WEDNESDAY, SEPTEMBER 25

Morning session

Nilanjana Datta: Convergence rates for quantum evolution and entropic continuity bounds in infinite dimensions

How fast do infinite-dimensional quantum systems evolve? How fast can entropies of infinite-dimensional quantum systems change? These are the questions that will addressed in this talk. By extending the concept of energy-constrained diamond norms, we obtain continuity bounds on the dynamics of both closed and open quantum systems in infinite-dimensions, which are stronger than previously known bounds. Our results have interesting applications including quantum speed limits, attenuator and amplifier channels, the quantum Boltzmann equation, and quantum Brownian motion. Next, we obtain explicit log-Lipschitz continuity bounds for entropies of infinite-dimensional quantum systems, and classical capacities of infinite-dimensional quantum channels under energy-constraints. These bounds are determined by the high energy spectrum of the underlying Hamiltonian and can be evaluated using Weyls law. Based on joint work with Simon Becker.

Fabien Clivaz: Unifying paradigms of quantum refrigeration: A universal and attainable bound on cooling

Cooling quantum systems is arguably one of the most important thermodynamic tasks connected to modern quantum technologies and an interesting question from a foundational perspective. It is thus of no surprise that many different theoretical cooling schemes have been proposed, differing in the assumed control paradigm, complexity and operating either in a single cycle or in steady state limits. Working out bounds on quantum cooling has since been a highly context dependent task with multiple answers, with no general result that holds independent of assumptions. In this letter we derive a universal bound for cooling quantum systems in the limit of infinite cycles (or steady state regimes) that is valid for any control paradigm and machine size. The bound only depends on a single parameter of the refrigerator and is theoretically attainable in all control paradigms. For qubit targets we prove that this bound is achievable in a single cycle and by autonomous machines.

Shishir Khandelwal: General relativistic time dilation and increased uncertainty in generic quantum clocks

The theory of relativity associates a proper time with each moving object via its world line. In quantum theory however, such well-defined trajectories are forbidden. After introducing a general characterisation of quantum clocks, we demonstrate that, in the weak-field, low-velocity limit, all "good" quantum clocks experience time dilation as dictated by general relativity when their state of motion is classical (i.e. Gaussian). For nonclassical states of motion, on the other hand, we find that quantum interference effects may give rise to a significant discrepancy between the proper time and the time measured by the clock. We also show how ignorance of the clocks state of motion leads to a larger uncertainty in the time measured by the clock a consequence of entanglement between the clock time and its center-of-mass degrees of freedom. We demonstrate how this lost precision can be recovered by performing a measurement of the clocks state of motion alongside its time reading.

Lennart Baumgärtner: Accuracy enhancing protocols for quantum clocks

The accuracy of the time information generated by clocks can be enhanced by allowing them to communicate with each other. Here we consider a basic scenario where a quantum clock receives a low-accuracy time signal as input and ask whether it can generate an output of higher accuracy. We propose protocols that, using a clock with a d-dimensional state space, achieve an accuracy enhancement by a factor d (in the limit of large d). If no feedback on the input signal is allowed, this enhancement is temporary. Conversely, with feedback, the accuracy enhancement can be retained for longer. The protocols may be used to synchronise clocks in a network and define a time scale that is more accurate than what can be achieved by non-interacting clocks.

Ben Dive: Remote Time Manipulation

Harnessing the flow of proper time of arbitrary external systems over which we exert little or no control has been a recurring theme in both science and science-fiction. Here we present heralded, non-relativistic scattering experiments which, freeze out, speed up or even reverse the free dynamics of an ensemble of identical quantum systems. This "time warping" effect is universal: it is independent of the particular interaction between the scattering particles and the target systems, or the (possibly non-Hermitian) Hamiltonian governing the evolution of the latter. The protocols require careful preparation of the probes which are scattered, and success is heralded by projective measurements of these probes at the conclusion of the experiment. We fully characterize the possible time translations which we can effect on n target systems through a scattering protocol of fixed duration; the core result is that time can be freely distributed between the systems, and reversed at a small cost. For high n, our protocols allow one to quickly send a single system to its far future or past.

Afternoon session

Stephen Patrick Walborn: Multiple degrees of freedom of photons for quantum information

For roughly 30 years, entangled photons have been produced using nonlinear optical processes such spontaneous parametric down-conversion. Moreover, entanglement has been observed in multiple photonics degrees of freedom, such as momentum, frequency, and polarization, even simultaneously. In addition to being the natural "flying" qubits, photons thus provide a vast array of interesting possibilities for the encoding of high-dimensional quantum information.

In this talk, I will first review the production of entangled and hyperentangled photons (entangled in multiple degrees of freedom), and their use in several quantum information studies and protocols. I will also present resent results in optical quantum metrology, where we have recently shown that hyper-entanglement can provide a "double quantum advantage", where the entanglement in each degree of freedom contributes to the gain in metrological precision.

Adrian Holzäpfel: Optical storage in an atomic frequency comb memory approaching a second

Quantum memories are key devices for future quantum networks. The atomic frequency comb (AFC) scheme in rare-earth doped crystals provides solid-state memories with many appealing features, such as high efficiency, multimode capacity and long storage times. The previous record storage time achieved in an AFC memory was around 1 ms, in a Europium-doped Y2SiO5 crystal at zero applied magnetic field. Even longer storage should be possible by dynamical decoupling (DD) of the spin states, but efficient DD was so far unsuccessful at zero field due to the double degenerate nuclear states. In our newest work we demonstrate storage of optical pulses for up to half a second using the AFC scheme and DD in a Eu:Y2SiO5 crystal under magnetic field.

Filip Maciejewski: Mitigation of readout noise by classical post-processing based on quantum detector tomography

We propose a simple scheme to reduce readout errors in any experiment on a quantum system with finite number of measurement outcomes. Our method relies on performing classical post-processing which is preceded by Quantum Detector Tomography, i.e., the process of reconstructing a Positive-Operator Valued Measure (POVM) describing a given quantum measurement device. If the reconstructed POVM differs from the ideal one only by an invertible classical noise, it is possible to correct the outcome statistics of later experiments performed on the same device. We analyze the influence of deviations from the noise model and the finite-size statistics on the performance of our correction scheme. Finally, we provide a characterization of readout noise occurring in IBM quantum devices, which show the agreement with the adopted noise model. We test our mitigation scheme for single- and five-qubit experiments on the IBM devices and observe improvement of results for the following tasks - Quantum State Tomography (single and two-qubit), Quantum Process Tomography (single qubit), application of quantum algorithms – Grover's and Bernstein-Vazirani (implementation on three qubits, measurement on two qubits), implementation of non-projective measurements via Naimark's extension (measurement on two qubits), and implementation of particular probability distributions (five qubits).

Alexandra Moylett: Classically simulating near-term noisy boson sampling

Boson Sampling is the problem of sampling from the same distribution as indistinguishable single photons at the output of a linear optical interferometer. It is an example of a non-universal quantum computation which is believed to be feasible in the near term and cannot be simulated on a classical machine. Like all purported demonstrations of "quantum computational supremacy", this motivates optimizing classical simulation schemes for a realistic model of the problem, in this case Boson Sampling when the implementations experience lost or distinguishable photons.

Over recent years classical algorithms have been proposed for when photons are partially distinguishable or lossy. Of note is point truncation, which combines both distinguishability and loss, and has a runtime which is polynomial in the number of photons. But while this runtime might be efficient asymptotically, in practice this polynomial is significantly large, depending superexponentially on the level of truncation.

In this work, we develop an alternative scheme for classical simulation of Boson Sampling under uniform distinguishability and loss, based on the idea of sampling from distributions where at most k photons are indistinguishable. We use techniques for modelling partial distinguishability and loss in linear optics to show that this model is akin to first sampling surviving photons, and from those sampling indistinguishable photons, from the binomial distribution.

We show that this algorithm provides a significant improvement in runtime over point truncation in terms of truncation level k, albeit at the cost of a worse error scaling. Via approximations of runtimes for both algorithms for simulating an imperfect Boson Sampling experiment up to a small error in the experimentally relevant regimes of 50-90 photons, we are able to demonstrate an improvement in what is classically simulable for near-term experiments. This raises the bar of what needs to be experimentally achieved in order to demonstrate a quantum advantage in Boson Sampling.

Charles Xu: Quantum metropolis sampling assisted by eigenstate thermalization

The problem of preparing or sampling from Gibbs (thermal) states of a many-body quantum system is of great theoretical and practical interest. Performing this task exactly is expected to be intractable for both classical and quantum computers, but a number of approximate sampling schemes have been proposed. These notably include the quantum Metropolis algorithm of Temme et al, which executes a random walk on energy eigenstates that converges to the Gibbs state as its fixed point. This process is described by a Markov chain with a transition matrix whose gap scales inversely with the algorithm's runtime.

In general the dependence of the runtime on system size is unknown, but we are interested in conditions that allow us to sample from the Gibbs state efficiently. In this work we show that the Eigenstate Thermalization Hypothesis (ETH) provides such a condition. ETH is an ansatz for the matrix elements of a local observable in the energy eigenbasis, which formalizes notions of "quantum chaos" and holds for a wide variety of non-integrable systems. Assuming that the Hamiltonian and the operators implementing each Metropolis step obey ETH, we prove that the algorithm converges to the Gibbs state in time scaling polynomially with the system size. This can be argued heuristically by "coarse-graining" the spectrum, but our main result is a rigorous calculation of the random walk's conductance, which gives an upper bound on the mixing time.

This result shows that ETH implies thermalization of many-body quantum systems not just locally under unitary evolution, but also globally under the Metropolis algorithm's model of system-bath dynamics. The techniques developed here may have wider application to other protocols for preparing or sampling from many-body Gibbs states.

THURSDAY, SEPTEMBER 26

Morning session

Antonio Acín: Correlations in quantum networks

We discuss the power of current and near-future quantum networks for quantum information processing. We start in the classical regime and review the concept of causal networks, designed to understand when a given cause pattern is able to reproduce some observed correlations. We then move to the quantum case and explain how Bells theorem can be interpreted as a gap between the correlations observed in a network when using classical or quantum causes. We present methods to characterise classical and quantum correlations in networks.

Marc-Olivier Renou: The triangle network: genuine quantum nonlocality and partial characterization of local, quantum and boxworld correlations

Network nonlocality extends standard Bell nonlocality to networks, where several independent sources are distributed to several parties according to the network structure. Contrary to standard Bell Nonlocality, this problem is non convex: no ecient systematic way to tackle it is known, either for local or quantum correlations. It is only partially understood for the simplest scenarios of bilocality (extended to star-locality and nonlocality on a line). However, for scenarios with loops, e.g. the triangle network, nothing is known except examples directly deduced from the usual form of quantum nonlocality (via the violation of a standard Bell inequality). This can even be done without using inputs. The question of nding a genuine quantum violation of triangle network locality was open the last years. In this talk, we rst present a novel example of quantum nonlocality without inputs in the triangle network, which we believe represent a new form of quantum nonlocality, genuine to the triangle network. It involves both entangled qubit states and joint entangled measurements. We generalize it to qutrits shared states and any odd-cycle networks. Then, we move to the question of the characterization of local and quantum correlations. We derive a bound, the quantum Finner inequality (already known to hold for local ressources), which we also demonstrate to hold when the sources are arbitrary no-signaling boxes which can be wired together. We generalizes this bound to all networks involving bipartite sources. We discuss it as an application for the device-independent characterization of the topology of a quantum network. We conclude with some open questions related to quantum network nonlocality.

Tamás Kriváchy: A neural network oracle for network non-locality

Of primal importance in devising new protocols on quantum information networks is the ability to determine the boundary of classical- and quantum-feasible distributions on networks. Whereas the boundary is linear in the probability space in simple cases, analytic methods as well as exact optimization are limited in even slightly complex scenarios, such as in the notorious ‘triangle’ configuration. We use neural networks to model the actions of actors in the network, giving us insight into the limits of classical strategies on any directed acyclic graph. We explore this novel method by applying it to two distributions in the triangle configuration where we are able to show that one is outside the local set, and gain insight on the noise robustness of both distributions.

Alexander Paige: Delocalised-interaction non-local quantum games

Entanglement can enable the performance of non-local tasks that would be classically impossible. Well studied examples include quantum steering and violating Bell inequalities. In this work we establish that entanglement can allow interactions to be delocalised in a manner impossible for classical systems, and that this enables new non-local tasks where some form of entanglement acts as a resource. To perform an in-depth study of this phenomenon we introduce the notion of delocalised-interaction non-local games. These involve Charlie setting tasks for Alice and Bob that test whether they can demonstrate delocalised interactions. We derive bounds on Alice and Bob's maximum winning probability in terms of the quantum state that they share. In particular we show that for qubits the winning probability can be bounded with the Hill-Wootters concurrence, thus providing a direct operational use of this entanglement monotone. We also derive a bound that captures the notion of a state's record quality, in terms of an easily calculable Kolmogorov (classical trace) distance. By performing numerical optimisation over possible choices of tactics for Alice and Bob, we study some specific families of states. This helps us to prove that the concurrence bound can be saturated for certain mixed states, and that the record quality bound is saturated for the 2-qubit Werner state, which in turn enables us to prove that with no additional resources entanglement is not sufficient to demonstrate delocalised-interactions. The Werner state example also proves that Bell non-locality is not necessary for delocalised-interactions. Further numerical work embedding the 2-qubit Werner state in a higher-dimensional Hilbert space indicates that if we allow Alice and Bob access to additional pure separable resources then entanglement is still not sufficient, but this is not yet analytically proved. Finally, we attempted to demonstrate and realise delocalised-interactions on a real super-conducting qubit device. We ran a 3-qubit demonstration that successfully achieved a non-classical win probability, but for the genuine 4 qubit realisation the device was too noisy and so we were unable to claim it was performing a delocalised-interaction. However, our results indicate that current superconducting devices are nearly up to the task and that future experiments should soon be able to convincingly realise delocalised-interactions.

Emmanuel Zambrini Cruzeiro: Informationally restricted quantum correlations

Separated observers can become correlated by communicating. We introduce and develop classical and quantum correlations under communication whose information content is operationally restricted. We show that such classical correlations can be characterized using convex programming tools and that quantum theory can violate these constraints. For simple scenarios, we derive optimal quantum correlations, constituting device-independent certificates of quantum information. We then show that the conventional approach in which information is equated with Hilbert space dimension emerges as a special instance of the introduced framework. In particular, information restricted quantum correlations can, sometimes dramatically, surpass the limitations of their dimension-bounded counterparts. Finally, we resolve an open problem by showing that quantum communication can always simulate any correlation obtained from classical communication assisted by shared entanglement, when no more than a fixed amount of information may be communicated. Inter alia, our results open a new avenue in semi-device-independent quantum information.

FRIDAY, SEPTEMBER 27

Morning session

Časlav Brukner: The covariance of physical laws in quantum reference frames

Every observation in physics is made with respect to a frame of reference. In practise, we use real physical systems as reference frames, and as such they obey quantum mechanical laws. I will introduce a general method to quantise reference frame transformations, which generalises the usual reference frame transformation to a superposition of coordinate transformations. I will describe how states, measurements, and dynamical evolutions transform between different quantum reference frames. While entanglement and superposition will be shown to be frame-dependent features, the form of the dynamical physical laws (e.g. the Schrödinger equation) remain the same in all frames, which generalises the notion of covariance of physical laws to quantum reference frames. I will end with two applications of our results: a definition of the rest frame for a quantum particle in a superposition of velocities, and, if time permits, with a resolution of an old problem of identifying the qubit for a relativistic spin particle.

Felix Huber: Codes of maximal distance and highly entangled subspaces

We present new bounds on the existence of quantum maximum distance separable codes (QMDS): the length n of all non-trivial QMDS codes with local dimension D and distance d is bounded by $n \leq D^2 + d - 2$. We obtain their weight distribution and present additional bounds that arise from Rains' shadow inequalities. Our main result can be seen as a generalization of bounds that are known for the two special cases of stabilizer QMDS codes and absolutely maximally entangled states, and confirms the quantum MDS conjecture in the special case of distance-three codes. Because the existence of QMDS codes is linked to that of highly entangled subspaces (in which every vector has uniform r-body marginals) of maximal dimension, our methods directly carry over to address questions in multipartite entanglement

Francesco Borderi: Semidefinite programming hierarchies for quantum error correction

We give asymptotically converging semidefinite programming hierarchies of outer bounds on bilinear programs of the form $\mathrm{Tr}\big[M(X \otimes Y)\big]$, maximized with respect to semidefinite constraints on X and Y. Applied to the problem of quantum error correction this gives hierarchies of efficiently computable outer bounds on the optimal fidelity for any message dimension and error model. The first level of our hierarchies corresponds to the non-signaling assisted fidelity previously studied by [Leung & Matthews, IEEE Trans. Inf. Theory 2015], and positive partial transpose constraints can be added and used to give a sufficient criterion for the exact convergence at a given level of the hierarchy. To quantify the worst case convergence speed of our hierarchies, we derive novel quantum de Finetti theorems that allow imposing linear constraints on the approximating state. In particular, we give finite de Finetti theorems for quantum channels, quantifying closeness to the convex hull of product channels as well as closeness to local operations and classical forward communication assisted channels. As a special case, this constitutes a finite version of Fuchs-Schack-Scudo's asymptotic de Finetti theorem for quantum channels. Finally, our proof methods also allow us to answer an open question from [Brandão & Harrow, STOC 2013] by improving the approximation factor of de Finetti theorems with no symmetry from $O(d^{k/2})$ to $\mathrm{poly}(d, k)$, where d denotes local dimension and k the number of copies.

Sébastien Designolle: Incompatibility robustness of quantum measurements: a unified framework

The existence of incompatible measurements, i.e., measurements that cannot be simultaneously performed on a single copy of a quantum state, constitutes an important difference between quantum mechanics and classical theories. Several measures have been proposed to quantify how incompatible a pair of quantum measurements is, but their properties are not well-understood. In this work we develop a general framework that encompasses all robustness-based measures of incompatibility studied so far. We study five commonly used measures and find that some of them do not fulfill some natural monotonicity requirements motivated by the resource-theoretic approach. Moreover, we find that when attempting to identify the most incompatible pairs of measurements, the answer depends on the specific measure we choose. We prove that for one of the measures, measurements corresponding to mutually unbiased bases are among the most incompatible pairs in every dimension. However, we also show that this is not the case for some of the remaining measures and we give explicit examples of measurements which are even more incompatible according to those measures.

Roope Uola: Quantifying quantum resources with conic programming

Resource theories can be used to formalize the quantification and manipulation of resources in quantum information processing such as entanglement, asymmetry and coherence of quantum states, and incompatibility of quantum measurements. Given a certain state, measurement or dynamical resource, one can ask whether there is a task in which it performs better than any resourceless object. Using conic programming, we prove that the general robustness measure (with respect to a convex set of free states, measurements or dynamical objects) can be seen as a quantifier of such outperformance in some discrimination task. We apply the technique to various examples, e.g. joint measurability, POVMs simulable by projective measurements, quantum memories, and causal separability.

Afternoon session

Ana Belén Sainz: Einstein-Podolski-Rosen steering in quantum theory and beyond

Our understanding of the foundations of quantum theory has been deepened by the discovery of post-quantum nonlocality, that is, the existence of nonlocal correlations which are stronger than those found in quantum theory, but, which are nonetheless consistent with the no-signalling principle. In this talk I will discuss how the phenomenon of Einstein-Podolsky-Rosen steering, a distinct form of quantum nonlocality, can also be found beyond quantum theory. This is not the case in the traditional bipartite steering scenario – any situation consistent with the no-signaling principle does indeed have a quantum explanation. To open the door for post-quantum steering one must therefore deviate from this traditional setting. In this talk I will present two ways to do this: firstly, I will present the case of an experiment with three observers, and secondly, I will discuss generalisations which remain intrinsically bipartite. I will finish by showing that post-quantum steering is a genuinely new phenomenon which is fundamentally different from post-quantum nonlocality.

Joris Kattemolle: Dynamical fidelity susceptibility of decoherence-free subspaces

In idealized models of a quantum register and its environment, quantum information can be stored indefinitely by encoding it into a decoherence-free subspace (DFS). Nevertheless, perturbations to the idealized register-environment coupling will cause decoherence in any realistic setting. Expanding a measure for state preservation, the dynamical fidelity, in powers of the strength of the perturbations, we prove stability to linear order is a generic property of quantum state evolution. The effect of noise perturbation is quantified by a concise expression for the strength of the quadratic leading order, which we define as the dynamical fidelity susceptibility of DFSs. Under the physical restriction that noise acts on the register k-locally, this susceptibility is bounded from above by a polynomial in the system size. These general results are illustrated by two physically relevant examples. Knowledge of the susceptibility can be used to increase coherence times of future quantum computers.

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

Quantum theory has an outstanding property, namely each state has its well defined purification - a state extremal in the set of states 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). However in any non-signaling GPT each state has a number of extensions to a larger system. We single out the most relevant among them, 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.