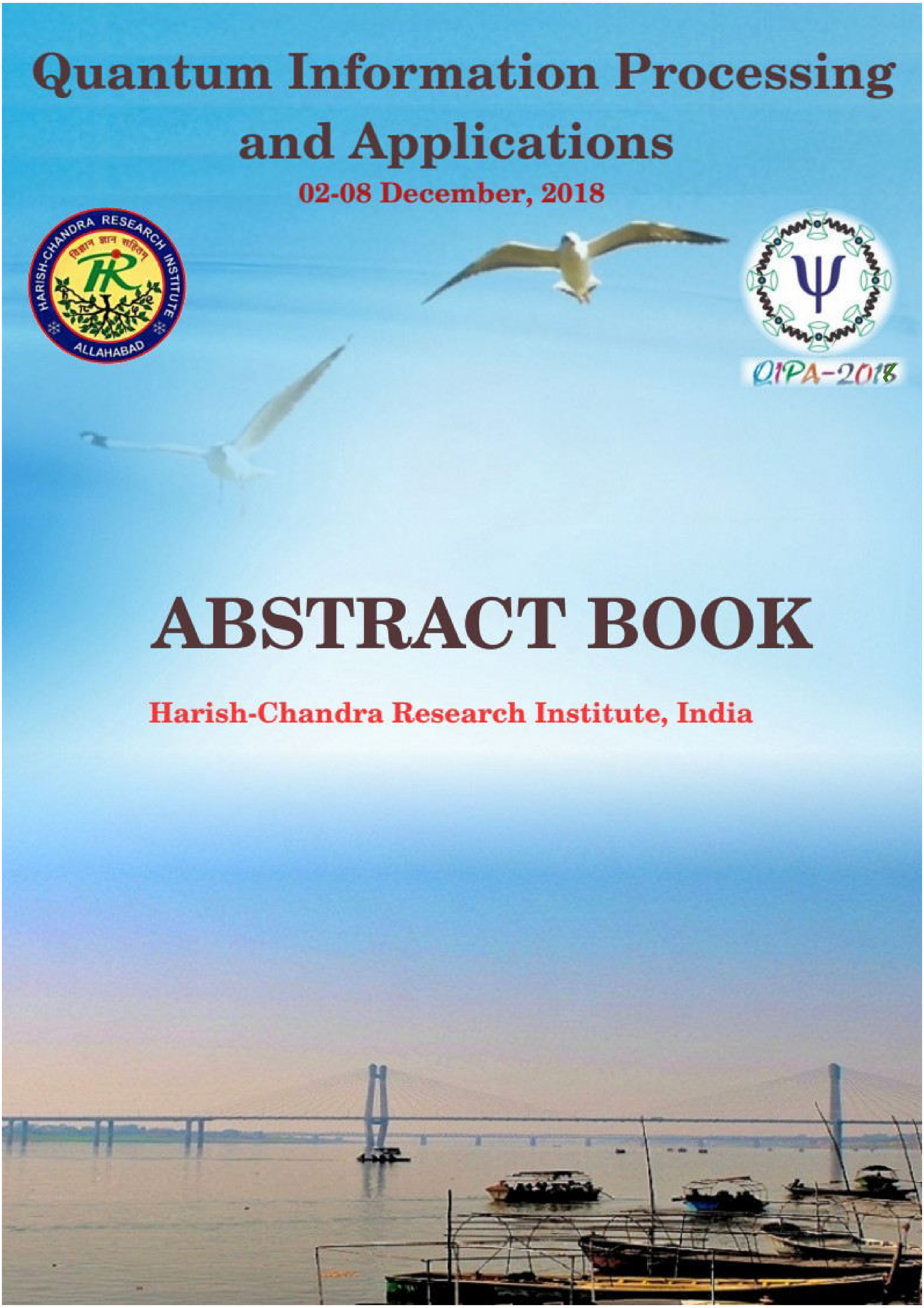
Quantum Information Processing and Applications

02-08 December, 2018

ABSTRACT BOOK

Harish-Chandra Research Institute, India



Meeting on
Quantum Information Processing and Applications
02-08 December, 2018

QIPA-2018

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

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Information for Participants of QIPA – 2018

Welcome to the Harish-Chandra Research Institute (HRI). We hope you will enjoy your stay and have an exciting time during the conference. You may find the following general information useful.

Accommodation: Your stay has been arranged at one of the following places (1) HRI guest house **"**Pratisthanpur**"** within the campus, (2) apartments within the campus, (3) HRI Jhunsi hostel, (4) HRI Trivenipuram hostel, and (5) Hotel Grand Continental (in the city). You can contact HRI guest house reception (0532-227-4080, 0532-227-4109) for any 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.

HRI Jhunsi hostel: The Jhunsi Hostel is outside the HRI campus and located in the Jhunsi village. It's contact number is 0532-256-7160. Food (breakfast, lunch, and dinner) has been arranged at HRI guest house. An arrangement of a vehicle for participants staying here has been made. It will pick you up at 8:00 am in the morning and will drop you at 8:30 pm. Also, HRI buses ply from HRI to Allahabad city via hostel whose schedule can be either found by inquiring at the HRI gate or from HRI website. If you face any problem there, then please contact the guard there or the HRI gate (the telephone numbers are given below). There are water filters in the hostel. However, it is advisable to carry water for the night from the campus.

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

Registration: 02. 12. 2018 from 8.00 AM to 8.45 AM outside the auditorium.

Posters: The posters can be displayed from day one till the end of the workshop at the lobby outside the auditorium.

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

For Breakfast	:	07:00 - 08:30 AM
For Lunch	:	12.30 - 02:00 PM
For Dinner	:	07.30 - 09:30 PM

(on Dec 05, there will be a conference-dinner which will be from 7.30PM)

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 and pantry has to be done to the respective staffs.

Internet facility: Wi-Fi 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.

The network proxy settings for accessing the internet are as follows:

Proxy	Port	Availability
No proxy	-	Entire campus
192.168.3.20	3100	Entire campus
192.168.3.50	3100	Entire campus

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 10.00 AM to 6.00 PM on Sundays and other holidays.

Medical facilities: We hope that you will not be required to avail this facility. However, if needed, there is a health center inside the campus (Ext. No: 4356), with first-aid kits and some basic medicines. The pharmacist on duty will assist you on simple problems, and a doctor is there on emergency night duty from 10.00 PM (day 1) to 06.00 AM (day 2). An ambulance is also available round the clock. A doctor is available for consultation on pre-scheduled days for an hour in the afternoon.

Going out: In case you decide to go out of the campus, please remember to carry the schedule of the HRI bus service (HRI bus-timings). We recommend you to use the HRI bus service for traveling back to the institute, otherwise, you may find returning back to HRI a bit difficult.

Walking around: You can enjoy a nice view of the Ganga River, inside the campus by taking a short walk towards the west boundary wall of the institute. The place is called “Kalidas point”.

Laundry: There is a paid laundry facility near the main gate (Extn. No: 4450). Timings: around 11.00 AM to 8.00 PM.

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Main Gate	4350, 4351(24 hours)/ 0532-254-8150 (from outside HRI campus)	
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ABSTRACTS FOR INVITED TALKS

Measurement Incompatibility and Pairwise Correlations

A.R. Usha Devi
Bangalore University, India

In this talk I will give an outline on the construction of a chained N-term correlation inequality based on the positivity of a sequence of moment matrices involving sequential pairwise correlations of dichotomic observables. This inequality gets violated only when incompatible sequential fuzzy measurements are employed. However, measurement incompatibility of the Positive-Operator-Valued-Measures (POVMs) employed is shown to lead to only necessary, but not sufficient condition, for the violation of the inequality in general [1]. It is shown that the N-term linear steering inequality proposed by Jones and Wiseman [2] unfolds an intrinsic connection between the optimal violation of the N term steering inequality and the incompatibility of the POVMs employed. This establishes an explicit one-to-one equivalence between steering and measurement incompatibility.

References:
[1] H. S. Karthik, A. R. Usha Devi, J. Prabhu Tej, A. K. Rajagopal, Sudha, A. Narayanan, *N term pairwise correlation inequalities, steering and joint measurability*, Phys. Rev. A, **95**, 052105 (2017).
[2] S. J. Jones, H. M. Wiseman, *Nonlocality of a single photon: Paths to an Einstein-Podolsky-Rosen-steering experiment*, Phys. Rev. A. **84**, 012110 (2011).

Resource theory of Wigner negativity and applications in optomechanical systems

Alessandro Ferraro
Queen's University, Belfast, UK

The development of quantum information science aims at exploiting quantum features as technological resources suitable to process information. This endevour has led to the introduction of precise mathematical definitions for various notions of quantum resources, and manipulations thereof. In this talk, I will introduce a resource theory for infinite-dimensional (continuous-variable) quantum systems, grounded on operations routinely available within current technologies [1]. The present theory lends itself to quantify both quantum non-Gaussianity and Wigner negativity as resources. This framework finds immediate application in continuous-variable quantum computation, where the ability to implement non-Gaussian operations is crucial to obtain universal control. In this context, I will illustrate a scheme to arbitrarily process quantum information over mechanical oscillators (e.g., opto- and electro-mechanical systems, photonic crystals, trapped ions, ...) [2,3]. In particular, I will show how universal non-Gaussian gates can be unconditionally attained by making use of cubic non-linearities.

References:
[1] F. Albarelli, M.G. Genoni, M.G. A. Paris, A. Ferraro, *Resource theory of quantum non-Gaussianity and Wigner negativity*, arXiv:1804.05763.
[2] O. Houhou, D.W. Moore, S. Bose, A. Ferraro, *Unconditional measurement-based quantum computation with optomechanical continuous variables,* arXiv:1809.09733.
[3] M. Brunelli, O. Houhou, D.W. Moore, A. Nunnenkamp, M. Paternostro, A. Ferraro, *Unconditional preparation of nonclassical states via linear-and-quadratic optomechanics,* arXiv:1804.00014.

Measuring dynamic properties of liquids using nano-scale NMR

Alex Retzker
Racah Institute of Physics, The Hebrew University of Jerusalem, Israel

Microfludic channels are now a well established platform for many applications including bio-medical research and Lab on a Chip operations. Yet, the nature of flow within this channels is still uncertain. There have been prior evidence that the mean drift velocity in these channels deviate from the regular Navier-Stokes solution with 'no slip' boundary conditions. Understanding these effects of fundamental fluid mechanics, are also of practical importance for the future development of microfludic and nanofludic infrastructure. In this talk I will describe a proposal based on a nano-NMR setup that estimates the mean drift velocity near the surface of a microfludic channel in a non intrusive fashion. In this talk I will show that this method could be used to estimate the self-diffusion coefficient and temperature of the liquid. I will discuss different possible experiments, and provide a detailed analysis of the measurement's sensitivity in each case. This scheme easily out-preforms current fluorescence based techniques.

Probing the quantum violation of various notions of macrorealism

Alok K. Pan
National Institute of Technology, Patna, India

Based on the assumptions of *Macrorealism per se* and *Non-invasive measurability*, in 1995, Leggett and Garg formulated a set of inequalities (LGIs) that provides an elegant scheme for empirically testing the incompatibility between the classical world view of *macrorealism* and quantum mechanics. In recent times, various other formulations, such as, Wigner form of LGIs, entropic LGIs and the no-signaling in time (NSIT) condition have also been proposed. In this talk, in the context of unsharp measurement, I first provide a comparative study of the robustness of the violation of various formulations of LGIs to the unsharpness. I then show probabilistic formulations of LGIs inequivalent and stronger than standard LGIs, in contrast to the CHSH scenario. Further, for three-time LG scenario, I show that there is scope of formulating new variants of standard LGIs. Importantly, the violation of the variants of standard LGIs can be larger than the standard case. By extending such a formulation for *n*-time measurement scenario, it can be shown that the quantum violations of variants of LGIs increase and for sufficiently large *n* the violation approaches algebraic maximum. Finally, I shall examine the notions of macrorealism involved in the LGIs and the NSIT condition based formulations of macrorealism.

References:

[1] S. Kumari, AKP, Phys. Rev. A **96**, 042107 (2017).
[2] S. Kumari, AKP, EPL **118** 50002 (2017).
[3] A. Kumari, Md. Qutubuddin and AKP (arXiv: 1806.01207, To appear in Phys. Rev A).
[4] AKP, Md. Qutubuddin and Swati Kumari (arXiv: 1806.01219, Submitted to Phys. Rev. A).

Efficient measurement of high-dimensional quantum states

Anand Kumar Jha
IIT Kanpur, Kanpur, India

The fact that a photon in a light beam can carry orbital angular momentum (OAM) in the integer multiples of $\hbar$ has made OAM a very important degree of freedom for quantum information protocols. However, one of the major challenges faced in the implementation of OAM-based high-dimensional protocols is the efficient detection of quantum states in the OAM basis. In this talk, we will describe the existing techniques for measuring quantum states in the OAM basis and also discuss their limitations. We will then present a new experimental technique that we have developed in order to efficiently measure high-dimensional quantum states in the OAM basis through just two intensity measurements. We will further discuss the extension of this technique for measuring the high-dimensional states in the transverse wave-vector basis.

Interference of indistinguishable particles: from dynamics to statistics

Andreas Buchleitner
University of Freiburg, Institute of Physics, Freiburg, Germany

Many-particle dynamics bear surprising phenomena already on the level of the interference of many-particle amplitudes, even in the absence of interactions. Questions arise such as what distinguishes quantum statistical from bona fide many particle interference effects? How are the latter affected by the particles' mutual degree of (in-)distinguishability? What can we learn from many-particle interference patterns, and can these be employed as (novel) diagnostic tools? The talk will discuss selected examples of many-particle quantum transport, with the particles' indistinguishability as a genuine source of complexity, and elaborate on the basic principles which determine the structure of many-particle interferences.

Quantum Information Processing by NMR: A Status Report

Anil Kumar
Department of Physics and NMR Research Centre, Indian Institute of Science, Bangalore, India

Till recently, the most successful of the various experimental techniques for the demonstration and verification of various QIP protocols and quantum algorithms has been that of Nuclear Magnetic Resonance (NMR). Our research group, which started experimental work in this field in late 90's, has performed several experiments which include; (i) preparation of pseudo-pure states, (ii) implementation of logic gates using one and two-dimensional NMR, (iii) implementation of Deutsch-Josza (DJ) and Grover's search algorithms, (iv) use of quadrupolar and dipolar coupled nuclei oriented in liquid crystal media for quantum information processing, (v) entanglement and entanglement transfer, (vi) observation of non-adiabatic geometric phase in NMR and its use in NMR QIP, (vii) implementation of some quantum games and (viii) implementation of adiabatic quantum algorithms by NMR. As part of "Introduction" some of these works will be highlighted.

Later developments include, (i) Experimental proof of Quantum No-Hiding theorem. (ii) Use of Nearest Neighbor (NN) Heisenberg XY interaction for creation of entanglement in a linear chain of 3-qubits (iii) Multi-Partite Quantum Correlations Revel Frustration in a Quantum Ising Spin System and (iv) use of Genetic Algorithm in NMR QC. We have also by NMR, non-destructively distinguished Bell states and more generalized orthogonal states. Some of these experiments have been repeated, with higher fidelity, by using the IBM's 5 qubit "Quantum experience". These will also be described.

Mixed state quantum computers as open systems

Anil Shaji
School of Physics, IISER Thiruvananthapuram, Vithura, Kerala, India

Precise identification of the computational resources that enable quantum computers working with mixed states to perform certain computational tasks exponentially faster than the best known classical algorithms is still not forthcoming. We review the status of the field and connect the presence of computationally useful multipartite entanglement in purifications of the mixed states with the utility of these states for performing computational tasks. We explore the connections between multipartite entanglement in the purifications and nonClassical correlations in the mixed subsystems in the many qubit context.

Fault-tolerant quantum metrology

Animesh Datta
University of Warwick, UK

We show how fault-tolerant quantum metrology can overcome noise beyond our control – associ- ated with sensing the parameter, as well as under our control – in preparing and measuring probes and ancillae. To that end, we introduce noise thresholds to quantify the noise resilience of param- eter estimation schemes. We demonstrate improved noise thresholds over the non-fault tolerant schemes. We use quantum Reed-Muller codes to retrieve more information about a single-phase parameter being estimated in the presence of full-rank Pauli noise and show that better devices, which can be engineered, can enable us to counter more noise in the field beyond our control. Further improvements in fault-tolerant quantum metrology could be achieved by optimising in tandem parameter-specific estimation schemes and transversal quantum error correcting codes.

Unconditional security of quantum cryptographic protocols: A myth or reality?

Anirban Pathak
Jaypee Institute of Information Technology, Noida, India

It's often stated that the protocols of quantum cryptography are unconditionally secure. We investigate the validity of this conjecture in view of a general scenario, where the set of protocols for quantum cryptographic tasks includes the schemes for secure multi-party computation and the quantum communication protocols beyond QKD ([1] and references therein). It is shown that the protocols for quantum cryptography are not always unconditionally secure. Further, the impact of Markovian and non-Markovian noise [2] and different types of optimal cloning machines on the security of a set of protocols for quantum cryptography have been discussed.

[1] Shenoy, A. H., Pathak, A., and Srikanth, R. (2017) Quanta **6**, 47.
[2] Thapliyal, K., Pathak, A., and Banerjee, S., (2017) Quantum Information Processing **16**, 115.

Sharing of nonlocal correlations among multiple observers

Archan S. Majumdar
S. N. Bose National Centre for Basic Sciences, Kolkata, India

We address the question as to whether the nonlocality of an entangled pair of particles can be shared among multiple observers on one side who act sequentially and independently of each other. Considering a pair of spin-1/2 particles, we first show that the optimality condition for the trade-off between information gain and disturbance emerges naturally in a quantum measurement when one employs a one-parameter class of positive operator valued measures (POVMs). Using this formalism we then prove analytically that it is impossible to obtain violation of the Bell-CHSH inequality by more than two Bobs in one of the two wings with an Alice in the other wing. We next consider the steering scenario for two-qubits with two measurement settings for each observer. We show that the analogue steering inequality can be violated for an Alice and at most two Bobs on the other side. Finally, we consider the nonlocal advantage of quantum coherence (NAQC), and show that the NAQC correlations can also be shared by a maximum of two Bobs with Alice on the other side.

References:

[1] S. Mal, A. S. Majumdar, D. Home, Sharing of nonlocality of a single member of an entangled pair is not possible by more than two unbiased observers on the other wing, Mathematics 4, 48 (2016).
[2] S. Sasmal, D. Das, S. Mal, A. S. Majumdar, Steering a single system sequentially by multiple observers, Phys. Rev. A 98, 012305 (2018).
[3] S. Datta, A. S. Majumdar, Sharing of nonlocal advantage of quantum coherence by sequential observers, Phys. Rev. A 98, 042311 (2018).

Tripartite mutual information, entanglement, and scrambling in permutation symmetric systems

Arul Lakshminarayan
Department of Physics, IIT Madras, Chennai

Many-body states that are invariant under particle relabeling, the permutation symmetric states, occur naturally when the system dynamics is described by symmetric processes or collective spin operators. We derive expressions for the reduced density matrix for arbitrary subsystem decomposition for these states and study properties of permutation symmetric states and their subsystems when the joint system is picked randomly and uniformly. Thus defining a new random matrix ensemble, we find the average linear entropy and von Neumann entropy which implies that random permutation symmetric states are marginally entangled and as a consequence the tripartite mutual information (TMI) is typically positive, preventing information from being shared globally. Applying these results to the quantum kicked top viewed as a multi-qubit system we find that entanglement, mutual information and TMI all increase for large subsystems across the Ehrenfest or log-time and saturate at the random state values if there is global chaos. During this time the out-of-time order correlators (OTOC) evolve exponentially implying scrambling in phase space. We discuss how positive TMI may coexist with such scrambling, although negative TMI is considered widely as a signature of scrambling.

Reference:

[1] Akshay Seshadri, Vaibhav Madhok, Arul Lakshminarayan, https://arxiv.org/abs/1806.00113. To appear in Phys. Rev. E.

Creation Multiphoton Bell's inequalities

Arvind
IISER Mohali, Punjab, India

Quantum Bell's inequalities are used to capture the non-local aspects of bipartite quantum systems. Original formulations of Bell's inequalities was for two spins and most of the initial experiments were done using two photons. We describe Bell type inequalities which are formulated for radiation modes rather than for photons and which can be applied to a wide variety of quantum states of the radiation field. We show how these inequalities can bring out the non-local and hence the non-classical aspects of various Gaussian and non-Gaussian radiation states. These inequalities have a natural connection with the notion of non-classicality as defined via the diagonal coherent state representation function.

Operational perspective of quantum simulations using quantum walks

C. M. Chandrashekar
The Institute of Mathematical Sciences, Chennai, India

Simulations of one quantum system by an other system has an implications in realization of quantum machine that can imitate any quantum systems and solve problems that are not accessible to classical computers. Classical random was has played an important role in simulating and understanding the dynamics of various classical systems around us. Quantum walks are considered to be quantum counterparts of classical random walk. Therefore, a similar role is envisioned to be played by quantum walk in simulating and understanding the dynamics of quantum systems. With the advancements in quantum information theory, different version of quantum walks and quantum random walks have been developed for application in quantum algorithms and mimicking/simulating dynamics of various physical systems. In this talk I will introduce different operational forms of quantum walks that have been developed to simulate Dirac equation (in flat and curved space [3]) . In particular will focus on the accelerated quantum walks which allows us to study the transition from localization to deloclaization as a function of acceleration.

Reference:

[1] Arindam Mallick, C. M. Chandrashekar, Dirac Quantum Cellular Automaton from Split-step Quantum Walk, Scientific Reports 6, 25779 (2016).
[2] Arindam Mallick, Sanjoy Mandal, Anirban Karan, C. M. Chandrashekar, Simulating Dirac Hamiltonian in curved space-time by split-step quantum Walk, arXiv:1712.03911 (2017)
[3] Shivani Singh, Radhakrishnan Balu, Raymond Laflamme, C. M. Chandrashekar, Accelerated quantum walk, two-particle entanglement generation and localization, arXiv:1810.02754 (2018)

Classification of three qubit states under local incoherent operations

Debasis Sarkar
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Entanglement has been established as one of the most important resources in quantum theory, providing ways to perform tasks better than or sometimes impossible by classical means and thus demarcating the classical limits. One of the main ingredients behind the creation of entanglement is coherent superposition of quantum states. The idea of coherence dates back to classical optics as a property of wave. However, in quantum domain the idea has been elevated to a governing principle. Since superposition depends on the measured basis, coherence is defined with respect to some fixed basis. Coherence could be viewed as the manifestation of quantumness without invoking correlations that involves composite quantum systems like, entanglement, discord, etc. A resource theoretic view point of quantum coherence has also been introduced recently.

In entanglement theory, LOCC or in general SLOCC plays the role of classifying states of composite quantum states. The recent investigations on classifying multipartite quantum states under LOCC/SLOCC indicate the complex nature of multipartite entangled states even if in pure states also. In this lecture, we will discuss the classification of three qubit states under local incoherent operations and its implication.

A technique for realizing q-plates with arbitrary retardance and its applications

G. Raghavan
Indira Gandhi Centre for Atomic Research, Kalpakkam, India

Polarization states of light are important in the field of classical and quantum optics. Such polarization states can be manipulated by using waveplates like half or quarter waveplates. These have a uniform retardance and a homogeneous fast axis orientation, which can be varied by rotating the waveplate. Apart from polarization, which constitutes the spin angular momentum, light also carries an orbital angular momentum (OAM)[1]. Conversion of SAM to OAM is easily carried out by using special liquid crystal based waveplates called 'q-plates'[2]. These q-plates are similar to regular waveplates in their retardance, but their fast axis α varies spatially as a function of the azimuthal angle φ given by $\alpha(\varphi) = q\varphi + \alpha0$; where q is the topological charge and α0 is a constant. The efficiency of spin to orbital angular momentum conversion is controlled by the retardance of the q-plate, with perfect conversion being achievable with q-plates having retardance π. Currently, the retardance of q-plates are varied by controlling temperature or applied voltage of the q-plate. In this work, we discuss a novel gadget for realizing variable retardance q-plates. We have applied this gadget for realizing a full Poincare beam(FPB)[3], which is a class of vector beams in which all the polarization states that are described on the surface of Poincare sphere are present in the transverse plane of the light beam. We have also studied spin to orbital conversion (STOC) of light in q-plates with different retardances[4]. Theoretical results and simulations are confirmed through experiments.

References:
[1] Les Allen, Marco W Beijersbergen, RJC Spreeuw, and JP Woerdman. Orbital angular momentum of light and the transformation of laguerre-gaussian laser modes. Physical Review A, 45(11):8185, 1992.
[2] Lorenzo Marrucci, C Manzo, and D Paparo. Optical spin-to-orbital angular momentum conversion in inhomogeneous anisotropic media. Physical review letters, 96(16):163905, 2006.
[3] Amber M Beckley, Thomas G Brown, and Miguel A Alonso. Full poincar´e beams. Optics express, 18(10):10777–10785, 2010.
[4] Ebrahim Karimi, Bruno Piccirillo, Eleonora Nagali, Lorenzo Marrucci, and Enrico Santamato. Ef- ficient generation and sorting of orbital angular momentum eigenmodes of light by thermally tuned q-plates. Applied Physics Letters, 94(23):231124, 2009.

Prime numbers and Quantum Computers

Germán Sierra
Instituto de Física Teórica UAM/CSIC, Universidad Autónoma de Madrid, Madrid, Spain

We shall explain the application of quantum computers to estimate the prime counting function $\pi(x)$, that gives the number of primes less or equal to a real number x. This is made possible by the efficient construction of the *prime state* which is the linear superposition of the prime numbers in the register of a quantum computer. This method would allow us to test the Riemann hypothesis beyond the limits of the known classical methods. We shall also explain how the pair correlations between the prime numbers are encoded into the entanglement properties of the prime state. Finally, we shall implement the prime state in the 5-Qubit IBM quantum computer.

References:
[1] "Quantum Computation of prime number functions", J.I. Latorre and G. Sierra., Quan. Info. Comm. **14**, 0577 (2014).
[2] "There is entanglement in the primes", J.I. Latorre and G. Sierra, Quan. Info. Comm. **15**, 0622 (2015)
[3] "Five Experimental Tests on the 5-Qubit IBM Quantum Computer", D. García-Martín and G. Sierra, J. of Applied Maths. and Phys, **6**, 1460 (2018).

Integrated Optics Modules for Free-Space QKD

Harald Weinfurter
Ludwig-Maximilians-Universität München, Germany
Max-Planck-Institut für Quantenoptik, Germany

Quantum Key Distribution (QKD) achieved a high-level of practicality in the recent years with commercial fiber based systems [1], implementations of large-scale networks [2] and space-to-ground links [3]. Here we report on the design of a QKD-sender module using integrated optics. Its compact footprint and high level of robustness make it suited for integration in virtually any conventional communication link. It has proven well suited for handheld devices with possible application for links in urban areas as well as to small scale satellites in the future.

References:

[1] www.idquantique.com
[2] http://english.cas.cn/newsroom/news/201703/t20170324_175288.shtml
[3] Sheng-Kai Liao et al., "Satellite-to-ground quantum key distribution", Nature **549**, 43 (2017).

Resource Theory of POVM based coherence

Hermann Kampermann
Institute for Theoretical Physics III, Heinrich-Heine-University Düsseldorf, Düsseldorf, Germany

Coherence is a fundamental and old concept in quantum mechanics. In recent years a resource theory of coherence was introduced [1,2] which allows to quantify, characterize and relate this resource to other concepts like entanglement and purity [3]. In this work, we develop a generalization of this resource theory that is based on positive operator valued measures (POVMs) in contrast to projective measurements. We relate this POVM coherence theory to coherence theory using Naimark extended spaces. We characterize the set of incoherent operations, a suited measure of POVM coherence, the convertibility power of POVM incoherent operations, and finally apply this framework to basic examples such as the qubit trine POVM. We also show that our framework reduces to the usual resource theory of coherence in case of projective measurements.

References:

[1] J. Aberg, *Quantifying Superposition*, preprint arXiv:quant-ph/0612146 (2006).
[2] T. Baumgratz, M. Cramer, and M. Plenio, *Quantifying Coherence*, Phys. Rev. Lett., **113**, 140401 (2014).
[3] A. Streltsov, G. Adesso, and M. B. Plenio, *Quantum coherence as a resource*, Rev. Mod. Phys., **89**, 041003 (2017).

Broadcasting of correlations in a quantum world

Indranil Chakrabarty
International Institute of Information Technology, Hyderabad, India

Heisenberg's uncertainty which arises from the non-commutativity of mutually complementary operators, on one hand imposes strict limitations [1]; whereas on other hand becomes of paramount advantage [2]. This leads to a famous "No-go" theorem, namely the *no-cloning* theorem [1], and its stronger version the *no-broadcasting* theorem which restricts perfect broadcasting of quantum correlations [3]. Quantum correlations, especially entanglement and discord, play a pivotal role in facilitating many quantum information processing tasks [4, 5]. In building quantum networks, it often becomes imperative to increase the number of entangled nodes than the degree of entanglement between the nodes. Broadcasting is a technique to create such lesser entangled nodes (pairs) from a given entangled node (pair) via cloning operations [6]. We investigate the quantum limits (possibilities and impossibilities) of this technique using various kinds of cloning operations [7]. We also show that arbitrary unitaries, beyond cloning, can be employed to further increase the efficiency of broadcasting process and outperform the standard broadcasting strategies [8]. Our investigations highlight a fundamental difference between the correlations defined from the perspective of entanglement and those that claim to go beyond entanglement.

References:

[1] W. K. Wootters and W. H. Zurek, *A single quantum cannot be cloned*, Nature, **299**, 802 (1982).
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Entanglement build-up and thermalization with Chromium atoms on a lattice

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An experimental setup with ultracold Chromium atoms trapped in an optical lattice potential offers a platform for experimentally studying coherent non-equilibrium dynamics of a large quantum many-body spin-model in a controlled environment [1]. We developed a semi-classical technique (the generalized discrete truncated Wigner approximation, GDTWA) that makes it possible to model the many-body evolution of this large three-dimensional and long-range interacting spin-3 model numerically. Here we present this new method and how it can be used to understand the experimentally observed dynamics of spin-state populations in terms of build-up of quantum entanglement and quantum thermalization concepts.

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Entanglement Witness 2.0 : Compressed Entanglement Witnesses

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Entanglement witnesses are observables that are non-negative for all separable states but not necessarily for an entangled states. observables in a single-copy level, that are non-negative for all separable states but not necessarily for an entangled state. In this work, we establish the framework of entanglement witness 2.0 that compresses two witnesses to a single one having both upper and lower bounds such that the bounds are satisfied by all separable but some entangled states, where the upper and lower bounds are characterized by distinct entanglement witnesses, respectively. We show that when a witness of the lower bound is given, the framework can be used to generate a witness of the upper bound, and vice versa. The framework can be generalized to compress more entanglement witnesses with an overhead of estimating the expectation value of an additional observable. All results are valid in, and can be applied to, multipartite quantum systems**.**

Distributed private randomness distillation

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We develop the resource theory of private randomness extraction in the distributed and device- dependent scenario. We begin by introducing the notion of independent random bits, which are bipartite states containing ideal private randomness for each party, and motivate the natural set of free operations. As the main tool of our analysis, we introduce Virtual Quantum State Merging, which is essentially the flip side of Quantum State Merging, without communication. We focus on the bipartite case and find the rate regions achievable in different settings. Perhaps surprisingly, it turns out that local noise can boost randomness extraction. As a consequence of our analysis, we resolve a long standing problem by giving an operational interpretation for the reverse coherent information in terms of the number of private random bits obtained by sending quantum states from one honest party (server) to another one (client) via the eavesdropped quantum channel.

Reference:

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Distinguishing classically indistinguishable states and channels

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For a given classical n-point probability vector p we describe the set of pure quantum states of order n which decohere to p. In particular, we analyze the question, how many mutually orthogonal quantum states decohere to the given classical state p. In other words, we ask, how many quantum states can be perfectly distinguished, even though their classical counterparts are identical and thus indistinguishable.

A similar problem can also be posed for channels: For a given classical map corresponding to a stochastic transition matrix T we look for quantum channel Φ, which induces the same classical transition matrix T , but is "more coherent". To quantify the coherence of a channel Φ we measure the coherence of the corresponding Jamiolkowski state J_Φ. We show that a classical transition matrix T can be coherified to a reversible unitary dynamics if and only if T is unistochastic. Otherwise the Jamiolkowski state J_Φ of the optimally coherified channel is mixed, and the dynamics must necessarily be irreversible. We find optimal coherifications for all one-qubit channels and provide a non-optimal coherification procedure that works for an arbitrary quantum channel and reduces its rank (i.e. the minimal number of required Kraus operators) from n^2 to n.

Creation and Protection of Fragile Quantum States on an NMR Quantum Computer

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Quantum correlations play a very important role in the field of quantum information processing. This talk will focus on the quantification of quantum correlations and their protection against decoherence. The discovery of the intriguing phenomenon that certain kinds of quantum correlations remain impervious to noise up to a specific point in time and then suddenly decay, has generated immense recent interest. We exploit dynamical decoupling (DD) sequences to prolong the persistence of time-invariant quantum correlations in a system of two NMR qubits[1]. While Uhrigh Dynamical Decoupling (UDD) schemes can well protect states against single- and two-axis noise they are not able to protect against general three-axis decoherence. Nested UDD (NUDD) schemes were hence proposed to protect multiqubit systems by nesting several UDD layers. We experimentally implemented a three-layer nested UDD sequence on an NMR quantum information processor[2]. We also demonstrate the efficacy of UDD sequences in experimentally preserving multipartite entanglement in systems of three qubits[3]. Our studies point the way to the realistic protection of fragile quantum states up to high orders and against arbitrary noise.

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Bengalis at Quantum Optics Group at ICFO

Maciej Lewenstein
ICFO – Institute of Photonic Sciences, Spain

In my talk I will focus on recent results obtained in my group by the Indian researchers: Manab Bera, Swapan Rana, Debraj Rakshit and more. I will start talking about quantum thermodynamics, and derivation of quantum thermodynamics “without temperature”. I will continue to talk about general properties and limitations of quantum batteries. Finally, I will talk about coherence theory and, in particular, coherence as resource.

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Ion trap based quantum information processor

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Ion trap technology is a forerunner in quantum computing, simulation, sensing and clocks. The versatile application of ion trap setups stem from their ability to control and manipulate single or multiple ions in a near isolated environment with negligible kinetic energy. Two such applications related to fundamental physics [1] and thermodynamics [2] at the quantum scale have been recently demonstrated in our setup. These two applications will be discussed in detail. In the first application we demonstrate that by proper feedback or noise filtering it is possible to preform frequency measurement with precision beyond the Heisenberg limit. The second experiment deals with understanding thermodynamics at the quantum limit. Both the experiments have been carried out using barium ion in a linear Paul trap using protocols engineered for each tasks.

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Fighting Errors in Topological Quantum Codes: From Concepts to Experiments with Trapped Ions

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Active quantum error correction using topological quantum error correcting codes provides to date one of the most promising routes towards large-scale fault-tolerant quantum information processing. In this talk, we present recent theoretical and experimental work on quantum error correction in topological quantum error correcting codes. We will particularly focus on the problem of fighting qubit loss, as caused e.g. by particle loss or electronic leakage processes in trapped ions-qubits, both for topological surface and color codes. In particular, we establish and explore a new connection between quantum information theory and classical statistical mechanics by studying the problem of qubit losses in 2D topological color codes [2]. We introduce a protocol to cope with qubit losses, and then show that determining the corresponding qubit loss error threshold is equivalent to a new generalized classical percolation process. We then discuss results from a recent experimental collaboration in which qubit loss detection and correction protocols have been implemented in a trapped-ion quantum information processor.

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Methods for a conclusive verification of bound entanglement

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Bound entangled states are a rather small and particular class of entangled states. Besides their theoretical importance, bound entangled states are notoriously difficult to prepare experimentally, because they are both, entangled and mixed. Even for a successful experimental preparation, yet another challenge is the actual verification that such a preparation was successful. In this talk I will present novel methods to find states which are most suitable for preparation and verification and I detail the methods for verifying that an experimental state was indeed bound entangled.

Tailored non-Gaussian multimode optical states

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Quantum technologies depend on information encoding into a physical system that can be coherently generated, manipulated and measured. Light provides a suitable platform, but the most easily generated quantum optical states- the Gaussian states- are simply described and cannot be used for nontrivial quantum computation.
We will explore here the conditional preparation of non-Gaussian states of light through appropriate non-Gaussian measurements on an ancillary system, and the control and characterization of these states. The objective is to benefit from the scalability and versatility of Gaussian states generation, along with the computational advantage offered by non-Gaussian states.
We will demonstrate experimentally such multimode states generated from ultrafast optical pulses (optical frequency combs) and parametric down conversion[1]. Mode dependent photon subtraction is implemented through sum-frequency generation[2], and characterization is performed through frequency resolved homodyne detection.
We will then study, both theoretically and experimentally, the influence of a non Gaussian ingredient on a Gaussian graph state. In particular, we will demonstrate propagation properties of non-gaussianity within the graph, and its implications on the nature of entanglement[3,4].

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Approximate Quantum Error Correction: Theory and Applications

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Quantum error correcting codes are critical for robust and scalable implementations of qubits. Approximate/Adaptive quantum error correction (AQEC) relaxes the constraints of perfect correction in such a way as to obtain comparable fidelity using fewer resources. Starting with the first approximate 4-qubit code to protect against amplitude damping noise, the idea of AQEC has seen significant progress over the last decade, including convex-optimisation-based formulations, algebraic conditions to check whether a given code is approximately correctable for a specific noise model, and construction of a near-optimal recovery map for arbitrary noise models [1,2]. In this talk, we will briefly survey the theoretical formulation of AQEC and discuss recent applications, including (a) an efficient numerical search for good quantum codes, (b) preserving entanglement under decoherence, and (c) achieving pretty good state transfer over disordered spin chains [3].

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Non-classicality of multi-photon added/subtracted multimode continuous variable states

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The broad areas of quantum information and optics are very actively indulged in variety of methods to produce non-Gaussian fields. This is mainly because, the non-Gaussian fields are increasingly found to be important in several quantum information tasks. The simplest way of producing and analyzing non-Gaussian fields is by adding/subtracting photons to the Gaussian continuous variable states. Interestingly, when photons are added/subtracted to the Gaussian fields they exhibit various degrees of non-classicality and quantum correlations. One of the important Gaussian fields is the Squeezed Vacuum state. We study the variation of entanglement and non-classicality with respect to multi-photon addition/subtraction to/from multi-mode continuous variable states.

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Controlling "Quantumness of Light"

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We demonstrate that, entangled atoms can be controlled to yield photons with desired statistics, while possessing super or subradiant character. Starting with two dipole coupled atoms, we explicitly show the effect of entanglement on emitted radiation at finite temperature. Subsequently, the case of three particles is investigated, which brings out, the role of 'monogamy score' in determining the quantum character of light. In particular, this measure of shareability of entanglement in a multi-party system shows the role of true many-body correlation on the nature of the emitted radiation in the far field domain.

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A programmable superconducting quantum processor with three pairwise coupled qubits

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Storing and processing information using quantum two level systems (qubits) promises tremendous speed-up for certain computational tasks like prime factorisation and searching an unsorted database. In addition, many problems in quantum mechanics can also be solved a lot more efficiently. Scientist and engineers all over the world are trying to build the hardware that can implement these quantum algorithms. In this talk, I will present one particular approach which uses superconducting electrical circuits operating at millikelvin temperatures to implement the quantum hardware. I will introduce a new three-qubit device, nicknamed "trimon" [1], which is based on a multi-mode superconducting circuit providing strong inter-qubit coupling. I will discuss the basic working principles of the device, the implementation of efficient multi-qubit gates and the capability of universal programmability [2]. Next, I will demonstrate the high-fidelity preparation of various two- and three-qubit entangled states and realization of a few quantum algorithms like Deutsch-Jozsa, Grover etc [3]. I will end by talking about the possibility of scaling to larger systems using the trimon as a building block and the challenges ahead.

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Non-separable States of Light: Classical and Quantum

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We will show a method to produce non-separable states of polarization and orbital angular momentum (OAM) of light in laboratory using laser beams. After discussing some interesting consequences of this property of light in classical experiments, we will demonstrate, how this non-separability can lead to hybrid entanglement of photons in polarization and OAM degrees of freedom. We provide a measurement of this entanglement through entanglement witness based on visibility of fringes obtained through coincidence counting.

Detection of genuine multipartite entanglement and its applications in secure communication

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In 1992, L. Hardy gave a proof of a no-go theorem for local hidden variables which requires only two qubits and does not require inequalities unlike Bell's non-locality proof. Hardy's proof uses a set of conditions on joint probabilities of measurement results impossible for classical (local-realistic) systems, but satisfied by predictions for a unique two-qubit entangled state. By referring to marginal probabilities, we have extended Hardy's idea and introduced a test for genuine multipartite entanglement. If all the local systems are two-levels then only a specific genuine multipartite entangled state can pass our test like in the case of original Hardy's proof. This feature finds many applications in quantum information processing tasks. Exploiting this feature, we have proposed secure quantum protocols for various communication and information processing tasks e.g., quantum key distribution, quantum random numbers generator, quantum digital signatures, quantum liar detection, quantum Byzantine agreement etc. Also, with the help of semidefinite programming, we have provide a device-independent and semi device independent security proofs of our proposed key distribution and random number generators protocols in a realistic noise scenario.

Time crystals and quantum synchronisation

Rosario Fazio
The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy

I will introduce boundary time-crystals where continuous time-translation symmetry breaking occurs at the boundary (or generically in a macroscopic portion) of a many-body quantum system. After introducing their definition and properties, I analyse in details a solvable model. I will provide examples of other systems where boundary time crystalline phases can occur. The existence of the boundary time crystals is intimately connected to the emergence of time-periodic steady state in the thermodynamic limit of a many-body open quantum system. Connection to quantum synchronisation will be also discussed.

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Quantum Synchronisation in the Quantum Regime

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It is well known that weakly coupled, self-sustained oscillators can mutually lock the phase of their oscillations in classical mechanics. Such a phenomenon is known as synchronisation. Given the experimental progress of seeing resonators in the quantum regime, there is an ongoing effort to observe synchronisation and other non-linear dynamical effects in quantum systems. It is desirable to observe such synchronisation of quantum systems not just in the classical regime, but also in the quantum regime. This quantum regime is defined by low number of excitations and a highly non-classical steady state of the self-sustained oscillator. In this talk, I will introduce quantum synchronisation and present several results relating to the synchronisation of quantum systems. I will also comment on the applications of these new ideas to quantum technologies.

Estimation of Optimal Singlet Fraction and Entanglement Negativity

Satyabrata Adhikari
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Structural physical approximation (SPA) has been exploited to approximate non-physical operation such as partial transpose. It has already been studied in the context of detection of entanglement and found that if the minimum eigenvalue of SPA to partial transpose is less than 2/9 then the two-qubit state is entangled. We find application of SPA to partial transpose in the estimation of optimal singlet fraction. We show that optimal singlet fraction can be expressed in terms of minimum eigenvalue of SPA to partial transpose. We also show that optimal singlet fraction can be realized using Hong-Ou-Mandel interferometry with only two detectors. Further, we show that a single copy and two measurements are enough to estimate the entanglement quantifier like entanglement negativity and concurrence. To achieve our aim, we establish a relationship between the entanglement negativity and the minimum eigenvalue of structural physical approximation of partial transpose of an arbitrary two-qubit state. The derived relation make possible to estimate entanglement negativity experimentally by Hong-Ou-Mandel interferometry with only two detectors. Also, we derive the upper bound of the concurrence of an arbitrary two-qubit state and have shown that the upper bound can be realized in experiment.

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Single Trapped Ion Optical Atomic Clock

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CSIR-NPL is the time keeper of the nation which maintains the Indian Standard Time (IST) and disseminates that to the users in pan India. We are responsible for measuring “time” and “frequency” at the highest level of accuracy in India and also for keeping them traceable to the International Bureau of Weights and Measures (BIPM) to realize the “second”, i.e., the unit of time in International System (SI) of Units. Higher accuracy in time synchronization is always a requisite in many advanced technologies, e. g., communication, navigation, weather forecast and many more. Keeping that in mind, we carry out research to develop state-of-the-art atomic clocks since they are the backbone for this purpose. As the highly forbidden ultra-narrow atomic transitions in the optical domain leads to better accuracy than those in the microwave frequencies (*e.g.*, cesium and rubidium atomic frequency standard), we have started developing an atomic clock based on the ultra-narrow $4f^{14}6s\ ^2S_{1/2}$ - $4f^{13}6s^2\ ^2F_{7/2}$ electric octupole (E3) optical transition of ytterbium-ion ($^{171}Yb^+$). It is expected that the next generation definition of the SI second will be based on an optical transitions and Yb-ion has been endorsed as a secondary standard by CIPM (international body for SI standards). In our laboratory, at present, we are assembling the Paul trap in a ultra-high vacuum housing and preparing the necessary optics for trapping and laser cooling of the ion. An overview of this activity together with possible applications of “precise time” will be presented.

Strong quantum nonlocality without entanglement

Somshubhro Bandyopadhyay
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A set of product states is said to exhibit "nonlocality without entanglement" if optimal discrimination of the states is not possible by any sequence of local operations and classical communication (LOCC), although the states can be prepared locally following some known set of rules. Here we present a stronger manifestation of this kind of nonlocality through the notion of local reducibility. A set of orthogonal quantum states on a composite Hilbert space is defined to be locally irreducible if it is not possible to locally eliminate one or more states from the set while preserving orthogonality of the post-measurement states. A locally irreducible set, by definition, is locally indistinguishable, but the converse doesn't always hold. We provide the first examples of orthogonal product bases on 3 X 3 X 3 and 4 X 4 X 4 that are locally irreducible in all bipartitions. The example on 3 X 3 X 3 achieves the minimum dimension required for such multiparty product states to exist. The existence of such orthogonal product bases implies that local implementation of a multiparty product basis measurement may require entangled resources in all bipartitions.

Handling Noisy Qubits: An NMR exploration

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Qubits, however insulated, are prone to noise - the undesired influences from the external world, and so it remains a major challenge to work with them. In this talk, we describe the nuclear magnetic resonance (NMR) studies on noise characterization, suppression, as well as manipulation. The specific topics include noise spectroscopy, algorithmic cooling, dynamical decoupling, and noise engineering.

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Momentum Kicks in Interference Experiments

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The two-slit interference experiment with a which-way detector has been a topic of intense debate. The scientific community is divided on the question as to whether the particle receives a momentum kick because of the process of which-way measurement [1-6]. It is shown here that the same experiment can be viewed in two different ways, depending on which basis of the which-way detector states one chooses to look at. In one view, the loss of interference arises due to the entanglement of the two paths of the particle with two orthogonal states of the which-way detector. In another view, the loss of interference can be interpreted as arising from random momentum kicks of magnitude $h/2d$ received by the particle, d being the slit separation. The same scenario is shown to hold for a three-slit interference experiment. The random momentum kicks for the three-slit case are of two kinds, of magnitude $\pm h/3d$. The analysis is further generalized to n-slit interference. The two alternate views are described by the same quantum state, and hence are completely equivalent. The concept of "local" *vs.* "nonlocal" kicks, much discussed in the literature, is not needed here. The controversy surrounding the momentum kicks is thus resolved.

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Entanglement mediated by gravity

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The talk will begin with brief review of major experiments where gravity influences quantum matter. It will be argued that they are all explainable within classical gravitation, either Newtonian or general relativistic. Then recent proposals for revealing quantum facet of gravity will be introduced, which are based on placing gravitational field in the role of mediator of quantum correlations. It will be shown what exactly one concludes from observation of the gain of quantum correlations and what are the required initial conditions. We will then move to a concrete setup of two massive oscillators coupled gravitationally and derive figure of merit relevant to the gain of quantum entanglement. The resulting experimental parameters are demanding, of course, but some of them are close to already realised in mechanical oscillators (mirrors in the LIGO interferometer). Finally, some thoughts on the limits of this approach will be presented.

Near-*100%* two-photon-like coincidence-visibility dip with classical light and the role of complementarity

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The famous Hong-Ou-Mandel two-photon coincidence-visibility dip (TPCVD), which accepts one photon into each port of a balanced beam splitter and yields an equal superposition of a biphoton from one output port and vacuum from the other port, has numerous applications in photon-source characterization and to quantum metrology and quantum computing. Exceeding 50% two-photon-coincidence visibility is widely believed to signify quantumness. In this talk, we show theoretically that classical light can yield a 100% TPCVD for controlled randomly chosen relative phase between the two beam-splitter input beams and experimentally demonstrate a 99.635 +/- 0.002% TPCVD with classical microwave fields. We show quantumness emerges via complementarity for the biphoton by adding a second beam splitter to complete an interferometer thereby testing whether the biphoton interferes with itself: Our quantum case shows the proper complementarity trade-off whereas classical microwaves fail.

References:

[1] Simanraj Sadana, Debadrita Ghosh, Kaushik Joarder, A. Nagalakshmi, Barry C Sanders, Urbasi Sinha, *Near-100 % two-photon-like coincidence-visibility dip with classical light and the role of complementarity*, arXiv: 1810.01297.

ABSTRACTS FOR CONTRIBUTORY TALKS

Estimating entanglement in large-scale noisy topological codes

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Entanglement is considered as resource in quantum information processing tasks. However, computation of the quantity is often challenging, particularly when the system is of large size, or when it is described by a mixed state -- for example, in the presence of noise. In this talk, we discuss how entanglement, as measured by localizable entanglement, in a noisy topological code of large size, such as the Kitaev's surface code and the color code, can be estimated via an experimentally accessible methodology using entanglement witness operators. We also demonstrate how graph states can be employed in the recipe, and discuss how insight about the distance dependence of entanglement can be obtained. The results are particularly relevant in characterizing the stabilizer states in the case of quantum error correction, where the topological codes serve as ideal candidate systems.

Uncertainty principle as post-quantum nonlocality witness for continuous variable multi-mode scenario

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Uncertainty principle is one of the central concepts in quantum theory. Different forms of this particular principle have been discoursed in various foundational and information theoretic topics. In the discrete input-output scenario the limited nonlocal behavior of quantum theory has been explained by fine-grained uncertainty relation. On the other hand, in continuous variable paradigm Robertson-Schrodinger (RS) uncertainty relation has been used to detect multi-mode entanglement. Here we show that RS uncertainty relation plays an important role to discriminate between quantum and post-quantum nonlocal correlations in multi-mode continuous outcome scenario. We provide a class of m-mode post-quantum nonlocal correlations with continuous outcome spectrum. While nonlocality of the introduced class of correlations is established through Calvalcanti-Foster-Reid-Drummond (CFRD) class of Bell inequalities, RS uncertainty relation detects their post-quantum nature. Our result is a hint towards a wider role of uncertainty principle in the study of nonlocality in continuous variable multi-mode systems.

Reference:
[1] arXiv:1806.08133.

An alternative multiparty quantum mutual information

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Mutual information, as the name suggests, qualifies the information that is common to or shared by two or more parties. Quantum mutual information for bipartite quantum systems is non-negative and bears the interpretation of total correlation between the two subsystems. This may, however, no longer be true for three or more party quantum systems. In my talk, I will discuss an alternative definition of multipartite information taking into account the shared information between two and more parties. It is non-negative, observes monotonicity under partial trace as well as completely positive maps, and equals multipartite information measure in literature for pure states.

Reference:
[1] Phys. Rev. A **96**, 012332 (2017).

Identifying and Quantifying Resource for Remote State Preparation using correlations beyond discord

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Exploring the possibility of using separable states as resource for achieving quantum information processing (QIP) tasks has been gaining increasing significance. In this context, a particularly important demonstration has been that separable states with nonvanishing discord can be used for remote state preparation(RSP). Here we argue that zero-discord states can also be useful as resource for implementing RSP, thereby unravelling a hitherto unnoticed usefulness of nondiscordant states. Further, through this analysis we develop a novel paradigm based on the measure of simultaneous correlations in three mutually unbiased bases which is nonzero for any non-product state to quantify usefulness of the resource for the RSP task with zero-discord states as well. Thus, this work reveals that, beyond discord, another possible resource for QIP tasks based on separable states can stem from simultaneous correlations in mutually unbiased bases. This also provides a novel operational meaning for such measures of correlations.

Magic in quantum systems : beyond algorithms

Chiranjib Mukhopadhyay
Harish-Chandra Research Institute, India

Quantum computation via magic state injection has seen significant development over past two decades since the announcement of Gottesman Knill theorem. We show that magic in quantum states can be quantitatively linked to the now well known resource theory for quantum coherence. We further discuss the idea of generation of magic in qubit states through an autonomous thermodynamic machine, and using magic to quantitatively describe quantum phase transition in a simple spin model, in so doing extending the utility of magic beyond quantum computation.

Reference:

[1] J Phys. A **51,** 414006 (2018).
[2] Phys. Rev A **98,** 012102 (2018).

Operational characterization of quantumness of unsteerable correlations

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Recently, the quantumness of local bipartite correlations arising from separable states in the context of a Bell scenario has been studied and linked with superlocality [Phys. Rev. A 95, 032120 (2017)]. Here we investigate the quantumness of unsteerable bipartite correlations in the context of a given steering scenario. Generalizing the concept of superlocality, we define as supercorrelation, the requirement for a larger dimension of the preshared randomness to simulate the correlations than that of the quantum states that generate them. Since unsteerable states form a subset of Bell local states, it is an interesting question whether certain unsteerable bipartite states can be supercorrelated. Here, we answer this question in the affirmative. In particular, the quantumness of certain unsteerable bipartite correlations can be pointed out by the notion of superunsteerability, the requirement for a larger dimension of the classical variable that the steering party has to pre share with the trusted party for simulating the bipartite correlations than that of the quantum states which reproduce them. This provides a generalized approach to quantify the quantumness of unsteerable bipartite correlations in convex operational theories. Finally, the notion of superunsteerability is generalized for tripartite unsteerable correlations.

Reference:

[1] D. Das et al., "Operational characterization of quantumness of unsteerable bipartite states", Physical Review A 97 (6), 062335 (2018).
[2] D. Das et al., "Characterization of the quantumness of unsteerable tripartite correlations", arXiv:1706.08415 [quant-ph].

Self-bound Bose-Fermi liquids in lower dimensions

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We study weakly interacting mixtures of ultracold atoms composed of bosonic and fermionic species in 2D and 1D space. When interactions between particles are appropriately tuned, self-bound quantum liquids can be formed. Formation of these droplets is due to the higher order correction terms contributing to the total energy and originating in quantum fluctuations. The fluctuations depend drastically on the dimensionality of the system. We concentrate here on low dimensional systems because they are the most promising from experimental point of view due to significant reduction of three-body losses. We analyse stability conditions for 2D and 1D systems and predict values of equilibrium densities of droplets.

Reference:
[1] arXiv:1808.04793

Quantum cryptography for socio-economic problems

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Unconditionally secure communication assured by quantum mechanics can be exploited beyond key distribution, which is shown composable to ensure security for complex socio-economic problems demanding security. For instance, quantum cryptographic schemes for voting [1], sealed-bid auction [2], private comparison [3,4], online banking [4,5], have been proposed recently. Here, we briefly review some of these recently proposed schemes [1-5] and also discuss the possibilities of their experimental implementation and future problems in the relevant area of research. Specifically, we discuss some quantum voting schemes [1], a sealed-bid auction protocol [2], and a set of quantum and semiquantum private comparison [3,4] and online-banking [4,5] schemes. It is also relevant to mention here that some of the simpler quantum communication schemes with application in such complex tasks have been recently realized. This motivates us to discuss the experimental feasibility of the set of quantum cryptographic schemes for socio-economic problems.

Reference:
[1] K. Thapliyal, R. D. Sharma, A. Pathak, Int. J. Quantum Inf. 15, 1750007 (2017).
[2] R. D. Sharma, K. Thapliyal, A. Pathak, Quantum Inf. Process. 16, 169 (2017).
[3] K. Thapliyal, R. D. Sharma, A. Pathak, arxiv: 1608.00101 (2016).
[4] C. Shukla, K. Thapliyal, A. Pathak, Quantum Inf. Process. 16, 295 (2017).
[5] K. Thapliyal, A. Pathak, arXiv:1807.08199 (2018).

Indefinite causal order enables perfect quantum communication with zero capacity channel

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Quantum mechanics is compatible with scenarios where the relative order between two events is indefinite. Here we show that two instances of a noisy process, used in a superposition of two alternative orders, can behave as a perfect quantum communication channel. This phenomenon occurs even if the original processes have zero capacity to transmit quantum information. In contrast, perfect quantum communication does not occur when the message is sent along a superposition of paths, with independent noise processes acting on each path. The possibility of perfect quantum communication through noisy channels highlights a fundamental difference between the superposition of orders in time and the superposition of paths in space.

Reference:
[1] arXiv:1810.10457.

ON STATIONARY CHAINS OF GAUSSIAN STATES

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We explore conditions on the covariance matrices of a consistent chain of mean zero finite mode Gaussian states in order that the chain may be exchangeable or stationary. For an exchangeable chain our conditions are necessary and sufficient. Every stationary Gaussian chain admits an asymptotic entropy rate. We give exact formula for entropy rate of such states.

Reference:
[1] To be submitted soon in arxiv.

Resource theory of non-Markovianity: A thermodynamic perspective

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We establish a connection between non-Markovianity and negative entropy production rate for various classes of quantum operations. Generalizing the definition of the entropy production rate for the non-equilibrium case we connect it with the rate of change of free energy of the system, and establish complementary relations between non-Markovianity and maximum loss of free energy. We naturally conclude that non-Markovianity in terms of divisibility breaking is a necessary resource for the backflow of other resources like purity or free energy under corresponding allowed operations. Based on this we propose a resource theory of non-Markovianity by constructing the free operations, free states and a generalized measure of non-Markovianity. The framework satisfies the basic properties of a consistent resource theory. The proposed resource quantifier is lower bounded by the optimization free Rivas-Huelga-Plenio (RHP) measure of non-Markovianity.

Reference:
[1] arXiv:1803.06881.

Witnessing bipartite entanglement sequentially by multiple observers

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We investigate sharing of bipartite entanglement in a scenario where half of an entangled pair is possessed and projectively measured by one observer, called Alice, while the other half is subjected to measurements performed sequentially, independently, and unsharply, by multiple observers, called Bobs. We find that there is a limit on the number of observers in this entanglement distribution scenario. In particular, for a two-qubit maximally entangled initial shared state, no more than twelve Bobs can detect entanglement with a single Alice for arbitrary – possibly unequal – sharpness parameters of the measurements by the Bobs. Moreover, the number of Bobs remains unaltered for a finite range of near-maximal pure initial entanglement, a feature that also occurs in the case of equal sharpness parameters at the Bobs. Furthermore, we show that for non-maximally entangled shared pure states, the number of Bobs reduces with the amount of initial entanglement, providing a coarse-grained but operational measure of entanglement.

Reference:
[1] arXiv:1806.01816 (to appear in Phys. Rev. A).

Quantum correlations as probes of chaos and ergodicity

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Long-time average behavior of various dynamically generated quantum correlations in a multi-qubit system, collectively modeled as a kicked top, is discussed. The behavior of quantum correlations such as entanglement, discord, concurrence, Bell correlation function and tangle is analyzed (as a function of initial state) for a large spin system (approaching the classical limit), as well as for a spin-3/2 system, which is deep into the quantum regime. Long-time average of these correlations reproduce the structures of the classical stroboscopic map (of a kicked top). Deeper investigations reveal that a quantum system of 3 or 4 qubits collectively modeled as a kicked top is exactly solvable and yet, interestingly, display signatures of ergodicity and thermalization. Interesting property of tunneling between the stable islands, as described by the classical limit in a regular phase space structure, is also observed in case of four qubits. Our analytical solutions are verified numerically, and comapred with the experimental data obtained from a recent transmon based system of 3 qubits.

Reference:
[1] Quantum correlations as probes of chaos and ergodicity Vaibhav Madhok, Shruti Dogra, Arul Lakshminarayan, Optics Communications, 420, 189-193 (2018).

Mutual uncertainty, conditional uncertainty, and strong subadditivity

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We introduce a concept, called the mutual uncertainty between two observables in a given quantum state, which enjoys features similar to those of the mutual information for two random variables. Further, we define conditional uncertainty as well as conditional variance and show that conditioning on more observables reduces the uncertainty. Given three observables, we prove a “strong subadditivity” relation for the conditional uncertainty under certain conditions. As an application, we show that by using the conditional variance one can detect bipartite higher dimensional entangled states. The efficacy of our detection method lies in the fact that it gives better detection criteria than most of the existing criteria based on geometry of the states. Interestingly, we find that for N -qubit product states, the mutual uncertainty is exactly equal to N − \sqrt{N }, and if it is other than this value, the state is entangled. We also show that using the mutual uncertainty between two observables, one can detect non-Gaussian steering where Reid’s criterion fails to detect it. Our results may open a direction of exploration in quantum theory and quantum information using mutual uncertainty, conditional uncertainty, and the strong subadditivity for multiple observables.

Reference:
[1] PRA, 98, 032123 (2018).

Noise scaling in Coherent Beam Combining

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High power lasers find essential applications in fundamental science and industry [1]. Coherent beam combination (CBC) is a method to scale laser power beyond the physical limits of optical amplifiers. In this technique, multiple beams are combined via constructive interference in a cascaded series of beam-splitters to generate a stable high power output beam [2]. The noise profile of the final output beam depends crucially on the relative phase stability of the intermediate beams at each combination. In CBC the noise variance of the bright output beam approaches the quantum noise limit asymptotically over many combinations due to statistical noise cancellation. In practice the output of an amplifier will suffer from both, amplitude and phase noise. We theoretically and experimentally study the role of these noises in CBC by combining two noisy beams of equal noise variance on a Mach-Zehnder interferometer. We characterize the dependence of the output noise variance on correlations in noise among the input beams and the finite bandwidth of the interferometric phase lock. Our investigations highlight a reduction in noise scaling at the output for generation of bright beams using coherent combining.

References:
[1] C. Jauregui /et al./, Nat. Phot. *7*, 861–867 (2013).
[2] H. Tünnermann /et al./, Opt. Express *19*, 19600–19606 (2011).

No purification in all discrete theories and the power of the complete extension

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Gdansk University, Poland

Quantum theory has an outstanding property that each state has its well defined purification in larger Hilbert space. It is known that the classical theory and the theory of non-signaling boxes does not have purification for all of their states. These theories are examples of the so called generalized probabilistic theories (GPTs), where each state has a number of extensions to a larger system. We single out the most relevant one, called a complete extension, unique up to local reversible operations on the extending system. We prove that this special, finite dimensional extension bares an analogy to quantum purification in that (i) it allows for an access to all ensembles of the extended system, (ii) from complete extension one can generate any other extension. It then follows, that an access to the complete extension represents the total power of the most general non-signaling adversary. A complete extension of a maximally mixed box in two-party binary input binary output scenario is up to relabeling the famous Popescu-Rohrlich box. The latter thus emerges naturally without reference to the Bell's non-locality. However the complete extension is not a purification (a vertex) in the generic case. Moreover, we show that all convex discrete theories does not provide purification for almost all of it states. In particular the theory of contextuality does not possess purification. The complete extensions are by nature high-dimensional systems. We were able however to provide explicit structure of complete extension for the noisy Popescu-Rohrlich-boxes and the 3-cycle contextual box.

Non-classicality and other resources in continuous-variable systems

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We lay down an operational framework for studying the resource of Glauber--Sudarshan nonclassicality in networks of passive linear elements and measurements with feed-forward. Defining new nonclassicality measures based on the quantum fluctuations of quadratures and the quantum Fisher information, we prove fundamental constraints on the manipulation of nonclassicality. Special cases include no-go results in the concentration of squeezing and a complete hierarchy of nonclassicality for single mode Gaussian states. Time permitting, we will also present a new extension of this project: a thermodynamic resource theory for continuous-variable systems.

Reference:

[1] arxiv:1804.10190

ABSTRACTS FOR POSTERS

Spin squeezing in symmetric multiqubit states with two distinct Majorana spinors

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Enhanced precision measurements using many particle collective quantum states is crucial for their technological applications in quantum information science and metrology. While achievable precision using uncorrelated N particle system increases with the number N of particles, it is limited by the standard quantum limit of 1/ ??? N. This opened up dedicated theoretical and experimental investigations employing entangled N particle states so that improved measurement precision beyond the standard quantum limit could be established. Squeezed spin states are a class of permutation symmetric N particle entangled states, which exhibit reduced quantum fluctuation in their collective spin angular momentum in a certain direction and they are useful for quantum enhanced metrology. Spin squeezing parameter offers a simple experimental criterion for the detection of entanglement in many-particle systems, where it is not possible to address individual particles. Here we investigate spin squeezing in different classes of N -qubit symmetric states consisting of all permutations of two distinct spinors and we employ Majorana geometric representation of multiqubit states obeying exchange symmetry for this purpose. While Dicke states, the N -qubit symmetric states consisting of two orthogonal spinors, are not spin-squeezed, we show that N qubit symmetric states consisting of two distinct, non-orthogonal spinors exhibit spin squeezing.

Reference:
[1] arXiv:1803.09143v3.

Pretty Good State Transfer via Adaptive Quantum Error Correction

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We examine the role of quantum error correction (QEC) in achieving pretty good quantum state transfer over a class of 1-d spin Hamiltonians. Recasting the problem of state transfer as one of information transmission over an underlying quantum channel, we identify an adaptive QEC protocol that achieves pretty good state transfer. Using an adaptive recovery and approximate QEC code, we obtain explicit analytical and numerical results for the fidelity of transfer over ideal and disordered 1-d Heisenberg chains. In the case of a disordered chain, we study the distribution of the transition amplitude, which in turn quantifies the stochastic noise in the underlying quantum channel. Our analysis helps us to suitably modify the QEC protocol so as to ensure pretty good state transfer for small disorder strengths and indicates a threshold beyond which QEC does not help in improving the fidelity of state transfer.

Reference:
[1] arXiv:1807.04062.

Experimental Entanglement Detection of Unknown Tripartite States on Spin Ensemble using NMR

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Experimental generation and detection of the entanglement is at the heart of, most if not all, the quantum computational tasks. In general, to determine whether a given state is entangled or not is an open and exigent problem in quantum mechanics. Here we give an experimental implementation of the scheme for tripartite entanglement detection on spin ensemble using NMR. This protocol not only detects the entanglement but also classify it into six inequivalent classes of three qubit entangled states. Only four observables suffice to experimentally differentiate the six classes. Experimental realization is achieved in an NMR scenario by mapping the desired observables, to Pauli's z-operators of the third qubit, followed by measuring the ensemble average in the state under investigation. Results have been substantiated with direct full quantum state tomography as well as negativity calculations and the comparison suggests that indeed the demonstration is a success.

References:

[1] A. Singh, H. Singh, K. Dorai, and Arvind, *Experimental Classification of Entanglement in Arbitrary Three-Qubit Pure States on an NMR Quantum Information Processor*, Phys. Rev. A 98, 032301 (2018).
[2] S. Adhikari, C. Datta, A. Das, and P. Agrawal, *Distinguishing different classes of entanglement of three-qubit pure states*, EPJ D 72, 157 (2018).
[3] V. Coffman, J. Kundu, and W. K. Wootters, *Distributed entanglement*, Phys. Rev. A, 61, 052306 (2000).
[4] A. Aćın, D. Bruß, M. Lewenstein, and A. Sanpera, *Classification of Mixed Three-Qubit States*, Phys. Rev. Lett. 87, 040401 (2001).

Response of entanglement to annealed vis-à-vis quenched disorder in quantum spin models

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University of Calcutta, Kolkata, India

We investigate bipartite entanglement in random quantum XY models at equilibrium. Depending on the intrinsic time scales associated with equilibration of the random parameters and measurements associated with observation of the system, we consider two distinct kinds of disorder, namely annealed and quenched disorders. We conduct a comparative study of the effects of disorder on nearest-neighbor entanglement, when the nature of randomness changes from being annealed to quenched. We find that entanglement properties of the annealed and quenched disordered systems are drastically different from each other. This is realized by identifying the regions of parameter space in which the nearest-neighbor state is entangled, and the regions where a disorder-induced enhancement of entanglement − order-from-disorder − is obtained. We also analyze the response of the quantum phase transition point of the ordered system with the infusion of disorder.

Reference:
[1] arXiv:1712.05226

Lower bound on entanglement to create a completely connected graph from a chain like structure

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Distribution of entanglement finds necessary applications in the field of quantum network. It is challenging task to create an EPR pair between two widely separated node. There are many known LOCC protocols but optimal one is hard to find. Here we have investigated a problem where a number of bipartite pure entangled states is shared between adjacent nodes forming a chain like structure. We defined two general LOCC schemes by which this chain transforms to completely connected graph with some probability. In such complete graph, any two nodes is connected by an EPR pair. We have calculated the lower bound of entanglement for each scheme and compared which scheme is more efficient.

New Facet Bell inequalities for multi qubit states

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Our recent paper on ?€?New Bell inequalities for pure three qubit states (Phys. Lett. A, 381, 3928, (2017))?€? introduces a special scenario where out of the three parties one party makes only one dichotomic measurement instead of two. Following this work we have constructed the facets of the local polytope for the scenario of three parties, two dichotomic measurement settings for two parties and one dichotomic measurement for the remaining and got only one nontrivial facet up-to relabelling of indices. We then showed that the propositions from the previous paper remain valid for the new facet inequality also. We also analysed the inequality for some noisy mixed states. Next we continued to construct facets for four parties (with two parties doing two dichotomic measurements) and five parties (again with two parties doing two dichotomic measurements). Interestingly, in both of these cases we again got only one nontrivial facet inequality (up-to relabelling of indices) like the three party case and the structure of the inequalities are exactly same in all these three cases. This makes us to extend these facet inequalities for n parties (with two parties doing two dichotomic measurements) having similar kind of structure.

Allowed region of the mean values of angular momentum observables and their uncertainty relation

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The expectation values of operators drawn from a single quantum state cannot be outside of a particular region, called their allowed region or the joint numerical range of the operators. Basically, the allowed region is an image of the state space under the Born rule. The maximum-eigenvalue-states---of every linear combination of the operators of interest---are sufficient to generate boundary of the allowed region. In this way, we obtain the numerical range of certain Hermitian operators (observables) that are functions of the angular momentum operators. Especially, we consider here three kinds of functions---combinations of powers of the ladder operators, powers of the angular momentum operators and their anticommutators---and discover the allowed regions of different shapes. By defining some specific concave (and convex) functions on the joint numerical range, we also achieve tight uncertainty (and certainty) relations for the observables. Overall, we demonstrate how the numerical range and uncertainty relations change as the angular momentum quantum number grows. Finally, we apply the quantum de Finetti theorem by taking a multi-qubit system and attain the allowed regions and tight uncertainty relations in the limit where the quantum number goes to infinity.

Reference:
[1] arXiv:1810.07937.

Manipulation of entanglement sudden death in an all-optical experimental setup

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Entanglement sudden death (ESD) is the phenomenon wherein disentanglement happens in finite time even when individual qubits decohere only asymptotically in time due to noise. Prolonging the entanglement is essential for the practical realization of entanglement-based quantum information and computation protocols. For this purpose, the local NOT operation in the computational basis on one or both qubits has been proposed for a photonic system [1]. In this talk, I will discuss the preparation, and characterization of a maximally entangled photon source (fidelity = 96.67%) along with the all-optical implementation of the NOT operations that can hasten, delay, or completely avert ESD, all depending on when it is applied during the process of decoherence for the polarization entangled photonic qubit system. The exciting experimental results on the manipulation of ESD will be presented along with the attendant theory.

References:
[1] Ashutosh Singh, Siva Pradyumna, A. R. P. Rau, and Urbasi Sinha, Manipulation of entanglement sudden death in an all-optical setup," J. Opt. Soc. Am. B 34, 681-690 (2017).

Swapping Intra-photon entanglement to Inter-photon entanglement using linear optical devices

Asmita Kumari
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We propose a curious protocol for swapping the intra-photon entanglement between path and polarization degrees of freedom of a single photon to intra-photon entanglement between two spatially separated photons which have never interacted. This is accomplished by using an experimental setup consisting of three suitable Mach-Zehnder interferometers along with number of beam splitters, polarization rotators and detectors. Using the same setup, we have also demonstrated an interesting quantum state transfer protocol, symmetric between Alice and Bob. Importantly, the Bell-basis discrimination is not required in both the swapping and state transfer protocols. Our proposal can be implemented using linear optical devices.

References:
1. C. H. Bennett et al., Phys. Rev. Lett. 70, 1895 (1993).
2. arXiv:1806.01201

Squeezed Schrodinger kitten states of a qubit-oscillator system

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We study the evolution of the hybrid entangled squeezed states of the qubit-oscillator system in the strong coupling domain. Following the adiabatic approximation we obtain the reduced density matrices of the qubit and the oscillator degrees of freedom. The oscillator reduced density matrix is utilized to calculate the quasiprobability distributions such as the Sudarshan-Glauber diagonal P -representation, the Wigner W -distribution, and the nonnegative Husimi Q-function. The negativity associated with the W -distribution acts as a measure of the nonclassicality of the state. The existence of the multiple time scales induced by the interaction introduces certain features in the bipartite system. In the strong coupling regime the transient evolution to low entropy configurations reveals brief emergence of nearly pure kitten states that may be regarded as superposition of uniformly separated distinguishable squeezed coherent states. However, the quantum fluctuations with a short time period engender bifurcation and subsequent rejoining of these peaks in the phase space. The above mentioned doubling of the number of peaks increases the entropy to its near maximal value. Nonetheless, these states characterized by high entropy values, are endowed with a large negativity of the W -distribution that points towards their non-Gaussian behavior. This may be ascertained by the significantly large Hilbert-Schmidt distance between the oscillator state and an ensemble of most general statistical mixture of squeezed Gaussian states possessing nearly identical second order quadrature moments as that of the oscillator. Moreover, we check the Kullback-Leibler divergence based on the smoothed nonnegative Q-functions for the two states. The bifurcation and rejoining of the squeezed kitten states may be of practical significance in building quantum computational network. The qubit-oscillator bipartite system with time-dependent coupling may be useful in this context.

Reference: Squeezed Schrodinger kitten states of a qubit-oscillator system: Generation and quantum properties in the phase space, M. Balamurugan , R. Chakrabarti , B. Virgin Jenisha , Physica A 473 (2017), 428-444.

Convex geometry of Markovian Lindblad dynamics and witnessing non-Markovianity

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We develop a theory of linear witnesses for detecting non-Markovianity, based on the geometric structure of the set of Choi states for all Markovian evolutions having Lindblad type generators. We show that the set of all such Markovian Choi states form a convex and compact set under the small time interval approximation. Invoking geometric Hahn-Banach theorem, we construct linear witnesses to separate a given non-Markovian Choi state from the set of Markovian Choi states. We present examples of such witnesses for dephasing channel and Pauli channel in case of qubits. We further investigate the geometric structure of the Markovian Choi states to find that they do not form a polytope. This presents a platform to consider non-linear improvement of non-Markovianity witnesses.

Reference:
arXiv:1805.11418

Ancilla induced amplification of quantum Fisher information

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Given a quantum state with an unknown parameter being measured with a suitable observable, Quantum Fisher Information (QFI) is the amount of information that one can extract about the unknown parameter. QFI also quantifies the maximum achievable precision in estimating the unknown parameter with a given amount of resource via quantum Cramer-Rao bound. In this work, we describe a protocol to amplify QFI of a single target qubit precorrelated with a set of ancillary qubits. Using an NMR system as an example, we show that a single

quadrature NMR signal of only ancillary qubits suffices to perform the complete quantum state tomography (QST) of the target qubit. We experimentally demonstrate this protocol using a star-topology spin-system consisting of a 13-C nuclear spin as the target qubit and three 1-H nuclear spins as ancillary qubits. We prepare the target qubit in various initial states, perform experimental QST, and estimate the amplification of QFI in each case using semi-analytical methods. We also show that the QFI-amplification scales linearly with the number of ancillary qubits and quadratically with their purity.

Reference:
arXiv: 1801.01396.

The Quantum Chesire Cat: some new aspects and possibilities

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Quantum Chesire Cat is a counterintuitive phenomenon that provides a new window into the nature of the quantum systems in relation to multiple degrees of freedom associated with a single physical entity. Under suitable pre and postselections, a photon (the cat) can be decoupled from its circular polarization (its grin). In this talk, we will explore whether the grin without the cat can be teleported to a distant location. This will be a totally disembodied teleportation protocol. Based on the original Quantum Chesire Cat setup, we design a protocol where the circular polarization is successfully teleported between two spatially separated parties even though the photon is not physically present with them. The process raises questions in our understanding about properties of quantum system. We also briefly discuss about a few interesting new aspects of the original Quantum Chesire Cat protocol.

Demonstration of quantum secret sharing principle and a new quantum binary voting protocol in IBM quantum computer

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Hillery et al. [Phys. Rev. A. 59, 1829 (1999)] proposed the quantum version of classical secret sharing protocol using GHZ states. Here, we implement this quantum secret sharing protocol in IBM 5-qubit quantum processor (IBMQX4) and compare the results obtained from the experiments with the theoretically predicted ones. The results are analyzed through quantum state tomography technique and the fidelity of these states were calculated for different number of executions made in the device. Further we extend this protocol to propose a new quantum binary voting protocol and analyze its security.

Quantum Coherence, Disturbance and Classical Information in Quantum measurements

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Quantum coherence is an essential quantum resource which plays important role in a quantum measurement processes. Once we do a complete measurement on a physical system in a given basis, the system undergoes decoherence and loses its coherence. In order to extract information about a physical system we need to measure some observable. Unlike classical systems, in quantum mechanics the measurement process necessarily disturbs the state of the system unless the state is prepared in one of the eigenstate of the observable being measured. Here we have investigated how coherence is related with the disturbance caused to a system, the amount of information loss and the extractable information. First we present trade-off relations between coherence and disturbance using relative entropy measure of coherence for single party and bipartite systems. Next we show that accessible coherence is upper bounded by the the Holevo quantity. We also show that the amount of extractable information is upper bounded by the initial coherence of the system.

Analysing the nuances of noise and weak measurements in the settings of a two-player game

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Nonlocal correlations in a shared quantum system hold an indispensable place in winning Bayesian games [1]. However, the quantum state ideally never passes through an interaction-free channel while distribution of its entangled qubits to the players [2]. In order to protect decoherence caused due to noise, we have considered the special case of weak measurement and its reversal operations [3]. Thus, to examine the optimal weak measurement settings that one should apply, we have analysed the effect of noise and weak measurement from the perspective of a game. Bell correlations have been considered when a two-qubit general Bell state is shared as an initial quantum resource; and Svetlichny correlations are studied in case of a general three-qubit GHZ state. Our game setting comprises of noise as one player and weak measurement reversal operation as another player; and payoffs are expressed as the difference of quantum correlations and the maximum classical correlations. Nash equilibrium payoffs and strategies are shown in comparison to the maximum payoff strategies of both the players. This analysis helps in worthwhile decision-making in choosing the best as well as equilibrium weak measurement reversal and noise parameters in the setting of a game.

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From entropic inequalities to secure quantum key distribution

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Bell's theorem, specifically CHSH inequality, has been instrumental in development of fully device independent quantum key distribution (DIQKD) protocols. In this paper, we show that the entropic version of Bell-CHSH also allows for secure DIQKD. We generalise the result to n observables with each party, which is difficult and has not been possible for standard Bell's inequalities. We find that a region of security does indeed exist for entropic inequalities which decreases for increasing number of observables per party. The work provides a pivotal step in application of entropic inequalities and is also experimentally realisable with current technologies.

Bounding the energy-constrained quantum and private capacities of phase-insensitive bosonic Gaussian channels

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We establish several upper bounds on the energy-constrained quantum and private capacities of all single-mode phase-insensitive bosonic Gaussian channels. The first upper bound, which we call the "data-processing bound," is the simplest and is obtained by decomposing a phase-insensitive channel as a pure-loss channel followed by a quantum-limited amplifier channel. We prove that the data-processing bound can be at most 1.45 bits larger than a known lower bound on these capacities of the phase-insensitive Gaussian channel. We discuss another data-processing upper bound as well. Two other upper bounds, which we call the "??-degradable bound" and the "??-close-degradable bound," are established using the notion of approximate degradability along with energy constraints. We find a strong limitation on any potential superadditivity of the coherent information of any phase-insensitive Gaussian channel in the low-noise regime, as the data-processing bound is very near to a known lower bound in such cases. We also find improved achievable rates of private communication through bosonic thermal channels, by employing coding schemes that make use of displaced thermal states. We end by proving that an optimal Gaussian input state for the energy-constrained, generalized channel divergence of two particular Gaussian channels is the two-mode squeezed vacuum state that saturates the energy constraint. What remains open for several interesting channel divergences, such as the diamond norm or the Renyi channel divergence, is to determine whether, among all input states, a Gaussian state is optimal.

Reference:

[1] New Journal of Physics, vol. 20, page 063025, arXiv:1708.07257.

Quantum Coherence - Their origin and trade-off relations

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The distribution of coherence in multipartite systems is examined. We use a new coherence measure with entropic nature and metric properties, based on the quantum Jensen Shannon divergence. The metric property allows for the coherence to be decomposed into various contributions, which arise from local and intrinsic coherences. We find that there are trade-off relations between the various contributions of coherence, as a function of parameters of the quantum state. In bipartite systems the coherence resides on individual sites or is distributed among the sites, which contribute in a complementary way. In more complex systems, the characteristics of the coherence can display more subtle changes with respect to the parameters of the quantum state. In the case of the XXZ Heisenberg model, the coherence changes from a monogamous to a polygamous nature. This allows us to define the shareability of coherence, leading to monogamy relations for coherence.

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Untangling entanglement and chaos

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The relation between chaos and entanglement has been a much debated topic. We present a method to calculate the upper bound on entanglement generation in spin systems using the Fannes-Audenaert inequality for the von Neumann entropy, which helps in resolving the past debate about entanglement and chaos. This bound can be applied in quantum and semiclassical regimes to regular as well as chaotic systems. The bound depends on the trace distance of a state from corresponding classical-like coherent states. We illustrate our method in the model, quantum kicked top (QKT). We show that the upper bound estimates the entanglement in the QKT very well. Further, we illustrate how our method helps to resolve the debate about entanglement and chaos using the QKT. This method to obtain an upper bound on entanglement generation in spin systems is also of interest for experiments. This work has been done in collaboration with Shohini Ghose.

Reference:
[1] M. Kumari and S. Ghose, "Untangling entanglement and chaos", arXiv preprint arXiv:1806.10545 (2018).

What reduces the accuracy of the IBM quantum computers:An answer from the perspective of quantum process tomography

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Recently, we have performed several experiments using IBM quantum computers [1]. Specifically, we have experimentally performed teleportation of multi-qubit states with optimal quantum resources [2] and nondestructive discrimination of Bell states [3]. In these experiments and the experiments performed by the other groups, the fidelity of the experimental output state and the theoretically expected output state have been found to be moderate. It?€?s also observed that very large circuits cannot be implemented using IBM quantum computer as the state fidelity reduces with the increase in the gate count. To understand the origin of this reduction in the state fidelity we perform quantum process tomography and obtained the gate fidelities of all the quantum gates (single qubit and two qubit gates) which are available for the direct implementation on the IBM quantum computers. The figure of merit of goodness of gates is given by fidelity of the experimental process matrix (i.e., chi matrix) with a theoretical process matrix which varies for different gates available in the two processors namely IBMQX2 and IBMQX4 available on the IBM quantum computing architecture [4]. The lower gate fidelities explain drastic faal in the fidelties of output states with increasing gate counts and impose a limit on circuit length in order to obtain a trustable result. Our study also provides a catalog of gate goodness to ease selection of processor for implementing given circuit. In general IBMQX4 provides better results (for all single qubit gates except for Y

gate). Comarison of IBM architecture with respect to other architectures via gate fidelities reveals inferior quality of IBM gates. The comparison has establishedthat IBM quantum computers need much improvement to achieve the desired scalability.

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[4] A. Shukla, M. Sisodia, and A. Pathak, arXiv:1805.07185 (2018).
Journal Reference: A. Shukla, M. Sisodia, and A. Pathak, arXiv:1805.07185 (2018).

Influence of intrinsic decoherence on dynamics of quantum correlation.

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In general, the system is always coupled with the environment. Due to this coupling the quantum correlation decaying with decoherence parameter. Interestingly, the quantum correlation is decreasing even in the absence of coupling of environment due to the intrinsic decoherence of system. Here, we study the influence of intrinsic decoherence on the dynamics of quantum correlation of anisotropic Heisenberg spin model. We show the possibility of inducement of quantum correlation in product and separable states. Finally, we observe that the intrinsic decoherence does not influence the steady-state correlation of the system.

Implications of collapse models for quantum speed limit

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Collapse models provide a dynamical mechanism for wave function collapse, and a falsifiable resolution of the quantum measurement problem. Quantum (position) superposition becomes approximate, with microscopic superpositions lasting for a very long duration, while macroscopic ones are extremely short-lived. The collapse rate introduces a new time scale which can be tested experimentally. In this work we investigate the possible impact of this new time scale on the quantum speed limit, and on the scale ability of quantum computing.

Information Entropy for Nonlinear Optical Solitons

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Information entropy plays an important role in the understanding of quantum communication and quantum computation. For the quantum mechanical systems, it possesses a great scientific challenge as it provides a deeper insight into the internal structure of the systems. It gives a measure of information about the probability distribution in position and momentum space. Though position space and momentum space entropies are individually unbounded, their sum is bounded from below. The present area is least explored in the case of nonlinear systems. A recently proposed continuous logarithmic measure of information, called configurational entropy, is used to derive the solitons width, defining the pulse, for which the informational content of the solitons spatial profile is more compressed, in Shannon?€?s sense. We have obtained the configurational entropy of the optical solitons arising in the nonlinear waveguides in position and momentum states and also verified the BBM inequality. It is found that for a particular width of the solitons there is minimum entropy. For lower information entropy, the wave function will be more concentrated and the accuracy in predicting the localization of the solitons wave will be higher. The information entropy in position and momentum space is obtained and Bialynicki-Birula and Mycielski inequality gets saturated for a specific value of the width of the optical solitons.

Quantum state engineering for quantum information processing

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For quantum computing and communication, we need various nonclassical (quantum) states which do not have any classical analogue. These states are of extreme importance as only these states can establish quantum supremacy in information processing tasks. However, these states are not available naturally and are often prepared using various methods of quantum state engineering [1]. Here, we elaborate on how the tricks of quantum state engineering can be used to generate a set of quantum states of radiation field having practical relevance (e.g., displaced Fock state [1,2], photon added and subtracted displaced Fock state [1,2], Fock state filtered quantum state [3]). The study revealed that certain tricks of quantum state engineering may be preferred over others to generate quantum states depending upon particular quantum information processing task in hand [1]. A specific attention has been given to the significant nonclassical properties of these states with a focus on the application of these states in the field of quantum.

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[1] P. Malpani, N. Alam, K. Thapliyal, A. Pathak, V. Narayanan, S. Banerjee, Lower- and higher-order nonclassical properties of photon added and subtracted displaced Fock states, arXiv: 1808.01458 (2018).
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Entangling power of time-evolution operators in integrable and non-integrable many-body systems

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The entangling power and operator entanglement entropy are state independent measures of entanglement. Their growth and saturation is examined in the time-evolution operator of quantum many-body systems that can range from the integrable to the fully chaotic. An analytically solvable integrable model of the kicked transverse field Ising chain is shown to have ballistic growth of operator von Neumann entanglement entropy and exponentially fast saturation of the linear entropy with time. Surprisingly a fully chaotic model with longitudinal fields turned on shares the same growth phase, and is consistent with a random matrix model that is also exactly solvable for the linear entropy entanglements. However an examination of the entangling power shows that its largest value is significantly less than the nearly maximal value attained by the nonintegrable one. The importance of long range spectral correlations, and not just the nearest neighbor spacing, is pointed out in determining the growth of entanglement in nonintegrable systems. Finally an interesting case that displays some features peculiar to both integrable and nonintegrable systems is briefly discussed.

Reference:

[1] arXiv:1805.11632

Controlled Bi-directional Quantum Teleportation

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We consider the problem of bi-directional controlled quantum teleportation between Alice and Bob using five qubit cluster state. This problem was studied earlier by Zha et al. (Zha, Xin-Wei, et al. "Bidirectional quantum controlled teleportation via five-qubit cluster state." International Journal of Theoretical Physics 52.6 (2013): 1740-1744) and Sang (Sang, Ming-huang. "Bidirectional quantum teleportation by using five-qubit cluster state." International Journal of Theoretical Physics 55.3 (2016): 1333-1335.), but the former of these schemes required two C-NOT operations and five von Neumann measurements and the latter of these required two C-NOT, two Bell-state measurements and one von Neumann measurements, in contrast to our scheme which requires only two Bell-state measurements and one von Neumann measurement. Also, in the latter scheme, the control and the target particles in the proposed C-NOT operators are not with the party performing the operation. Our scheme also results in unit fidelity.

Quantum error correction for ternary logic

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Ternary quantum systems are being studied because they provide more computational state space per unit of information, known as qutrit. A qutrit has three basis states, thus a qubit may be considered as a special case of a qutrit where the coefficient of one of the basis states is zero. Hence both (2??2)-dimensional and (3??3)-dimensional Pauli errors can occur on qutrits. In this paper, we (i) explore the possible (2??2)-dimensional as well as (3??3)-dimensional Pauli errors in qutrits and show that any pairwise bit swap error can be expressed as a linear combination of shift errors and phase errors, (ii) propose a special type of error called a quantum superposition error and show its equivalence to arbitrary rotation, (iii) formulate a nine-qutrit code which can correct a single error in a qutrit, and (iv) provide its stabilizer and circuit realization. As an extension of the previous work, we have proposed a quantum error correcting code for ternary quantum system by using ternary coded decimal system and extending the Hamming code to ternary logic. In contrast to the Steane code, this code requires six qutrits to correct a single error. In the previous work, the error correction procedure was two-folds - first, the error was detected and then corrected. The stabilizer structure for the six qutrit code can correct an error in a single step, thus reducing the overhead. This code is near optimum, as we have proved that like binary quantum systems, correction of a single error in ternary quantum systems requires at least five qubits. Journal Reference: Majumdar, R., Basu, S., Ghosh, S., & Sur-Kolay, S. (2018). Quantum error-correcting code for ternary logic. Physical Review A, 97(5), 052302. The six qutrit code is yet to be communicated. The manuscript is under preparation and will be available in arXiv soon.

Towards a unified description of Markovianity and its applications

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We present a general framework for the information backflow (IB) approach of Markovianity that not only includes a large number, if not all, of IB prescriptions proposed so far but also is equivalent to completely positive divisibility for invertible evolutions. Following the common approach of IB, where monotonic decay of some physical property or some information quantifier is seen as the definition of Markovianity, we propose in our framework a general description of what should be called a proper ?€?physicality quantifier?€? to define Markovianity. We elucidate different properties of our framework and use them to argue that an infinite family of non-Markovianity measures can be constructed, which would capture varied strengths of non-Markovianity in the dynamics. Moreover, we show that generalized trace-distance measure in two dimensions serve as a sufficient criteria for IB Markovianity for a number of prescriptions suggested earlier in the literature.

Reference:
Physical Review A 97, 032130 (2018)

Phase boundaries in alternating field quantum XY model with Dzyaloshinskii-Moriya interaction: Sustainable entanglement in dynamics

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We report all phases and corresponding critical lines of the quantum anisotropic transverse XY model with uniform and alternating transverse magnetic fields (ATXY) in presence of the Dzyaloshinskii-Moriya (DM) interaction by using appropriately chosen order parameters. We prove that when DM interaction is weaker than the anisotropy parameter, it has no effect at all on the zero-temperature states of the XY model with uniform transverse magnetic field (UXY), which is not the case for the ATXY model. However, when DM interaction is stronger than the anisotropy parameter, we show appearance of a new gapless chiral phase - in the XY model with uniform as well as alternating field. We further observe that first derivatives of nearest neighbor two-site entanglement with respect to magnetic fields can detect all the critical lines present in the system. We also find that the factorization surface at zero-temperature present in this model without DM interaction becomes a volume on the introduction of the later. Moreover, DM interaction turns out to be good to generate bipartite entanglement sustainable at large times, leading to a proof of ergodic nature of bipartite entanglement in this system.

Reference:
[1] arXiv:1710.11037

Strong quantum nonlocality without entanglement

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A set of orthogonal quantum states on a composite Hilbert space is locally irreducible if it is not possible to locally eliminate one or more states from the set while preserving orthogonality of the post-measurement states. A locally irreducible set, by definition, is locally indistinguishable, but the converse doesn't always hold. We provide the first examples of orthogonal product bases in three-qudit, tripartite quantum system (with d = 3,4) that are locally irreducible in all bipartitions. In particular, the construction for d = 3 achieves the minimum dimension necessary for such product states to exist. The existence of such product bases implies that local implementation of a multiparty separable measurement may require entangled resources across all bipartitions.

Reference:
[1] arXiv:1808.00318

Spin Squeezing and Entanglement for Bipartite Pure State

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It appears that there exist a confusion regarding relationship between spin-squeezing and entanglement. Some authors [1-3] find the two interrelated and one leading to the other for some states. Another group of authors [4,5] show that spin squeezing is sufficient condition for entanglement but not necessary. We resolved the controversy for bipartite pure states and showed that we can build spin operator whose squeezing is equivalent to entanglement of the state.

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Mutually disjoint, maximally commuting set of physical observables for optimum state determination

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We studied the state determination problem from the point of Mutually Unbiased Bases (MUBs). Analogous to Pauli operators of spin-1/2 system, which are experimentally implementable and correspond to the optimum measurement in characterizing the spin-1/2 density matrix, the question we have posed is whether it is possible to construct such operators which are aesthetically appealing and experimentally viable for any finite dimensional system in general and spin-j system in particular. We have shown in our work that it is possible construct such operators when the existence of MUBs is known. Instead of just inhomogeneous magnetic field, we show higher order multipole fields are required. Also for the new orthonormal set of operators which are also Hermitian, commutation and anti-commutation relations are studied in detail. The structure constants characterizing the algebra are explicitly calculated.

Quantum Teleportation with a Class of Non-Gaussian Entangled Resource States

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Non-Gaussian entangled states of light, in contrast to the Gaussian ones, are known to improve the success of quantum teleportation. Earlier works in the literature focused mainly on two-mode non-Gaussian states generated by de-Gaussification of two-mode squeezed vacuum states. In the current work, we study quantum teleportation with a class of non-Gaussian entangled resource states that are generated at the output of a passive beam splitter (BS), with different input single mode non-Gaussian states, viz., the squeezed number state, photon added squeezed vacuum state and the photon subtracted squeezed vacuum state. We focus on
identifying those attributes of the resource states that are necessary for quantum teleportation (QT). To this end we first evaluate two attributes considered in the literature, viz. squeezed vacuum affinity (SVA) and EPR correlation. While SVA is not non-zero for all two-mode resource states, EPR correlation is found to be not necessary. Then, we look into the question of whether two-mode quadrature squeezing, as defined by Simon et. al. [Phys. Rev. A 49, 1567 (1994)], could be a necessary condition. Our numerical results on the de-Gaussified two-mode squeezed vacuum state as well as the BS generated non-Gaussian states point to the possibility that two-mode quadrature squeezing may well be a necessary condition for QT, in general. We argue the plausibility of this conclusion by giving an analytical proof that two-mode quadrature squeezing is a necessary condition for QT for a subclass of two-mode Gaussian states.

Reference:
[1] "Quantum Teleportation with a Class of Non-Gaussian Entangled Resource States" Soumyakanti Bose and M. Sanjay Kumar, arXiv: 1804.00190 (2018).

Adiabatic freezing of entanglement with insertion of defects in a one-dimensional Hubbard model

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We report on ground state phases of a doped one-dimensional Hubbard model, which for large onsite interactions is governed by the t−J Hamiltonian, where the extant entanglement is immutable under perturbative or sudden changes of system parameters, a phenomenon termed as adiabatic freezing. We observe that in the metallic Luttinger liquid phase of the model bipartite entanglement decays polynomially and is adiabatically frozen, in contrast to the variable, exponential decay in the phase-separation and superconducting spin-gap phases. Significantly, at low fixed electron densities, the spin-gap phase shows remarkable affinity to doped resonating valence bond gas, with multipartite entanglement frozen across all parameter space. We note that entanglement, in general, is sensitive to external perturbation, as observed in several systems, and hitherto, no such invariance or freezing behavior has been reported.

Reference:
[1] Phys. Rev. B **98**, 125125 (2018).

Quantum Heat Machines

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QHMs, to be specific the heat engines and the refrigerators, among others have been examined in quantum domain, utilizing discrete strokes or continuous strokes. Heat engines take the heat from a hot bath, deliver a certain amount of work, and release heat to the cold bath. Existing proposition for executing quantum heat engines necessitate that the system interacts with the hot bath and the cold bath (both modeled as a classical system) in an alternative fashion and therefore assumes the ability to switch off and on the interaction with the bath during a particular stage of the heat cycle. However, it is not possible to decouple a quantum system from its 'always-on interaction' with the bath without the utilization of complex pulse sequences. It is likewise difficult to recognize two different baths at two distinct temperatures in the quantum domain that sequentially interact with the system. Here, we show how the reciprocating heat cycle of a quantum Otto engine (QOE) can be executed

utilizing a trapped ion as the working subs tance, in the presence of a thermal bath. The electronic states of the ions act as a working substance, while the vibrational mode is modeled as the cold bath. The heat exchange with the cold bath is mimicked by the projective measurement of the electronic states. In our model, the coupling to the hot and the cold baths is never turned off in an alternative fashion during the heat cycle, unlike other existing proposals of quantum heat engines. Using two ions, one can even build a refrigerator, which takes heat from a cold bath and with certain work on the system, releases heat into the bath. We found exciting results using longer spin chains and the effect of correlations on the engine efficiency.

References:

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Frequency multiplexed readout of superconducting qubits using broadband parametric amplifier

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Efficient control and measurement of multiple qubits is an important challenge to build scalable superconducting quantum processors. Frequency multiplexed readout has been demonstrated earlier in 2D cQED architecture to enable efficient use of resources. Here, we propose and demonstrate a frequency-multiplexed readout scheme in 3D cQED architecture. We use four transmon qubits coupled to individual rectangular cavities which are aperture-coupled to a rectangular waveguide. At the other end of the waveguide, a common feedline is coupled to it via a coaxial to waveguide transformer which allows to launch and collect the multiplexed readout signal. Same feedline is used to send excitation to the qubits. The reflected readout signal is amplified by an impedance engineered broadband parametric amplifier with 420 MHz of bandwidth. We are able to perform Rabi oscillations and observe quantum trajectories of four qubits simultaneously. This provides us high fidelity single-shot readout of multiple qubits using compact microwave circuitry, an efficient way for scaling up to more qubits in 3D cQED.

Entanglement in hypergraph quantum states

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In combinatorics, hypergraphs are the generalization of combinatorial graphs. A hypergraph consists of a vertex set and a set of hyperedges. A hyperedge may contain more than two vertices, in contrast to an edge in a graph contains at most two vertices. There is a pure multipartite quantum state corresponding to any hypergraph. To generate a hypergraph state we correspond a |+> state to every vertex. For every hyperedge, we apply a controlled-Z gate on the vertices belonging to the hyperedge. A hypergraph state is fully entangled if the hypergraph is connected. In my talk, I like to illustrate how entanglement depends on the underlined structure of the hypergraph.

Supremacy of quantum theory over supra-quantum models of communication

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Quantum correlations can provide dramatic advantage over the corresponding classical resources in several communication tasks. However a broad class of probabilistic theories exists that attributes greater success than quantum theory in many of these tasks by allowing supra-quantum correlations in ‘space-like’ and/or ‘time-like’ paradigms. Here we propose a communication task involving three spatially separated parties where one party (verifier) aims to verify whether the bit strings possessed by the other two parties (terminals) are equal or not. We call this task authentication with limited communication, the restrictions on communication being: (i) the terminals cannot communicate with each other, but (ii) each of them can communicate with the verifier through single use of channels with limited capacity. Manifestly, classical resources are not sufficient for perfect success of this task. Moreover, it is also not possible to perform this task with certainty in several supra-quantum theories. Surprisingly quantum resources can achieve the perfect winning strategy. The proposed task thus stands apart from all previously known communication tasks as it exhibits quantum supremacy over supra-quantum strategies.

Forbidden and Possible correlations prepared from Thermal states

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Presence of correlation in quantum states finds applications in several branches of quantum physics, especially in thermodynamics. The possibility of correlating thermal states has been a question of recent interest and has been quantified in several studies. Apart from quantification, the structural form of correlation also turns out to be of interest for deciding the usefulness of quantum states in several information and communication tasks. In this work, we characterize the correlations which can be prepared from two copies of thermal states under the action of global unitary. This task is nontrivial since the prepared correlations has to satisfy a thermodynamic constraint that the marginals should remain thermal. This restriction forbids a class of entangled and classically correlated states to be obtained from the thermal states under the action of global unitary. In general the final entangled states may have with different marginal temperatures. We also address the question of sustaining the prepared entanglement when the distant particles are connected to local baths. Another important aspect of our study revolves around the thermodynamic cost of creating correlation which was first introduced by Huber et. al. They derived a bound on the temperature of two identical thermal states required to make them entangled. In the present work, we move beyond their framework by deriving a general trade-off relation between the local temperatures required to create entanglement.

Periodicity of quantum correlations in the quantum kicked top

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Quantum kicked top is a fundamental model for time-dependent, chaotic Hamiltonian system and has been realized in experiments as well. As the quantum kicked top can be represented as a system of qubits, it is also popular as a testbed for the study of measures of quantum correlations such as entanglement, quantum discord and other multipartite entanglement measures. Further, earlier studies on kicked top have led to a broad understanding of how these measures are affected by the classical dynamical features. In this work, relying on the invariance of quantum correlation measures under local unitary transformations, it is shown exactly these measures display periodic behaviour either as a function of time or as a function of the chaos parameter in this system. As the kicked top has been experimentally realised using cold atoms as well as superconducting qubits, it is pointed out that these periodicities must be factored in while choosing of experimental parameters so that repetitions can be avoided.

Reference:

[1] arXiv:1806.06184v1 (Under review in Physical Review E.)

Role of Entangling Operators in the Modified Eisert-Wilkens-Lewenstein Quantization scheme

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One of the central ideas in the theory of quantum games is to quantize the classical games in a proper mathematical and physical framework [1]. In order to understand the prowess of quantumness, it is ensured that classical game is the subset of the quantized version of the game. This has been stressed and established by Eisert, Wilkens, and Lewenstein(EWL) quantization scheme [2], by imposing a commutation condition between the

entangling operator and the suitable strategies of the game. In the present work, we modify the EWL scheme by relaxing this condition on commutation with an aim to explore the significance of two-qubit operators. For pure and mixed strategies in the modified EWL scheme, we establish two well-known results- non-conversion of a zero-sum game to non-zero sum game[3], and conversion of the symmetric game to potential game [4] by finding suitable two-qubit operators. Thus, results of this work validate the generality of EWL scheme.

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Quantum Digital Signature using QKD

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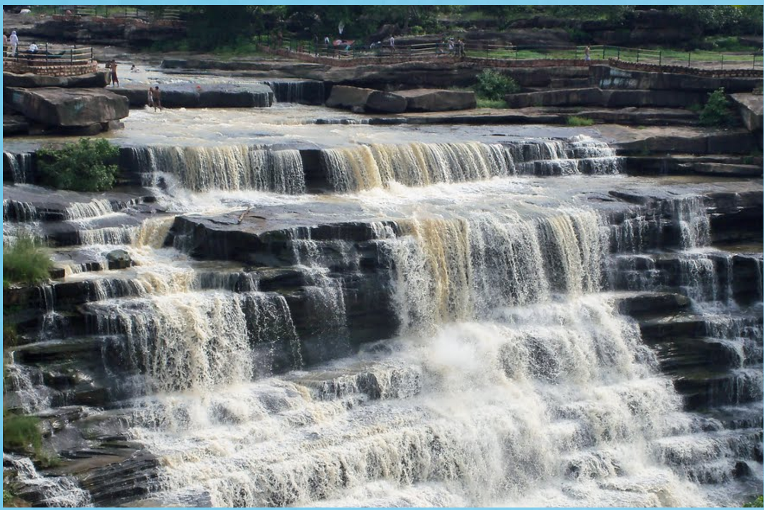
Quantum Cryptography permits a number of crypto-tasks, wherein security, in contrast to classical cryptography, arises from information theoretic principles guaranteed by quantum mechanical laws, rather than from computational complexity assumptions. One such task is Quantum Digital Signature (QDS). A digital signature is used to authenticate a message and guarantee the identity of the sender, even when the message is transferred. In particular, this means that the sender cannot at a later time disclaim the message. Although the original proposed implementations of QDS required quantum memory or a multiport, a recent work by Wallden et al. (Phys. Rev. A 91, 042304 (2015)) shows how to realize practical QDS using only the experimental components of quantum key distribution (QKD). Here, we propose to use the Noh09 counterfactual QKD protocol to realize QDS. Three parties are assumed here, clients Bob and Charlie along with sender Alice. There are two parts to the protocol: the message part and the signature part. While the former can be conducted as a QKD task, for the latter we show how a generalization of the Noh09 protocol from a bipartite to a three-party scheme can be employed.

Thanks!



Rajdari-Debdari Falls

Allahabad Fort

Khusroo-Bagh

Anand- Bhawan

Sangam

Peacock at HRI