristic for small number of particles and the asymptotic regime, in which quantum enhancement amounts to a constant factor improvement. Lastly, we are able to propose a noise model, motivated by the quantum magnetometry setups, that allows for the asymptotic constant to be arbitrarily enlarged and hence, when one is able to fully control the Hamiltonian part of the system evolution, the scaling enhancement to be retrieved despite the presence of decoherence.

A Reversible Quantum Memory for Orbital Angular Momentum Qubits

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Orbital angular momentum states of light (OAM states) hold the promise for a high-dimensional encoding in quantum information processing with a potential increase in capacity. Their use has therefore been proposed in several quantum communication and information processing schemes [1]. We report here on the first implementation and characterization of a quantum memory for quantum bits encoded in this optical degree of freedom. This provides an essential step towards future quantum networks [2] exploiting the potential of OAM of photons for quantum information applications. Specifically, we prepare weak light pulses in Laguerre-Gaussian modes with p=0 and l=±1 and superpositions thereof via a computer-controlled spatial light modulator. They are stored in an ensemble of cold Cs atoms using dynamical electromagnetically induced transparency. A complete tomography of the states retrieved from the memory is performed using a setup of forked holograms, an interferometer and single-photon counters. The retrieved state corresponds to the input state with a fidelity above 90%. Comparing the obtained fidelities with the classically possible limit [3] for a varying mean photon number per pulse (between 0.3 and 50), we show that our system is indeed a quantum memory for OAM encoded qubits [4].

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Lower Bounding Convex Roofs

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The convex roof construction plays an important role in quantum information theory. In this work we develop a general method to find lower bounds on the convex roof for a large class of functions using insights from entanglement theory. It can be tackled numerically with the help of semidefinite programming and can be applied to various different problems. We demonstrate this for entanglement questions of the bipartite and multipartite setting, including: bipartite entanglement quantification via full, partial or device-independent knowledge, Schmidt rank determination, detection of genuine multiparticle entanglement and discrimination between the W and GHZ class of three qubit systems.

Decoherence in Multiqubit Systems

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Panjab University, Chandigarh, India

We study decoherence of systems of varying number of qubits while passing through different quantum channels, which are dephasing channel, depolarizing channel, zero temperature bath and collective dephasing channel. In our approach we have sampled states from entire Hilbert space in order to remove any biases of a particular channel towards a specific state. Besides general states, we have also calculated how decoherence occurs in generalized GHZ states and generalized W states.

Improving the Fidelity of Teleportation Through Noisy Channels Using Weak Measurement

Tanumoy Pramanik
S N Bose National Centre for Basic Sciences, Kolkata, India

We employ the technique of weak measurement in order to enable preservation of teleportation fidelity for two-qubit noisy channels. We consider one or both qubits of a maximally entangled state to undergo amplitude damping, and show that the application of weak measurement and a subsequent reverse operation could lead to a fidelity greater than 2/3 for any value of the decoherence parameter. The success probabilty of the protocol decreases with the strength of weak measurement, and is lower when both the qubits are affected by decoherence.

Pre-Verification of Quantum Processes

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Centre for Quantum Technologies, Singapore

We present a method to hypothesis test quantum processes where only limited data is available. By considering the asymptotic limit of many copies, we discuss a hypothesis test whereby one can accept or reject a given hypothesis at the end of a limited number of measurements. We compare this number with the asymptotic minimal error probability and discuss noisy measurements and imperfect state preparations.

QIT Measures in the Vicinity of a Quantum Critical Point

Amit Tribedi
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Recently some Quantum Information Theoretic (QIT) measures like Entanglement and Quantum Discord (QD) have emerged as very important tools for investigating quantum systems theoretically as well as for performing Quantum Information tasks. I have studied a few of the QIT measures in a critical spin system which undergoes a Luttinger Liquid (LL) to Charge Density Wave (CDW) Transition and obtained interesting nontrivial features exhibited by the measures near Quantum Critical Point. I also have studied the nature of variation of those measures with a non-frustrative disorder-inducing next-nearest-neighbor interaction of the model system.

Aspects of Uncertainty and Complementarity

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ABSTRACTS FOR POSTERS

On the k-separability of Multipartite States

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We derive two k-separability criteria of multipartite states to identify various partial separable states in different classes of multipartite entangled states [1,2]. Using this criteria, one can detect any k-separable (k = 2,3,...,n) n-qubit and n-qudit states under all possible partitions. We also discuss all possible separability of GHZ and W states when mixed with isotropic noise [3].

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On the Weakness of Quantum Correlations

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Quantum correlations, which satisfy the Tsirelson bound, are known to be weaker than that required by no-signaling. Among reasons proposed to explain this discrepancy are information causality [1], properties of local quantum mechanics [2], Heisenberg uncertainty [3], complementarity [4], properties like unitarity and linearity [5], properties of joint measurements [6]. A prohibition on the algebraic maximal limit (PR boxes), assuming the existence of closed timelike curves (CTCs), is discussed in Ref. [7]. All these approaches require no-signaling as an assumption. Here we investigate the question of whether Tsirelson bound can be derived without invoking no-signaling. In Ref. [8], it was pointed out how the assumption that singlet correlations have no local part and are isotropically unbiased, imply no-signaling. This study, inspired by modelling correlations in terms of an underlying realistic models, suggested that in a nonlocal world, no-signaling appears more like an emergent phenomenon rather than a basic axiom. The present work attempts to extend that line of thought to correlations corresponding to non-maximal entanglement.

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Chaining Property and Measures of Two-Qubit Operator Entanglement

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It is known that Schmidt strength and linear entropy are inequivalent in capturing the nonlocal features of two-qubit operators. These measures are utilized to quantify the operator entanglement of two-qubit gates. While Schmidt strength is known to be violating chaining property, we show that the linear entropy also fails to satisfy the property. As a consequence, chaining property of the measures fails to indicate a tight lower bound on the number of gates required to perform a particular quantum operation.

Classical Spin Models with Broken Symmetry: Persistence of Spontaneous Magnetization in Presence of a Random Field

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We consider classical spin models of two- and three-dimensional spins with continuous symmetry, and investigate the effect of a symmetry-breaking unidirectional quenched disorder, on the magnetization of the system. We work in the mean field regime. We show, by perturbative calculations and numerical simulations, that although the continuous symmetry of the spontaneous magnetization is lost due to disorder, the system still magnetizes in specific directions. The critical temperature, at which the system starts magnetizing, as well as the magnetization at low and high temperature limits, with the introduction of disorder, are estimated. Moreover, we treat the SO(n) n-component spin model to obtain the generalized expressions for the near-critical scaling, which suggest that the effect of disorder in magnetization increases with increasing dimension. We also study the behavior of magnetization of the classical XY spin model in the presence of a constant magnetic field, in addition to the quenched disorder.

Bell Nonlocality for Light Beams with Topological Singularities

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We consider optical beams with topological singularities which possess Schmidt decomposition and show that such classical beams share many features of two mode entanglement in quantum optics. We demonstrate the coherence properties of such beams through the violations of Bell inequality for continuous variables using the Wigner function. This violation is a consequence of correlations between the (x, p_x) and (y, p_y) spaces which mathematically play the same role as nonlocality in quantum mechanics. The Bell violation for the Laguerre-Gaussian beams is shown to increase with higher orbital angular momenta l of the vortex beam. This increase is reminiscent of enhancement of nonlocality for many particle Greenberger-Horne-Zeilinger states or for higher spins. The states with large l can be easily produced using spatial light modulators.

Study of Decoherene in an Open Two-Spin System

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We investigate the case where two interacting spins are coupled to the same phonon bath . It is known that the subspace with the same value of S^z_T (z-component of total spin) forms a DFS. We study the case where S^z_T is not conserved and show that the decoherence is dependent on the nature of the initial state; we analyze the decoherence for subohmic, ohmic and superohmic cases. Contrastingly, when the spins are coupled to different phonon baths, the decoherence phenomenon is shown to be drastically different.

Characterizing Genuine Multisite Entanglement in Isotropic Spin Lattices

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We consider a class of large superposed states, obtained from dimer coverings on spin-1/2 isotropic lattices. We show that they are genuinely multiparty entangled, irrespective of the geometry and dimension of the isotropic lattice. We then present an efficient method to characterize the genuine multisite entanglement in the case of isotropic square spin-1/2 lattices, with short-range dimer coverings. We use this iterative analytical method to calculate the multisite entanglement of finite-sized lattices, which, through finite-size scaling, enables us to obtain the estimate of the multisite entanglement of the infinite square lattice. The method can be a useful tool to investigate other single- and multisite properties of such states.

Effectiveness of Depolarizing Noise in Causing Sudden Death of Entanglement

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In view of the recent observation[1] that depolarizing noise is more effective in causing sudden death of entanglement [2--5] in two-qubit states , we carry out a study to establish this fact even in qubit-qutrit and qutrit-qutrit systems. Considering a maximally entangled pure state of a qubit-qutrit , we examine the sudden death of entanglement due to the action of noise on only one part of the state, either qubit or qutrit. The noise models that we consider are amplitude noise, phase noise depolarizing noise and generalized amplitude noise (GAD). We show that while amplitude, phase noise lead to asymptotic decay of entanglement, depolarizing and Generalized amplitude damping cause sudden death of entanglement in these states. The disentanglement times due to depolarizing noise is found to be shorter than that due to Generalized amplitude damping, thus proving that depolarizing noise is more effective in causing sudden death of entanglement compared to other noises. We carry out a similar analysis for maximally entangled pure qutrit-qutrit systems and arrive at the same conclusion. We employ negativity of partial transpose as the measure of entanglement in both qubit-qutrit and qutrit-qutrit cases.

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Engineered Quantum Noise: Characterization by Noise Spectroscopy and Suppression by Dynamical Decoupling

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In quantum information processing, the quantum information of the quantum system encoded in the form of coherences of quantum bits inevitably undergoes irreversible transformations over certain time-scales due to the omnipresent environmental interferences. This process, known as decoherence, is a fundamental threat to quantum computation as well as quantum communication. Hence, preserving quantum information against decoherence is an important area of current research. Our work is an attempt towards a better study and control of decoherence by subjecting the system qubits to engineered quantum noise, characterizing the artificial

decoherence and its supression using dynamical decoupling techniques on a two qubit NMR quantum information processing device.

Entropic Uncertainty Relation with Conditioned Sequential Measurements

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The Uncertainty Principle (UP) marks a “classic” departure from the seemingly expected world of Classical Physics. This, along with entanglement, has been highlighted as marking the non-classical regime. Apart from the foundational significance, UP can be applied to construct security proofs in quantum cryptography [1]. Heisenberg’s UP involves product of variances of two non-commuting observables and places bound on the precision one can achieve in incompatible measurements. UP essentially reflects ignorance linked with measurement of incompatible observables. From an information-theoretic perspective, it is natural to capture this “ignorance” in terms of Shannon entropies rather than variances. Entropic Uncertainty Relations (EUR) have broadened and strengthened the original notion of Heisenberg’s UP [2]. Berta et al. generalized and proposed an extended EUR revealing that uncertainties of incompatible observables get reduced when they are measured in the presence of an entangled quantum memory [1]. In this work we investigate EUR arising from sequential measurements of observables in a single quantum system and show that temporal correlations of the observables could lead to reduction of uncertainties. We also obtain entropic temporal steering inequality analogous to Einstein-Podolsky-Rosen steering inequality. The temporal steering inequality is obeyed if the correlations fall within the macrorealistic tenet (which implies an underlying convex product form for the probabilities associated with the sequential measurements of temporally separated observables) and could get violated in the presence of temporal correlations. Our result is thus useful in witnessing temporal correlations in a single quantum system.

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Almost all Multipartite Pure States are Monogamous for all Quantum Correlation Measures in Large Quantum Systems

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Monogamy is a non-classical property that restricts the sharing of the quantum correlation among the constituents of a multipartite quantum system. Quantum correlations may satisfy or violate monogamy for different quantum states. Here we provide evidence that almost all pure quantum states of systems consisting of a large number of subsystems are monogamous with respect to all quantum correlations of both the entanglement-separability and the information-theoretic paradigms. Put differently, the volume of the monogamous quantum states increases with an increasing number of parties. Nonetheless, we identify an important class of pure states, namely the Dicke states, that remain non-monogamous with respect to quantum discord and quantum work-deficit, irrespective of the number of qubits. We identify conditions for which a given quantum correlation measure satisfies vis-a-vis violates monogamy.

Entanglement Dynamics of Two Atoms in Tavis-Cummings Model

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We investigate the entanglement dynamics between two atoms in two two-level atoms interacting with a single mode coherent field (Tavis-Cummings model) [1], when the field is previously in a maximally entangled state. We obtain results to all orders in coupling time for atoms, which are initially in (i) fully excited, (ii) superradiant and in (iii) ground states. We use the negativity criterion [2, 3] for entanglement and found that if the atoms are initially in the excited stated they are highly entangled, but are in superradiant or ground state they become slightly entangled. We have also studied the relation between atomic squeezing and entanglement. Using our recently reported criterion for atomic squeezing [4, 5] and Sorensen Criterion [6], we show that the Sorensen criterion of atomic squeezing is not suitable for characterizing entanglement of composite systems.

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Entanglement Entropy for Non-Zero Genus Topologies

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Over the last three decades entanglement entropy has been obtained for genus zero topologies like Spheres. For these topologies, it has been shown, for spin-0 particles, that the entanglement entropy scales as area. In the last few years non-trivial topologies are increasingly relevant for different areas. For instance, in describing quantum phases, it has been realised that long-range entangled states are described by topological order. In the context of black-hole thermodynamics, it has been conjectured that higher genus black-hole solutions may solve the information paradox. If quantum entanglement can plausibly provide explanation for any of these, it then imperative to obtain entanglement entropy in these topologies. However, calculation of entanglement entropy of scalar field in these topologies are prohibitively involved. In this talk, we obtain the entanglement entropy in $S_1 \times S_1$ and $S_2 \times S_1$ topologies in two different approximations/limits.

Unambiguous Discrimination of Two Squeezed States Using Probabilistic Quantum Cloning

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Unambiguous state discrimination of two squeezed states of light beam has been investigated [D. K. Mishra, Optics Communications, 285 (2012) 1560-1565]. We calculated optimal success probability for unambiguous discrimination of two squeezed states of light beam. We propose a general scheme for unambiguous state discrimination using probabilistic quantum cloning for any two known pure quantum states.

Quenching and Generation of Random States in a Kicked Ising Model

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We present the study of various entanglement properties for the non-integrable kicked Ising model with both a pulsed transverse and a continuous longitudinal fields. We calculate concurrence, Q- measure and von Neumann entropy numerically using sinusoidal transverse and longitudinal fields. Oscillations feature in the concurrence, Q-measure and entropy as the transverse field quenches to zero, with a overall decrease in the concurrence and an increase in the other measures for small longitudinal fields, signaling the generation of multipartite entanglement. This multipartite entanglement is not produced if the longitudinal fields are large enough so that the disordering effects of the transverse field are not felt. We find the effect of number of kicks (or kicking interval) on entanglement measure such as von Neumann entropy. We find a phenomena similar to quantum resonance when the entanglement does not evolve for certain values of the pulse duration. Away from the resonance the longitudinal field can drive the system where the entanglement corresponds to very large values that we have identified with those of random states. The eigenvalues and eigenstates distribution confirm the random state nature of generic quenched states in the presence of both transverse and longitudinal fields. For a qualitative comparison, we have also presented the cases of fixed field kicking using open as well as periodic chains.

Constructive Interference Between Disordered Couplings Enhances Multiparty Entanglement in Quantum Heisenberg Spin Models

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Decoherence of a Pair of Interacting Spins Coupled to a Thermal Bath

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Decoherence of qubits even interacting weakly with a thermal bath poses severe problem before the practical implementation of quantum computers. For two interacting spins with and without an external magnetic field, dechorence process has been studied in our case. The interaction with the thermal bath was mimiced with the help of random Hamiltonian matrices coupled with spin components. The studies on time evolution and decoherence of the system were made numerically for various inetractions within the spin pair.The initial state is chosen to be either maximally entangled one of the Bell states or a completely separable state. It was found that the pair with isotropic Heisenberg or XXX type exchange interaction is very much fragile against thermal bath caused decoherence while those under XX interactions and XXZ interactions are relatively much more immuned. The immunity offered by the spin pair in XXZ case is quite strong particularly at certain values of anisotropy parameter. For the initial Bell state, entanglement between the pair decreases monotonically with time; while for the initial separable state the time evolution of the same shows quasi-periodic behaviour till the system decoheres completely. As already reported in the literature for some other models, here also, the decoherence time scale can be considerably augmented by the use of sufficiently strong external magnetic field along a suitably chosen direction.

Ultracold Atoms in Disordered Potentials

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Disordered potentials are accepted as most promising candidate to study various open problems in condensed matter systems like super solids, spin liquids etc. Recently, ultra cold atomic gases in optical lattice have emerged as clean and tunable quantum laboratory. By overlaying two different optical lattices, various kinds of disorders could be produced in the system. We theoretically investigate the dynamics of weakly interacting ultracold atoms under the influence of disordered optical lattice (DOL) in strong transverse confinement. A number of disordered potentials are proposed and exact analytical treatments of these potentials are provided. We study the dynamics of localized excitations under various kinds of nonlinearity and disorders. We demonstrate that the disorder-ness in the potential is proportional to the power of the laser intensity and its periodicity. Our novel analytical method will pave the possibility of tuning the DOL potential and observing the corresponding system dynamics. Our method generates a family of exact solution; oscillatory solutions are natural and demonstrated in great detail.

Key words: Ultra-cold atoms, Solitons, Nonlinearity, disorder

The Operator Sum-Difference Representation for Quantum Maps: Application to the Two-Qubit Amplitude Damping Channel

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On account of the Abel-Galois no-go theorem for the algebraic solution to quintic and higher order polynomials, the eigenvalue problem and the associated characteristic equation for a general noise dynamics in dimension d via the Choi-Jamiolkowski approach cannot be solved in general via radicals. We provide a way around this impasse by decomposing the Choi matrix into simpler, not necessarily positive, Hermitian operators that are diagonalizable via radicals, which yield a set of `positive' and `negative' Kraus operators. The price to pay is that the sufficient number of Kraus operators is d^4 instead of d^2, sufficient in the Kraus representation. We also extend the quantum error-correction condition to operator sum-difference formalism. We consider various applications of the formalism: the Kraus repesentation of the 2-qubit amplitude damping channel, the noise resulting from a 2-qubit system interacting dissipatively with a vacuum bath; defining the maximally dephasing and purely dephasing components of the channel in the new representation, and studying their entanglement breaking and broadcast properties.

Markovian Evolution of Classical and Quantum Correlations in the Transverse-Field XY Model

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Quantum discord, a general measure of quantum correlations, has been proposed as a resource in certain quantum information processing tasks. But the utilization of quantum correlations is limited by the problem of decoherence. The Markovian dynamics of the quantum correlations due to decoherence can be studied using the Kraus operator formalism for different types of quantum channels representing system-environment interactions. In this poster, we present some important results of our studies on the Markovian dynamics of quantum correlation present in the ground and thermal states of a well-known quantum spin models – the XY model in a transverse field. Appropriate quantities associated with the dynamics of quantum correlations are identified which provide signatures of quantum phase transitions. Results for further-neighbour two-qubit states at zero and finite temperatures are also reported.

Towards Quantum Feedback using Field Programmable Gate Arrays

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One of the key challenges for solid-state quantum information processing is to protect a quantum system against environmental decoherence. This can be achieved using quantum error correction protocols where a logical quantum bit (qubit) is encoded among several physical qubits. One possible technique involves the use of quantum feedback protocols which in turn require real-time tracking of the evolution of the quantum system. In order to meet the high speed digital signal processing requirements for real-time tracking, we have developed a Field Programmable Gate Arrays (FPGA) based algorithm and demonstrated single qubit state tracking using simulated measurement signals.

The Effect of Magnetic Field on the Information Transfer in a Dimerized Spin Chain

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State transfer process through a dimerised spin chain has been studied. The protocol proposed by S. Yang et al. (Phys. Rev A, 84, 20302(R) (2011)) has been used to devise an efficient communication through quantum channel, where inherent entanglement of strongly correlated spin system has been exploited. In our study an additional uniform magnetic field was applied and its influence on the whole process was investigated. Adopting the proposal, two bits of classical information are encoded in the spin chain (governed by dimerised isotropic Hesienberg exchange interaction or XXX model) by a single opration on the qubit 1. This operation changes the ground state of the entire system to a new state, whose time evolution transfers the density matrix of the first two qbits along the chain. The last two qubits are measured in the bases of initial rotated states of the first two qubits. The quality of communication through state transfer is quantified by fidelity factor between the initial encoded state of first two spins with the state of last two spins of the spin chain after time t. The result shows that the presence of magnetic field significantly changes the temporal behaviour of the fidelity factor at any particular value of magnetic field. Hence an optimum value of the magnetic field may be ascertained.

All Multiparty Quantum States Can Be Made Monogamous

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We show that arbitrary multiparty quantum states can be made to satisfy monogamy by considering increasing functions of any bipartite quantum correlation that may itself lead to a non-monogamous feature. This is true for states of an arbitrary number of parties in arbitrary dimensions, and irrespective of whether the state is pure or mixed. The increasing function of the quantum correlation satisfies all the expected quantum correlation properties as the original one. We illustrate this by considering a thermodynamic quantum correlation measure, known as quantum work-deficit. We find that although quantum work-deficit is non-monogamous for certain three-qubit states, there exist polynomials of the measure that satisfy monogamy for those states.

Whirling Waves in Interference Experiments

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In a double slit interference experiment, the wave function at the screen with both slits open is not exactly the sum of the wave functions with the slits individually open one at a time. The three scenarios represent three different boundary conditions and as such, the superposition principle should not be applicable. However, most well known text books in quantum mechanics implicitly and/or explicitly use this assumption, the wave function hypothesis, which is only approximately true. In our present study, we have used the Feynman path integral formalism to quantify contributions from non-classical paths in interference experiments which provide a measurable deviation from the wave function hypothesis. A direct experimental demonstration for the existence of these non-classical paths is hard. We find that contributions from such paths can be significant and we propose simple three-slit interference experiments to directly confirm their existence.

Roots of Completely Positive Maps

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The structure of positive maps between matrix algebras gained importance with the development of quantum information theory. Positive maps which are not completely positive can detect entangled states. Extending the works of Wolf and Cirac , we study various roots of completely positive (CP) maps in dimensions 3 and above. We show that all positive maps which are not CP are square root of some CP maps. The study of roots of positive operators is an well developed subject. We try to make a similar study for the case of CP maps. In this way, we try to discover new examples of positive maps which are not CP and can potentially detect new entangled states. We also try to comment on the divisibility of CP maps and the structure of different roots (for the cases where the division is possible).

Nonlocal Subspaces and Dual Quantum Secret Sharing

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We construct degenerate Bell operators for graph states via the stabilizer formalism, whereby more than one such state violates the associated Bell inequality to the algebraic maximum. The set of these Bell-degenerate states constitute a nonlocal subspace into which a quantum secret can be encoded and shared among an authorized group of agents, or securely transmitted to a designated secret retriever through a process similar to one-way quantum computation. We point out two methods to derive such Bell inequalities, one of which is appropriate for quantum error correcting codes. The security of our cryptographic scheme stems from the monogamy of quantum correlations, and the fact that the nonlocality of the code space can be witnessed by the Bell operator. The geometric properties of graph states can be exploited to implement certain access structures for quantum secret sharing or information splitting. Our use of nonlocality allows for extracting secrecy in the device-independent cryptographic scenario, in which untrusted devices are allowed, and also in the presence of a general non-signaling adversary.

Ancilla Assisted Quantum State Tomography

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The standard method of quantum state tomography (QST) relies on the measurement of a set of noncommuting observables, realized in a series of independent experiments. Ancilla-assisted QST (AAQST) proposed by Nieuwenhuizen and co-workers [Phys. Rev. Lett. 92 120402 (2004)] greatly reduces the number of independent measurements by exploiting an ancilla register in a known initial state. In suitable conditions AAQST allows mapping out density matrix of an input register in a single experiment. Here we describe methods for explicit construction of AAQST experiments in multiqubit registers. We also report nuclear magnetic resonance studies on AAQST of (i) a two-qubit input register using a one-qubit ancilla in an isotropic liquid-state system and (ii) a three-qubit input register using a two-qubit ancilla register in a partially oriented system. The experimental results confirm the effectiveness of AAQST in such multiqubit registers.

Entanglement Concentration Protocols for Cat State, GHZ-like State and all families of 4-qubit entangled states

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Two Entanglement concentration protocols (ECPs) are proposed. The first ECP is shown to be useful for creation of maximally entangled cat state and GHZ-like states from the corresponding non-maximally entangled states. The second ECP is found to be useful for creation of maximally entangled n-qubit state $\frac{1}{\sqrt{2}}\left(|\psi_{0}\rangle|0\rangle+|\psi_{1}\rangle|1\rangle\right)$ from the corresponding non-maximally entangled n-qubit state $\alpha|\psi_{0}\rangle|0\rangle+\beta|\psi_{1}\rangle|1\rangle$ where $|\psi_{0}\rangle$ and $|\psi_{1}\rangle$ are mutually orthogonal n-qubit states. It is also shown that all the 9 different families of 4-qubit entangled states that are not connected by stochastic local quantum operations assisted by classical communication (SLOCC) can be expressed as $\frac{1}{\sqrt{2}}\left(|\psi_{0}\rangle|0\rangle+|\psi_{1}\rangle|1\rangle\right)$ for specific choices of the parameters that define a family and consequently our second ECP is applicable to all families of 4-qubit entangled states. Quantum circuits for implementation of the proposed ECPs are provided and the intrinsic probabilistic nature of the proposed protocols is discussed. Further, it is shown that several existing ECPs can be obtained as special cases of the schemes proposed here. Possibilities of physical realization of the ECPs proposed here are also discussed with appropriate importance.

Teleportation and Superdense Coding Using D-particle W-like States

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Quantum entanglement is essential not only to understand the fundamental aspects of the quantum mechanics but also to be used as an efficient resource to transfer information using protocols such as teleportation and super dense coding. We identify a four-qubit W-type state to be used as a resource for efficient teleportation and dense coding protocols. Although deterministic teleportation protocol using our states with unit probability and fidelity is a possibility with multiqubit projective measurements, we emphasis on a protocol where an entangled state with a user will be shared between the user having the entangled state and another user at a distant location by using only standard projective measurements. We show that for the certain value of a real parameter associated with the initial entangled state, one can share a maximally entangled state between the two users in the protocol.

We also compare the efficacy of three and four-qubit W-type states as resources in terms of concurrence of the finally shared entangled state between the two users. Interestingly, our results show that for certain ranges of parameters associated with the initial entangled state and three and four qubit W-type states, the four qubit W-type states are more efficient resources in comparison to three qubit W-type states for achieving optimal concurrence shared between two users. We also found that certain non-maximally entangled GHZ class states are always more efficient in comparison to four-qubit W-type states when used as resources for sharing the entanglement.

Furthermore, the dense coding protocol using our states is also optimal.

Quantum Reading of Digital Memory Using Photon Added Coherent State

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Quantum reading refers to the use of non-classical light to read classical digital memory. Recently Pirandola [1] showed that two-mode squeezed vacuum (TMSV) state, which has Einstein-Podolsky-Rosen (EPR) correlations retrieves more information (quantified in terms of positive information gain G) from digital memory compared to classical light in the regime of low signal intensity (few photons) and high reflectivities. It was also shown that G can have positive values for a few classes of entangled non-Gaussian states [2]. Further, in [3], Nair pointed out that single mode photon number states minimize the error probability when compared with two mode EPR correlated states in low photon regime and for some chosen reflectivities. This brings forth a broader question "is it non-classicality or entanglement of radiation that assists in improved reading of digital memory?" We try to address this question by exploring reading ability of single mode photon added coherent state (PACS) [4] and another related family of single mode non-classical light [5]. Our results reveal that one can indeed achieve significantly more information gain G with single mode non-classical light over that realizable using classical coherent state of light.

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Quantum Otto Engine: Work, Efficiency and Friction

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Models of quantum heat engines reveal interesting interplay between thermodynamic properties and the quantum behavior. We constructed a four-staged Otto cycle in which two spin-half particles with isotropic exchange interaction [1] serve as the working medium. The adiabatic process is done by changing the external magnetic field. Analysis of work and efficiency can be done in the limit of slow driving as well as in finite time. In the former case, the validity of quantum adiabatic theorem is assumed. We derive an upper bound for efficiency in the coupled-spins case which is tighter than Carnot bound. The local description of the system at different stages is studied using reduced density matrix. In finite time case, we observed a mechanism which causes friction in our model during the adiabatic branches [2,3]. The frictional effect in quantum heat engines arises when non-commutative property of the internal and external Hamiltonian leads to non commutativity of the

Hamiltonian at different times [4]. As a signature of friction, the entropy production and reduction in work extracted are observed. The lower and upper bounds of the work corresponding to sudden and slow processes are found out and compared with finite-time work output. With a special case, we show that the non-commutativity of internal and external Hamiltonian by itself is not a sufficient criterion for friction.

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Superconducting Resonators for Quantum Information Processing

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Quantum information processing using superconducting circuits has been touted as the most favourable platform for realizing a practical quantum computer. In the circuit QED architecture, one uses circuit elements like inductors, capacitors and Josephson junctions to build quantum bits (qubits) and couple them to microwave photons in a resonator for information processing. In this work, we discuss the simulation, fabrication and characterization of resonators both in planar and 3D geometries necessary for qubit measurement and control. The resonators have resonance frequencies in the 4-8 GHz range suitable for operating in the quantum regime at temperatures close to 10 mK.

LIST OF INVITED SPEAKERS OF QIPA-2013

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