Speaker: Robert Alicki, University of Gdańsk
Title: Work and heat in quantum thermodynamics

Abstract:
In the standard thermodynamics of macroscopic systems the operational definitions of work and heat apparently do not pose any conceptual problems. On the other hand, for microscopic and mesoscopic systems the proper decomposition of energy into heat and work, which is consistent with the notions of entropy and entropy production is not obvious. The proper definitions are necessary to avoid artificial “quantum miracles” often claimed in the recent literature. The critical discussion of three approaches to this problem is presented: a) Markovian dynamics with slow external modulation [1], b) Master Equation with a sink as a work depository [2], c) Quantum open system with a quantum work reservoir. The last concept is illustrated by a simple quantum Markovian model of a harmonic oscillator coupled to chemical reservoirs. The proper definition of work output is formulated in terms of ergotropy. The model exhibits two physically distinct regimes: self-oscillations and self-replication. The discussion suggests that the very definition of work in purely quantum terms meets the same conceptual difficulties as the quantum theory of measurement [3].


Speaker: Koji Azuma, NTT Basic Research Laboratories
Title: All-photonic quantum internet

Abstract:
Quantum communication holds promise for unconditionally secure transmission of secret messages and faithful transfer of unknown quantum states. Quantum repeaters are necessary for extending the achievable distance of quantum communication towards the quantum internet [1]. However, all the conventional paradigms required repeater nodes to be equipped with demanding matter quantum memories. Here we show that this requirement is not necessary at all, by presenting all-optical quantum communication schemes [2,3]. In particular, these schemes use only optical devices such as linear optical elements, single-photon sources, photon detectors and active feedforwards, that is, without any matter quantum memory. Nonetheless, these schemes can work efficiently as intercity/intercontinental backbone quantum links for the future quantum internet.

I acknowledge the support from the Project UQCC by the National Institute of Information and Communications Technology (NICT), a MEXT Grant-in-Aid for Scientific Research on Innovative Areas 21102008, the ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan), and the CREST, Japan Science and Technology Agency (JPMJCR1671).

**Speaker:** Almut Beige, University of Leeds  

**Title:** Quantising the electromagnetic field near semi-transparent mirrors  

**Abstract:**  
Here we use a quantum image detector method and the same notion of photons as in free space [1] to model light scattering on flat surfaces [2]. These range from perfectly-reflecting to highly-absorbing mirrors. Instead of restricting the Hilbert space of the electromagnetic field to a subset of modes, we double its size. In this way, the flow of energy between the electromagnetic field and the mirror surface, during which mirror images become real and real wave packets become mirror images, can easily be taken into account. Our approach reproduces well-known results, like free-space decay and the sub and super-radiance of an atom in front of a perfectly-reflecting mirror, and paves the way for the modelling of more complex systems with a wide range of applications in quantum technology.


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**Speaker:** André Carvalho, Griffith University  
( Co-authors: J.K. Eastman, J. J. Hope)  

**Title:** Tuning quantum measurements to control chaos  

**Abstract:**  
Environment-induced decoherence has long been recognised as being of crucial importance in the study of chaos in quantum systems. In particular, the exact form and strength of the system-environment interaction play a major role in the quantum-to-classical transition of chaotic systems. In this work, we focus on the effect of varying monitoring strategies, i.e. for a given decoherence model and a fixed environmental coupling, there is still freedom on how to monitor a quantum system. We show here that there is a region between the deep quantum regime and the classical limit where the choice of the monitoring parameter allows one to control the complex behaviour of the system, leading to either the emergence or suppression of chaos. Our work shows that this is a result from the interplay between quantum interference effects induced by the nonlinear dynamics and the effectiveness of the decoherence for different measurement schemes.

**Speaker:** Carlton M. Caves, University of New Mexico  
**Title:** Diving Deep into a Quantum-Information-Processing Problem: Quantum Limits on the Performance of Linear Amplifiers  
**Abstract:**  
Josephson-effect linear amplifiers now operate at the fundamental quantum limit on noise temperature for linear amplifiers. So why not do this old problem—quantum limits on the performance of linear amplifiers—right, using the modern tools of quantum information theory? I will discuss the general limits on the performance of linear amplifiers, both those that act deterministically and those that, like air travel, only work some of the time. I might get around to discussing how this question generalizes to arbitrary linear phase-space transformations for multiple modes. All of this illustrates how an old problem—in this case, a problem 70 years old—just keeps on giving as improving experimental techniques pose new questions and new theoretical tools allow those questions to be answered.

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**Speaker:** Giulio Chiribella, University of Hong Kong  
**Title:** Storing identically prepared particles in the smallest amount of memory  
**Abstract:**  
One of the consequences of the No Cloning Theorem is that many copies of the same quantum state contain more information than just one copy. But what kind of information? And how much?  
A natural way to approach these questions is provided by the task of quantum data compression, where information is defined as the minimum amount of memory needed to store the quantum state. Knowing the ultimate compression limit is important for the design of quantum machines with finite memory, and also for the design of communication networks where quantum data collected at different nodes are transmitted to a central location for joint processing. In this talk I will present recent results on the optimal compression of identically prepared particles, highlighting the interplay between physical and information-theoretic aspects, suggesting applications, and discussing open problems.

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**Speaker:** Marcos Curty, University of Vigo  
**Title:** Relaxing the security assumptions of quantum key distribution  
**Abstract:**  
In theory, quantum key distribution (QKD) holds the promise of offering information-theoretically secure communications based on the laws of quantum physics. In practice, however, it does not because security proofs of QKD employ assumptions which are not satisfied by the real systems. For instance, this includes assuming that the QKD setups do not contain malicious devices and there is a protected space devoid of any unwanted information leakage in which the legitimate parties can privately generate, process and store their classical data by means of trusted classical post-processing units. Here, we present recent results to relax these unrealistic and hardly feasible assumptions of QKD and come closer to bridging the gap between theory and practice.
Speaker: Animesh Datta, University of Warwick

Title: Nonadaptive fault-tolerant verification of quantum supremacy with noise

Abstract:
Quantum samplers are believed capable of sampling efficiently from distributions that are classically hard to sample from. We consider a sampler inspired by the Ising model. It is nonadaptive and therefore experimentally amenable. Under a plausible average-case hardness conjecture, classical sampling up to additive errors from this model is known to be hard. We present a trap-based verification scheme for quantum supremacy that only requires the verifier to prepare single-qubit states. The verification is done on the same model as the original sampler, a square lattice, with only a constant factor overhead. We next revamp our verification scheme to operate in the presence of noise by emulating a fault-tolerant procedure without correcting on-line for the errors, thus keeping the model non-adaptive, but verifying supremacy fault-tolerantly. We show that classically sampling up to additive errors is likely hard in our revamped scheme. Our results are applicable to more general sampling problems such as the Instantaneous Quantum Polynomial-time (IQP) computation model. It should also assist near-term attempts at experimentally demonstrating quantum supremacy and guide long-term ones. [Paper at https://arxiv.org/abs/1703.09568]

Speaker: Lidia del Rio, University of Bristol

Title: Subjectivity in quantum thermodynamics

Abstract:
Maxwell's demon has taught us that agents may have different descriptions of the same physical system, and thereby extract different amounts of work. In this talk we will explore the role of subjectivity in thermodynamics, both in classical and quantum settings. We will start with the example of Landauer's principle, used to relate information and thermodynamic work, and extend it to the case where agents may have quantum information about the state of a system. We will also see how information can be transformed into different types of work depending on agents' restrictions and resources. We will then lay out the idea of temperature as an operational concept, and how the same system may be act as a bath of different temperatures for different observers - depending on factors like correlations between agent and bath, the agent's instruments and their acceleration.

Speaker: David Kribs, University of Guelph

Title: Private algebras in quantum information: on the theory and connections with quantum error correction

Abstract:
In this talk, I will give a short introduction and discuss my ongoing work with collaborators on the development of a structure theory for a fundamental notion in quantum privacy and cryptography; known in different settings as private quantum channels, private quantum codes, quantum secret sharing, private subsystems, decoherence-full subsystems, and private algebras. I'll also discuss connections with quantum error correction, which is strongly linked to quantum privacy through the bridge provided by complementary quantum channels. This talk is based on collaborations with Jason Crann (Carleton), Tomas Jochym-O'Connor (Caltech), Raymond Laflamme (Waterloo), Rupert Levene (Dublin), Jeremy Levick (AIMS & Guelph), Rajesh Pereira (Guelph), Sarah Plosker (Brandon), Ivan Todorov (Belfast).
Speaker: Fereshteh Rajabi, Institute for Quantum Computing, University of Waterloo  
(Co-authors: Taehyun Yoon, Jeremy Flannery, Sreesh Venuturumilli, Michal Bajcsy)

Title: Raman (three-level) superradiance and two-level superradiance with Cs cold atoms inside a hollow-core photonic-crystal fiber

Abstract:
We study superradiant Raman scattering of light (superradiance in a three-level lambda scheme) and two-level superradiance from an ensemble of cold Cs atoms inside a hollow-core photonic crystal fiber (HCPCF). This phenomena can be used to probe long range coherence in the atomic ensemble and to provide insight about the symmetry of atom-field couplings in the HCPCF platform. In our experiment, the Cs atoms, initially cooled using a magneto-optical trap (MOT), are guided and confined inside a short piece of HCPCF with a magic-wavelength dipole trap. For the three-level superradiance experiment, the Raman laser field dresses the atoms propagating through the fiber. A Fabry-Perot cavity can also be integrated into the fiber using photonic-crystal slabs which act as planar mirrors and which are attached to the ends of the fiber piece. The two-level superradiance does not need a cavity but requires a fast pumping process.

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Speaker: Nachiket Sherlekar, Institute for Quantum Computing, University of Waterloo  
(Co-authors: O. Dixon-Luinenburg, M. Zeeshan, A. Ahmadi, S. Gibson, and M. E. Reimer)

Title: Transmission and far-field emission profiles of semiconductor nanowire quantum dot sources

Abstract:
Single photons are essential for quantum communication and linear optical quantum computing. High transmission rates and well-defined Gaussian far-field emission profiles are requirements for a source of single photons for these applications [1, 2]. Semiconductor quantum dots embedded in tapered nanowire waveguides serve as ideal candidates for such a source [1, 2, 3]. However, optimizing their architecture to maximize brightness, while maintaining a single-mode, Gaussian emission profile remains a challenge [1, 4]. We address this challenge through a theoretical study of the transmission efficiency and far-field emission profile of these nanowire-based sources. The influence of the diameter and tapering angle of the nanowire waveguide as well as the placement of the quantum dot within these nanowires were investigated. With the results obtained from these simulations, a bright, efficient source of single photons with a Gaussian emission profile in the far-field can be designed.


**Abstract:**

How much entanglement is required to play a non-local game optimally or near-optimally? This question has proven very difficult to answer in general. Recently we have found non-local games which cannot be played optimally with any finite amount of entanglement. In this talk, I will explain how this result arises out of a connection between linear system non-local games and group theory. This connection opens up a number of avenues for further research in entanglement requirements, self-testing, and complexity.

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**Speaker:** Mankei Tsang, National University of Singapore  
**Title:** Quantum Information Kills Rayleigh's Criterion

**Abstract:**

Two traumas await starlight at a telescope: The aperture amputates its high spatial frequencies, while the detectors measure its energy in rough quanta. The raw image, as a result, looks blurry and noisy. Rayleigh's criterion for resolving two stars, though archaic, remains a curse even if we allow image postprocessing: if the two stars are so close that they violate his criterion, the Fisher information for estimating their separation from the corrupted image drops to zero. This drop in Fisher information imposes fundamental limits to any postprocessing of the corrupted image. The same problem plagues fluorescent microscopy.

Surprisingly, one can do much better. Using quantum information theory, we discovered that there is a lot more information in the light than previously realized---we just need a better measurement to extract it. Inspired by this discovery, we invented several devices that can extract the full information, simply with linear optics and photon counting. Four experimental demonstrations have since been reported, and the rest is just engineering. Rayleigh's criterion is not just beaten but dead, and quantum information killed it.

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**Speaker:** Peter S. Turner, University of Bristol  
(Co-author: Stasja Stanisic)  
**Title:** On the quantum information of quantum interference

**Abstract:**

Recent advances in scaling photonics for universal quantum computation, and the race to demonstrate quantum `supremacy' via analog computations that sample the scattering amplitudes of multipartite states, spotlight the need for a thorough understanding of practicalities such as distinguishability in multimode quantum interference. Rather than the usual second quantized approach to such situations, we can gain insight by bringing quantum information concepts to bear in first quantization. Distinguishability can then be modelled as entanglement between degrees of freedom, where loss of interference is caused by decoherence due to correlations with an environment carried by the particles themselves. This is formalized by observing that Fock states can be Schmidt decomposed, corresponding to what has been called unitary-unitary duality in the representation theory of many-body physics. One pertinent idea from quantum information is state discrimination; we start by showing how this reproduces the well known Hong-Ou-Mandel test for distinguishability, and apply it to a new analysis of quantum interference for three photon scattering in three modes. We also show that completely distinguishable particles can be postselectively filtered so as to become completely indistinguishable without operating on, or indeed having any knowledge of, the distinguishing degree of freedom, a result inspired by the quantum information concept of decoupling. In principle the formalism accommodates any number of particles or modes, and we discuss the extension of these techniques to large scale photonic information processing.
Speaker: Sreesh Venuturumilli, IQC, University of Waterloo  
(Co-authors: G. Bappi, M. Bajcsy)  

Title: Photon arithmetic in directional waveguide QED systems  

Abstract:  
The fundamental quantum processes of adding and subtracting a single photon would allow us to manipulate, generate, and explore highly non-classical states of light. This has important implications in engineering quantum information protocols, and testing the foundations of quantum physics [1,2]. To improve upon previous implementations of deterministic single photon subtraction [3], which relies on a high-Q spherical microresonator, we explore the possibility of using a three-level emitter strongly coupled to a one-dimensional directional waveguide. Waveguide QED allows us to obtain large Purcell enhancements by achieving small mode volumes through tight light confinement, and slow-light through engineering the dispersion curve. Furthermore, by breaking the symmetry of light emitted into the waveguide mode using chiral-light matter interaction and asymmetric cavity, we propose schemes to implement single photon extraction and addition. Recent experimental demonstrations have provided evidence for near-ideal directional emission into waveguide modes [4]. Given arbitrary input light states, we calculate the probability of extracting or adding a single photon along with their final states through input-output formalism as a function of the emitter-waveguide coupling and directionality. Based on this, we describe realistic experimental platforms to check the feasibility of implementing the schemes, all of which are based on atoms and solid-state emitters. In particular, quantum dots and nitrogen-vacancy center embedded in nanophotonic [5] structures seems to offer a suitable platform for tailoring the required interactions.


Speaker: Philip Walther, University of Vienna  

Title: Advantages of photonic quantum technology for novel quantum computing schemes  

Abstract:  
The advantages of the photons makes optical quantum system ideally suited for fundamental quantum physics experiments and a variety of applications in quantum information processing. Here I will review results for the realization of secure quantum cloud computing, where quantum information is securely communicated and computed. As for photons ideally suited quantum computational architectures I will present experiments that are based on the superposition of the order of quantum gates as well as multi-photon processing using integrated waveguide structures.  
The last part of my talk will be dedicated to the measurement of experimental benchmark values for hyper-complex extensions of quantum mechanics that relay on quaternions (instead of complex numbers). As outlook I will briefly discuss the scale-up of photonic quantum computing by using high-efficient detectors and solid-state single-photon sources.
Speaker: Dong-Sheng Wang, University of British Columbia  
(Co-authors: Ian Affleck, Robert Raussendorf)

Title: Topological qubits from valence bond solids

Abstract:
Topological qubits based on SU(N)-symmetric valence-bond solid models are constructed. A logical topological qubit is the ground subspace with two-fold degeneracy, which is due to the spontaneous breaking of a global parity symmetry. A logical Z-rotation by angle $2\pi/N$ is provided by a global twist operation, which is protected by the gap and the SU(N) symmetry, and robust against small perturbation. General concatenation scheme with standard quantum error-correction codes is also proposed, which can lead to better codes. Generic error-correction properties of symmetry-protected topological order are also demonstrated.

Speaker: Soeren Wengerowsky, University of Vienna

Title: A Significant-Loophole-Free Test of Bell’s Theorem with Entangled Photons

Abstract:
Local realism is the world-view in which physical properties of objects exist independently of measurement and where physical influences cannot travel faster than the speed of light. Bell’s theorem states that this concept is incompatible with the predictions of quantum mechanics, as is expressed in Bell’s inequalities. Many previous experiments convincingly supported the quantum predictions. Yet, every experiment performed to date required assumptions that provide loopholes for a local realist explanation. We report a test of Bell’s theorem that closes the locality, freedom-of-choice, fair-sampling, coincidence-time, and memory loopholes simultaneously. Using a well-optimized source of entangled photons, rapid setting generation, and highly efficient superconducting detectors, we observe a violation of a Bell inequality with high statistical significance. The purely statistical probability of our results to occur under local realism does not exceed $3.74 \times 10^{-31}$, corresponding to an 11.5 standard deviation effect.

Speaker: Haidong Yuan, Chinese University of Hong Kong  
(Co-author: Chi Hang Fred Fung, Huawei Technology, Munich Research Center)

Title: Ultimate precision limit for quantum parameter estimation

Abstract:
Measurement and estimation of parameters are essential for science and engineering, where the main quest is to find out the highest achievable precision with given resources and design schemes to attain it. We present a general framework for quantum metrology which relates the ultimate precision limit directly to the underlying quantum dynamics. This framework provides efficient methods for computing the ultimate precision limit and optimal schemes to attain it. It also provides an efficient method to identify the optimal controls that can improve the precision limit maximally. It is shown that with noiseless dynamics a universal time scaling emerges as a fundamental property under the optimal controlled scheme for quantum parameter estimation, this restores an intuition that has been recently questioned in the field, that time is always a valuable resource.

Entangled photon sources are crucial for quantum optics and quantum information applications. Semiconductor quantum dots in nanowires have recently emerged as promising candidates considering its bright and directional photon emission [1] and Gaussian emission profile for near-unity fiber coupling efficiency [2]. However, strain and structural asymmetry in quantum dots lifts the degeneracy [3, 4] of the recombination paths for the biexciton-exciton cascade and severely limits the use of quantum dots as sources of entangled photon pairs with high fidelity. Here, we propose a novel approach for generating a pair of entangled photons from a semiconductor nanowire quantum dot by correcting the spatial asymmetry of the excitonic wave function via application of a quadrupole electrostatic potential. We demonstrate theoretically that the spatial asymmetry of the excitonic wave function can be tuned without compromising the spatial overlap between electron and holes. These results pave the way toward a deterministic source of entangled photons with high fidelity and collection efficiency.

On-demand entangled photon pair generation

Andreas Fognini\textsuperscript{1}, Arash Ahmadi\textsuperscript{2}, Mohd Zeeshan\textsuperscript{3}, Sandra Gibson\textsuperscript{3}, Nachiket Sherlakar\textsuperscript{3}, Michael E. Reimer\textsuperscript{3}, Val Zwiller\textsuperscript{1,4}

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Developing on-demand entangled photon pairs with high fidelity are crucial for the advancement of quantum information technologies. However, such a source has remained elusive until now. Here we present a new source of entangled photon pairs based on a quantum dot embedded in a nanowire waveguide. Due to the high brightness of the source, we perform quantum state tomography of the photon pair in all 36 possible basis states for the first time in quantum dot-based sources and demonstrate a high fidelity (88.2\%) of the entangled state. We further show that our source exhibits no dephasing, thus paving the way towards perfect entangled photon sources in the future. One key factor causing the reduction of the measured entanglement strength is the fine-structure splitting (FSS) caused by the asymmetry of the quantum dot (QD) confining potential. We propose a universal eraser technique for fully compensating the FSS with near-unity efficiency. This work is a significant step in our understanding of the entangled photon generation process in QDs and the possibility of generating on-demand entangled photon pairs with near-unity fidelity.

Figure 1: Left) picture of a typical nanowire; the QD is placed ~ 200nm from the bottom of the nanowire. Right) emission profile of the QD that illustrates the waveguiding effect of the nanowire. The photons are collected by an objective at the top of the nanowire and are sent to the analyzing optics.
Quantum information of photovoltaic cells

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Juelich-Aachen Research Alliance Institute (JARA), Fundamentals of Future Information Technologies, 52425 Juelich, Germany

(Dated:

Abstract

Similar to quantum bits that outperform classical bits for supercomputation, quantum heat engines have the potential to exhibit superefficiency in light-harvesting biocells and photovoltaic cells. However these engines have not yet been studied within the context of quantum information theory, thus many of their quantum features are yet unknown. Recently we introduced a new formaism to consistently evaluate the flow of quantum information in all quantum systems and realized that a large amount of the flow is neglected in current literature. Moreover we found exact correspondence between information flow and physical flows. This correspondence makes the entropy a measurable quantity. We studied quantum information flow in several quantum heat engines, such as the 4-level engine introduced recently by Scully et al. that already exhibited elevated output powers. We noticed new and interesting features in all of these engines, some of which are: In photovoltaic cells with lower decoherence time entropy transfer between cold and hot reservoirs can take place much faster than what the 2nd law predicts; There is an unexpected lower bound on the flow of entropy that proposes some quantum bounds on energy fluctuations in these devices. Further studying quantum information features in quantum devices can help to find ways of instant measurement of information leakage, fidelity, and crosstalk effects.
Laser-induced filamentation of phase space: from molecular echoes to harmonics generation in free electron lasers

Ilya Sh. Averbukh

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Abstract

Echoes are common in many areas of physics, including NMR, plasma physics, nonlinear optics, cavity quantum electrodynamics, cold atoms physics, and dynamics of proton storage rings. Recently we found (probably) the simplest system featuring the echo phenomenon—a collection of randomly oriented free rotors with dispersed rotational velocities. Following excitation by a pair of time delayed impulsive kicks, the mean orientation or alignment of the ensemble is predicted to exhibit multiple echoes and fractional echoes. We elucidated the mechanism of the echo formation by the kick-induced filamentation of the rotational phase space, and provided the first experimental demonstration of alignment echoes by measuring laser-induced birefringence in a thermal gas of CO$_2$ molecules excited by a pair of femtosecond laser pulses [1]. Fractional echoes in the same system were detected via the third harmonic generation from an additional probe pulse [2]. More recently, we used the technique of coincidence Coulomb explosion imaging for a direct spatiotemporal analysis of various molecular alignment echoes [3,4] and observed fractional echoes of high order, spatially rotated echoes, and counter-intuitive imaginary echoes at negative times. The described mechanism of the echo formation is rather general and has implications in other fields of physics. The recent SLAC demonstration of the efficient generation of high harmonics (up to the 75th) from tailored electron beams in free-electron lasers [5] is based on a mechanism similar to fractional echoes of high order observed in our molecular experiments.


Laser-cooled atoms confined in a hollow-core fibre by a magic-wavelength dipole trap

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Hollow-core photonic-crystal fibres (HCPCFs) loaded with warm [1] or laser-cooled atomic ensembles [2] have been used in the past for demonstrations of strong optical nonlinearities arising from the tight transverse confinement of both photons and atoms. The laser-cooled ensembles in particular offer the advantage of having no Doppler broadening and the possibility to trap the atoms in a fibre-guided red-detuned optical dipole trap, which keeps the atoms from hitting the fibre walls and opens the potential for long coherence times of the atoms’ ground state.

The past experiments in this platform [2, 3] have used laser-cooled rubidium atoms. To avoid the inhomogeneous broadening arising from the AC-Stark shift caused by the dipole trap, these experiments rely on rapid amplitude modulation of the dipole trap and have to restrict the atom probing and manipulation to the microsecond time windows when the trap is off.

Caesium atoms offer a conveniently located 935nm ‘magic-wavelength’ dipole trap, which AC-Stark-shifts the ground and excited states by the same amount and in the same direction and thus induces no inhomogeneous broadening. This wavelength is guided by the same HCPCF that can also guide light resonant with the caesium optical transition (852nm).

We report loading of cold caesium atoms into such fibre-guided dipole trap and demonstrate a system with optical depths of ~300, in which photons propagate confined to an area with the diameter of several wavelengths over essentially unlimited distance. We discuss the prospects for high-fidelity photon storage and single-photon conversion, as well as for novel super radiance regimes in this platform.

Manipulating the information content of a memory register has an associated thermodynamic cost: the erasure and copying of information can only be realised through physical operations necessitating adequate resources [1–5]. Landauer’s principle epitomizes such correspondence by quantifying the minimum amount of work required to reset a memory register [6, 7].

Controlling the conversion of information to energy will be key to the implementation of quantum-limited micro- and nano-engines and, in general, to the development of quantum technologies. In the light of Landauer’s principle, the simple act of monitoring a system through a quantum measurement implies a thermodynamic cost whose quantification has been the focus of recent debate [8–12].

Any quantum measurement introduces a disturbance to the state of the monitored system. This which requires the optimization of the trade-off between the intrusivity of a measurement and the degree of information acquired through it. Weak measurements [15, 16] are valid tools to achieve such a compromise.

In this talk we discuss the thermodynamic cost of generalized measurements in a photonic architecture [13,14]. Starting from the framework set in Ref. [8], we introduce a new figure for quantifying the efficiency of the measurement in a real experiment. The flexibility of our setup allows for the interpolation between weakly disturbing and strong measurements. Our results show the energetic equivalence of performing measurements of arbitrary invasiveness. While extending Landauer-like arguments, our endeavors open up the exploitation of generalized measurements in information-to-energy conversion processes.

Abstract

Title
Quantum heat engine operating between thermal and spin reservoirs

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Landauer’s erasure principle is a cornerstone of thermodynamics and information theory. According to this principle, erasing one bit of information incurs a minimum energy cost. Recently, Vaccaro and Barnett [1] explored information erasure in the context of multiple conserved quantities and showed that the erasure cost can be solely in terms of spin angular momentum. As Landauer’s principle plays a fundamental role in heat engines, their result considerably widens the configurations that heat engines can have. Motivated by the VB erasure, in this work we propose a novel optical heat engine that operates under a single thermal reservoir and a spin angular momentum reservoir. The working fluid of our heat engine consists of a three level system with two energy degenerate electronic ground states and an excited state. We demonstrate the conversion of thermal phonon energy into a coherent work, effectively at the cost of a spin polarization in the spin bath. The engine operation consists of two stages (a) extracting thermal phonon energy using lasers and (b) an erasure of entropy using a polarized spin bath that acts as a low entropy sink. We model the stage (a) using a spin-boson model and the stage (b) is modelled using a collisional model of spin exchange between the working fluid and the spin reservoir.

References
Parasitic photon-pair suppression via photonic stop-band engineering

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Spectrally degenerate photons are an important resource in optical implementations of quantum information processing as well as fundamental tests of bosonic interference. For integration with existing infrastructure, it is desirable that they be produced via spontaneous four-wave mixing (SFWM) \(^1\), a process that comes in two distinct flavors: single-pump, defined as using a single exciting pump with center frequency \(\omega_P\) to generate photons, with frequencies \(\omega_S\) and \(\omega_I\), to either side of the pump frequency as dictated by energy conservation \(\omega_S + \omega_I = 2\omega_P\); and dual-pump, defined as using two exciting pumps with center frequencies \(\omega_{P1}\) and \(\omega_{P2}\) to generate photons located between the two pump frequencies according to \(\omega_S + \omega_I = \omega_{P1} + \omega_{P2}\).

Achieving simultaneous generation of spectrally degenerate photons using single-pump SFWM is challenging, for it requires simultaneously heralding a photon from each of two photon-pair sources. Dual-pump SFWM, on the other hand, can directly produce pairs of spectrally identical photons. Unfortunately, to date degenerate photon-pair generation via dual-pump SFWM has suffered from noise due to each pump generating its own parasitic pairs of non-degenerate photons via single-pump SFWM \(^2,\,3\).

In this work \(^4\) we theoretically examine the use of a Bragg grating to suppress these undesired single-pump processes. We calculate that an appropriate modification of the field associated with only one of the photons of a photon pair can suppress generation of the pair entirely. From this general result, we develop a method for suppressing the generation of undesired photon pairs utilizing photonic stop bands. For a third-order nonlinear optical source of frequency-degenerate photons, we calculate the modified frequency spectrum (joint spectral intensity) and show a significant increase in a standard metric, the coincidence to accidental ratio (CAR). These results open a new avenue for photon-pair frequency correlation engineering.

References

Spin Squeezing in Optical Lattice Clocks with Cavity QED

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June 26, 2017

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State of the art optical lattice atomic clocks have reached a relative inaccuracy level of order $10^{-18}$, making them the most stable time references in existence. These clocks operate near the standard quantum limit (SQL) of quantum projection noise, a limitation that can be overcome by entangling the atoms. I will discuss how techniques of cavity quantum electrodynamics (cQED) can be used to control and characterize this entanglement, both via quantum non-demolition measurement and via light-mediated atom-atom interactions. I will then report on recent experimental progress toward realizing these techniques in an Yb optical lattice clock, where we use a high-finesse micromirror-based cavity operating in the strong coupling regime of cQED to produce the necessary interactions. By exceeding the SQL in this state of the art system, we are aiming to advance precision time metrology and expand the boundaries of quantum control and measurement.
Controllable Exchange Mediated Two Electron Correlations on Precision Placed Donors in Silicon

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This work demonstrates the first important step toward controllable spin-spin interactions between single electrons confined to phosphorus donors in silicon. We use precision placed donor atoms fabricated with STM hydrogen resist lithography, where each atom is tunnel coupled to an in-plane single electron transistor. Figure 1a shows the lithographic pattern identifying two donor sites with $V_L$ and $V_R$ gates to measure the charge stability map shown in Fig. 1b. We operate around the (2,0)-(1,1) charge region where electron exchange interactions are expected as a result of the coherent tunnel coupling between the two donors sites \cite{1, 2}.

We initialize the electrons in the (1,1) region, after which we pulse along a detuning axis towards the (2,0) charge region (white arrow in Fig. 1c) \cite{3}. As a function of this detuning we observe the onset of the exchange interaction, leading to anti-correlated spins states.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{(a) Few donor double-dot patterned by STM lithography. Around the patterned donors are in-plane gates \{G_L, G_M, G_R, G_S\} and a SET charge sensor used for spin readout. (b) Close-up of the lithographic outline of $L$ and $R$ which contain 2 and 1 phosphorus donors respectively. (c) Charge stability map showing charge regions of the two donor sites. Spin readout for $L$ and $R$ are performed at the red and blue circles respectively. The exchange interaction is controlled by pulsing along the detuning axis shown by the white arrow.}
\end{figure}

In addition, we measure singlet-triplet mixing and determine their associated $T_1$ lifetimes to be of the order 10s of seconds. Our results pave the way towards a coherent two-electron exchange gate in donor based systems.

\begin{thebibliography}{9}
\end{thebibliography}
Fluctuations in Vaccaro-Barnett erasure

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(Dated: July 14, 2017)

Recently, Vaccaro and Barnett [1–4] explored the role of multiple conserved quantities in information erasure, and demonstrated that for energy degenerate spin reservoirs, the cost of erasure can be achieved solely in terms of spin angular momentum and not energy

\[ \Delta J_z \geq \gamma^{-1} \ln 2, \]  

where \( \gamma \) is the Lagrange multiplier associated with the equilibrium state of an ensemble of energy-degenerate spin-1/2 particles.

We analyzed this cost allowing for fluctuations to occur, from this we introduced an analogous Jarzynski equality [1, 5–7]

\[ P_{\epsilon}(\Delta L_s < -\gamma^{-1} \ln 2 - \epsilon) \leq e^{-\gamma \epsilon}. \]  

With an improved bound of

\[ P_{\epsilon}(\Delta L_s < -\gamma^{-1} \ln 2 - \epsilon) \leq C e^{-\sqrt{\pi} \epsilon}. \]  

In addition we obtained an equivalent first law of thermodynamics

\[ \Delta J_z = \Delta L_s + \Delta Q_s, \]  

where \( \Delta J_z \) represents a change in average spin polarization, \( \Delta Q_s \) represents average spin heat (spin equivalent of heat), and \( \Delta L_s \) represents average spin labor.

Using the obtained first law the average spin heat and average spin labor were compared to Vaccaro and Barnett’s bound Eq 1. With the total average spin heat always being greater than \( \gamma^{-1} \ln 2 \). An interesting result found that the total average spin labor cost under certain parameters was able to violate this bound.

To conclude, we find that the fluctuations below the Vaccaro-Barnett bound are possible and that are tighter bound can be accomplished. We exposed the tradeoff between the cost of erasure and size of the fluctuations. In addition we showed an equivalent first law of thermodynamics equation with interest outcomes.

Synthesizing complex spin networks with spin-motion coupled neutral atoms in photonic crystals

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An exciting frontier in quantum information science is the realization of complex many-body systems whose interactions are designed quanta by quanta. With recent experimental and theoretical developments, hybrid quantum nanophotonic systems with cold atoms[1] have emerged as the paradigmatic platform for engineering long-range spin models from the bottom up with unprecedented complexities. Here, we develop a toolbox for realizing “fully programmable” pairwise-interacting complex spin networks with spin-motion coupled neutral atoms in the vicinity of 1D photonic crystal waveguides. The enabling platform allows the synthesis of strongly interacting quantum materials mediated by normal modes (phonons) from the underlying collective motion of the atoms. We demonstrate the versatility of our assembly language approach towards arbitrary SU(2) -lattice spin models with explicit constructions of familiar Hamiltonians for perfect state transfer in 1D spin chains[2], lattice gauge theories[3], and topologically ordered quantum spin liquids[4]. To demonstrate SU(2) -vector spin coupling, we further construct Dzyaloshinski-Moriya interaction in a Kagome lattice for the realization of chiral spin liquids[5]. The underlying principle of our approach can be readily applied to other physical platforms such as ion trap quantum simulators and spin-coupled quantum optomechanical systems.

Robust and high-fidelity control for quantum computation

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An essential prerequisite for quantum information processing is precise coherent control of the dynamics of quantum systems or quantum bits (qubits). Most of the control sequences implemented in quantum experiments are developed and designed based on the assumption of having ideal (closed) quantum coherent systems. However, almost every quantum system interacts inevitably with its surrounding environment resulting in decoherence and dissipation of the quantum system. We have applied the quantum optimal control theory to construct fast and high-fidelity quantum gates taking into account decoherence from dissipative environment for non-Markovian open quantum systems [1,2] and for various promising physical quantum systems [3-5]. Recently, we have developed a systematic method to find pulses for quantum gate operations robust against both low and high-frequency (comparable to the qubit transition frequency) stochastic time-varying noise [6]. Our method that includes detailed information of stochastic time-varying noise in the cost function for optimization can be applied to different system models and noise models. Here we applied this method to construct robust single-qubit and two-qubit gates for quantum-dot spin qubits in purified silicon with fidelity enabling large-scale fault-tolerant quantum computation.

References

Experimental demonstration of Gaussian protocols for one-sided device independent quantum key distribution

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Quantum Key Distribution (QKD) [1] has been developed rapidly in the recent years. However, it is realized soon that the real-life implementation of QKD protocols might differ from the theoretical predictions. This leads to the development of the protocols with least amount of assumptions on the devices. In fully device-independent (DI) protocols Eve can control over all experimental devices where the security is linked to Bell’s non-locality [2]. These schemes are extremely challenging to implement. Interestingly, the asymmetric form of non-locality, Einstein–Podolsky–Rosen (EPR) steering [3], plays a role in protocols where Eve controls only the devices of one of the communicating parties, known as one-sided device-independent (1sDI) quantum key distribution (QKD) [4]. Here we present our theoretical and experimental investigation of the security of the entire family of 16 Gaussian continuous-variable (CV) QKD protocols against arbitrary attacks in the asymptotic setting [5]. We identify all Gaussian protocols that can be 1sDI. Surprisingly, this includes a protocol that uses only coherent states. We also establish a direct link between the relevant EPR steering inequality and the secret key rate, further strengthening the relationship between these asymmetric notions of non-locality and device independence. We experimentally implement both entanglement-based and coherent-state protocols, and measure the correlations necessary for 1sDI key distribution up to an applied loss equivalent to 7.5 and 3.5 km of optical fiber transmission, respectively. The new protocols we uncover apply the cheap and efficient hardware of CV-QKD systems in a significantly more secure setting.

References:

From the first loophole-free Bell test to a quantum Internet

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For more than 80 years, the counterintuitive predictions of quantum theory have stimulated debate about the nature of reality. In his seminal works, John Bell proved that no theory of nature that obeys locality and realism (and free will) could reproduce all the predictions of quantum theory. The resulting Bell inequality provided a recipe for experimental tests of the fundamental principles underlying the laws of nature. In the past decades, numerous ingenious Bell inequality tests have been reported; however, because of experimental limitations, all required additional assumptions to obtain a contradiction with local realism, resulting in “loopholes”.

I will discuss our recent experiments providing the first loophole-free violation of Bell’s inequality [1,2]. We employ an event-ready scheme that generates entanglement between diamond electron spins separated by more than 1 km. Furthermore, I will sketch how we can combine these techniques with full control over individual nuclear spins to enable entanglement distillation on an elementary network of quantum bit registers [3]. In the long run, such networks may lead to a quantum Internet secured through device-independent protocols – reaching the ultimate physical limits of privacy [4].

Quantum Chemistry with Noisy Superconducting Qubits

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The applicability of near-term quantum computers is of intense current interest, especially for the field of quantum chemistry, where exactly solving the electronic structure problem has exponential cost when addressed with classical computing methods. However, despite the appearance of early ideas almost two decades ago, experimental implementations on quantum hardware have been restricted to the most elementary molecules. In this work, we use a superconducting quantum processor to find variational solutions to ground state energy problems of increasing size, using up to six qubits for the molecular Hamiltonian of BeH$_2$ [1]. This is enabled by a hardware-efficient preparation of variational trial states that utilize the naturally occurring entangling interactions on the physical device, in conjunction with a compact encoding of the fermionic problem onto qubits [2], and a robust stochastic optimizer. We numerically demonstrate the viability of such trial states for the small molecular Hamiltonians considered in this work, and elucidate the hardware requirements to achieve practically relevant accuracies. The agreement of our experimental results with numerical simulations of the noisy experiment paves the way for further improvements with error mitigation [3] protocols requiring no additional quantum resources.

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Quantum Information Summoning Using Quantum Secret Sharing and Teleportation

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Summoning is the task of encoding and transmitting quantum information to a configuration of spacetime causal diamonds such that the quantum information can be reconstructed in any one of these causal diamonds [1, 2, 3]. Summoning cannot be guaranteed to work for every configuration of causal diamonds because quantum information cannot be copied or transmitted superluminally [1]. Two diamonds are causally related if the earliest point of one can communicate with the latest point of the other, and summoning is only possible for a configuration of causal diamonds if every pair of diamonds is causally related [2].

Our aim is to construct an algorithm that designs protocols for summoning quantum information in any configuration of pairwise-related causal diamonds. Our algorithm yields summoning protocols that require only the primitive operations of (2, 3) quantum secret sharing [4, 5] and quantum teleportation [6]. The key to this universality result is that our recursive subalgorithm reduces summoning in a configuration of causal diamonds to summoning in smaller configurations of causal diamonds. The number of qubits, gates and quantum transmission channels used by our protocol is linear in the number of causal diamonds, which is a quadratic improvement in the number of qubits over existing summoning techniques [2].

Our results show that summoning in any configuration of causal diamonds is achievable with simple primitive operations. These basic building blocks have been demonstrated experimentally [7, 8], therefore putting summoning within reach of state-of-the-art technology.

References


Abstract

It is well known in the realm of quantum mechanics and information theory that the entropy is non-decreasing for at least the class of physical processes that are unital, also called doubly stochastic [1, 2]. However, in general, the entropy does not exhibit monotonic behaviour. This has restricted the use of entropy change in characterizing evolution processes. Recently, a lower bound on the entropy change was provided in [3]. We explore the limit that this bound places on the physical evolution of a quantum system and discuss how these limits can be used as witnesses to characterize quantum dynamics. In particular, we derive a lower limit on the rate of entropy change for Markovian quantum dynamics that provides a witness of non-unitality. This limit on the rate of entropy change allows us to naturally generate several witnesses of non-Markovianity in quantum dynamics. We provide an example in which our witness can detect non-Markovianity even when the well-known BLP measure [4] does not. Furthermore, from the aforementioned lower bound on entropy change we naturally obtain a measure of non-unitarity for unital evolutions, which we evaluate for the qudit depolarizing channel.

References


Symmetric extendibility of quantum states [2] has been proven to be useful in various areas of quantum information and quantum communication such as detection of entanglement, determining entanglement distillability, and characterizing anti-degradable channels [3]. Thus, it is important to determine whether a quantum state has a symmetric extension or not. So far, the necessary and sufficient conditions for the existence of a symmetric extension of quantum states is known only for 2-qubit states [2]. This question is open for general 2-qudit states, though it has been studied for specific classes of qudit states [4]. We provide a sufficient condition for the nonexistence of 3-qudit symmetric extension of any 2-qudit state using the existence of nonlocal quantum correlations in the quantum state measured via Bell inequalities [1]. First, we prove that any 2-qubit state that violates the Bell Clauser-Horne-Shimony-Holt (CHSH) inequality cannot have a symmetric extension. Next, we prove that if a 2-qudit Bell inequality is monogamous, then any 2-qudit state that violates this inequality cannot have a symmetric extension. Finally, we conjecture that Bell Collins-Gisin-Linden-Massar-Popescu (CGLMP) inequality for 2-qutrit states is monogamous based on numerical work. A key feature of our work is that our analysis of qudit states is general and provides a sufficient condition for testing the symmetric extension of quantum states of any dimension.

References
Irreducible noncontextuality inequalities from the Kochen-Specker theorem
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Recent work [1] has shown how operational noncontextuality inequalities robust to noise can be obtained from Kochen-Specker uncolourable (or KS-uncolourable) hypergraphs. In contrast to traditional approaches, this operational approach does not assume outcome determinism. The result of Ref.[1] relied on an explicit numerical enumeration of the vertices of the polytope of noncontextual assignments of probabilities to the measurement outcomes. Here we focus on an analytical approach to deriving such noncontextuality inequalities that relies on constraints arising directly from the structure of the hypergraph. This cleanly identifies the operational quantities that one can expect to be constrained (and why) by the assumption of noncontextuality instead of having to guess these quantities or obtaining them from brute-force numerical methods without any guiding principles to identify them. Indeed, we show how to identify a minimal set of independent noncontextuality inequalities for any KS-uncolourable hypergraph. We build on previous work in the following ways:

1. The numerical approach to obtaining the upper bound on the noncontextuality inequality of Ref. [1] is replaced by an analytical approach based on a deeper understanding of the structure of KS-uncolourable hypergraphs.
2. The fine-grained inequalities seen to be obtained from Fourier-Motzkin elimination [2,3] can be motivated from different principles that do not need quantifier elimination to obtain the inequalities. We illustrate this for the case of a family of 2-regular KS-uncolourable hypergraphs.
3. It paves the way to understanding these noncontextuality inequalities in terms of hitherto unappreciated hypergraph-theoretic properties associated with KS-uncolourable hypergraphs.

References:

Prediction and Characterization of Multiple Extremal Paths in Continuously-Monitored Qubits

Philippe Lewalle, Areeya Chantasri, Mahdi Naghiloo, Dian Tan, Patrick M. Harrington, Kater W. Murch, and Andrew N. Jordan

Abstract

We examine optimal paths between initial and final states for diffusive quantum trajectories in continuously monitored qubits, obtained as extrema of a stochastic path integral. We demonstrate the possibility of “multipaths” in the dynamics of continuously-monitored qubit systems, wherein multiple optimal paths travel between the same pre- and post-selected states over the same time interval. Optimal paths are expressed as solutions to a Hamiltonian dynamical system. The onset of multipaths may be determined by analyzing the evolution of a Lagrangian manifold in this phase space, and is mathematically analogous to the formation of caustics in ray optics or semiclassical physics. We demonstrate the existence of multipaths in two sample systems: First we investigate the evolution of pure states in a qubit simultaneously monitored along two non-commuting observables [1], as in the recent experimental implementation [2], and second we consider a Rabi-driven qubit monitored with imperfect efficiency through its fluorescence signal [3]. In both cases we show that multipaths appear due to paths with different “winding numbers” around the Bloch sphere, and due to the formation of catastrophes in the Lagrangian manifold. For the driven fluorescence case, multipaths have been observed in experiment, and found to be in good agreement with theoretical predictions [3].

Title: Error Correction and Non-stoquastic Hamiltonian in quantum annealing

Authors: S. Matsuura, H Nishimori, W Vinci, T Albash, D.A. Lidar

Abstract:
The performance of quantum annealing is adversely affected by diabatic transitions as well as thermal excitations out of the ground state. While the presence of energy gaps between the ground and excited states suppresses such excitations, error correction techniques are required to ensure full scalability of quantum annealing.

Quantum annealing correction (QAC) is a method that aims to improve the performance of quantum annealers when control over only the problem (final) Hamiltonian is possible, along with decoding. It is directly implemented on current generations of quantum annealers, and has been experimentally demonstrated to successfully error-correct a range of optimization problems. In this talk I provide an analytical understanding of its operating mechanism by using tools from quantum statistical mechanics. Especially I explain the effect of QAC on second and first order phase transitions.

While QAC controls over the problem Hamiltonian, there have been attempts to improve the performance by controlling over quantum fluctuations, namely the driver Hamiltonian. There are two classes of the driver Hamiltonians in the viewpoint of complexity. The traditional form of the driver term gives a stoquastic Hamiltonian which allows to be simulated efficiently in classical computers. The other class of Hamiltonians, non-stoquastic Hamiltonians, is realized by simply adding antiferromagnetic couplings to the traditional form. This class of Hamiltonians is difficult to simulate in classical computers.

By using the encoding structure of QAC, I will show that computational performance of quantum annealing can be significantly improved by simply adding local anti-ferromagnetic terms.

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Phys Rev Lett.116. 220501
One-way quantum repeaters
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Quantum information degrades over distance due to the unavoidable imperfections of the transmission channels. This simple fact limits quantum communication technologies (which rely on propagating quantum systems) to work only within metropolitan distances. A solution to this issue is to introduce quantum repeaters at regular intervals along a lossy channel, that revive the quantum signal. In contrast to repeaters based on entanglement swapping, we developed unitary one-way quantum repeaters that do not need to implement measurements nor require quantum memories, and that are therefore considerably simpler than other schemes.

The main idea behind one-way quantum repeaters is to treat loss as an error and mimic what happens in Quantum Error Correction (QEC). The advantage with respect to the typical resource overhead of QEC is that as optical loss compounds, we can get away with correcting only for a single error (i.e. the loss of a single photon) per optical mode, as long as we do it frequently enough.

We present two methods to construct Hamiltonians that generate a repeater interaction that can beat the fundamental repeaterless key rate bound asymptotically, even in the presence of an additional coupling loss, with signals that contain only a handful of photons. The natural evolution of our work will be to approximate a repeater interaction by combining simple optical elements, to make repeater units inexpensive and reliable.

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Coherent Control in Quantum Chaotic Systems

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Control of molecular dynamics with external fields is a long-standing goal of physics and chemistry research. Great progress has been made by exploiting the coherent nature of light-matter interaction. At the heart of coherent control is the interference of quantum pathways leading to the desired target state from a well-defined initial state. In this context, an exponential sensitivity to the initial conditions, characteristic for classically chaotic systems, poses an important question about the controllability in the quantum limit. As the underlying classical ro-vibrational dynamics of the majority of large polyatomic molecules is often chaotic, the answer to this question has far reaching implications for the ultimate prospects of using coherence to control chemical reactions.

We experimentally study coherent control of a quantum system, whose dynamics is chaotic in the classical limit. Interaction of diatomic molecules with a periodic sequence of ultrashort laser pulses leads to the dynamical localization of the molecular angular momentum, a characteristic feature of the chaotic quantum kicked rotor. By changing the phases of the rotational states in the initially prepared coherent wave packet, we control the rotational distribution of the final localized state and its total energy. We demonstrate the anticipated sensitivity of control to the exact parameters of the kicking field, as well as its disappearance in the classical regime of excitation.
Benchmark for the coherent control of reversible quantum dynamics

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Controlling quantum systems is crucial for a variety of new technologies. The control is typically achieved through a sequence of classical pulses, suitably engineered to enforce a target dynamics. Here we explore a different approach, where the dynamics is controlled by a quantum system. We show that quantum strategies offer an advantage over all classical strategies that measure the control system and conditionally operate on the target. To certify the advantage, we provide a benchmark that guarantees the successful demonstration of coherent quantum control in realistic experiments.

Introduction. We live in the middle of the second quantum revolution [1], a process that turned the puzzling features of quantum mechanics into working principles for new technologies. The hallmark of the second quantum revolution is the ability to control quantum systems. Most often, the control is achieved classically, by decomposing the target dynamics into elementary operations and using classical pulses to implement them. However, there exist situations where classical control is not the most convenient approach. First, classical control may require strong pulses, which may introduce unwanted perturbations in the surroundings of the system—think e. g. of the case of operations performed within a biological sample. Second, the sequence of control pulses may be long and may take more time than the coherence time of the system. Third, classical control requires a classical description of the target dynamics. Such a description may not be available if the dynamics is defined relatively to the state of a quantum system—this is the case, e. g. when one wants to rotate the Bloch vector of a quantum bit (qubit) around the direction indicated by the spin of a quantum particle, as in Figure 1. To cope with these scenarios, it is important to explore a different paradigm of control, where the dynamics is controlled by a quantum system rather than a sequence of classical pulses [2–9].

The quantum mechanical nature of the control system introduces genuinely new questions. How does the size of the control system affect the accuracy? How many times can one reuse the control system before it loses its ability to command the dynamics of the target? Is the best performance attained in a classical way, by reading out the instructions written in the control and conditional operating on the target, or is it attained in a quantum way, by letting target and control interact as a closed system? Here we answer these three questions, focussing on the problem of rotating the spin of a quantum particle around a direction determined by the spin of another particle. We establish the ultimate quantum limit to the accuracy as a function of the size of the control, showing that error vanishes inverse linearly with the spin size. The limit is attained by a coherent control mechanism, whereby the two spins interact with each other without leaking any information into the outside world. We show that this coherent strategy reaches a higher accuracy than all classical strategies where the control spin is measured in order to extract information about the target dynamics. For example, measurement-based strategies using a control system of spin $j = 3/2$ can achieve at most fidelity 64% in flipping a target qubit around a variable direction, while the optimal quantum strategy achieves 71% fidelity. To the best of our knowledge, this is the first rigorous demonstration that coherent quantum control beats all conventional strategies based on measurement and feed-forward. The gap between quantum and classical strategies allows us to establish a benchmark for the demonstration of coherent quantum control in realistic experiments. In the macroscopic limit the gap disappears at the leading order, leading to an asymptotic equivalence between quantum and classical control. Nevertheless, the error of the best quantum strategy vanishes twice as fast as the error of the best classical strategy.

Accuracy vs size. Suppose that a magnetic field is turned on for a limited period of time. During this time,
Talk submitted to the CQIQVII meeting in Toronto, August, 2017

Title: The Transition Path Time Distribution - Quantum Mechanics, Vanishing Tunneling Flight Times and Special Relativity

Name: Eli Pollak

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Abstract:

Recent experimental measurements of the transition path time distributions of proteins demonstrate that these distributions are experimentally measurable. The folding unfolding dynamics of proteins is classical mechanical in nature but the experiments suggest that there is value in developing a quantum theory of transition path time distributions.

The formalism[1-3] is used to study the quantum dynamics of thermal position correlation functions. Highlights are the proof of a vanishing mean tunneling time at the parabolic barrier crossover temperature [2] and that increasing the length of the path traversed decreases the mean transition time [1]. The mean transition path time is used to define a coarse grained momentum for passage from one side of the barrier to the other. The product of the uncertainty in this momentum with the uncertainty in the location of the particle is shown under certain conditions to be smaller than the ħ/2 formal uncertainty limit [2].

The transition path formalism will then be used to define a tunneling flight time which is found to vanish for an Eckart barrier and a rectangular barrier, irrespective of the barrier width and height. This generalizes the Hartman effect. Yet, as shall be shown, special relativity is not violated.

References:
Orthogonal temporal modes (TM), which are longitudinal wave-packet-shape functions, remain a largely untapped basis for encoding quantum information (QI) in light [1]. They are truly field-orthogonal, practically multidimensional, and easily applicable in diverse embedded and integrated photonics systems. Mastery of TMs will not only benefit optimal storage and/or transfer of QI amongst solid-state and atomic-ensemble quantum memories [2] (a necessity for quantum repeaters), but will enable full exploitation of pulsed quantum resources with the completion of the photonic manipulation toolkit.

A key missing technology necessary for TM-based designs is the ideal Quantum Pulse Gate (QPG) [3], a device that unitarily multiplexes/demultiplexes TMs with zero crosstalk. Parametric nonlinear optical processes (such as sum-frequency generation and stimulated Raman quantum memories) pumped with time-nonstationary control fields, have long been explored as potential means for QPG implementation [4–6]. In QPGs based on traveling-wave interactions in media with simple dispersion profiles, a natural limit exists for achievable TM selectivity, limiting the usefulness of this approach [7–9]. We propose an interferometric method to overcome said limit and asymptotically approach unit selectivity [10–12]. And we showcase an experimental effort to demonstrate this technique, called temporal-mode interferometry, by performing cascaded frequency conversion in second-order nonlinear waveguides.

Our setup double-passes coherent optical pulses centered around 800 nm and 400 nm through a 5 mm long, commercial MgO:PPLN second-harmonic generation waveguide. We verify the selectivity limit for a single-pass setup [13], for 500 fs wide TMs at near-IR frequencies. We theoretically verify an interferometric selectivity enhancement in a double-pass configuration.

References


Ultracold $^{23}$Na$^6$Li Molecules with Electric and Magnetic Dipole Moments

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Ultracold molecules with permanent electric dipole moments are promising candidates to study quantum many-body physics and quantum chemistry. An additional magnetic dipole provides an extra degree of control, for example to tune collisional resonances [1], or study spin-lattice Hamiltonians [2]. $^{23}$Na$^6$Li in their triplet ground state is well suited for such studies, with a dipole moment of 0.2 D and a magnetic moment of $2\mu_B$ from the aligned electron spins [3]. We create fermionic dipolar $^{23}$Na$^6$Li molecules in their triplet ground state from an ultracold mixture of $^{23}$Na and $^6$Li [4]. Using magneto-association across a narrow Feshbach resonance followed by a two-photon STIRAP transfer to the triplet ground state [5, 6], we produce $3 \times 10^4$ ground state molecules in a spin-polarized state. We observe a lifetime of 4.6 s in an isolated molecular sample, approaching the $p$-wave universal rate limit. The long-lived nature of triplet NaLi molecules contrasts recent results in other ultracold molecule experiments, where rapid loss was observed even in chemically stable species [7–10]. In addition to lifetime measurements, electron spin resonance spectroscopy of the triplet state was used to determine the hyperfine structure of this previously unobserved molecular state.

Title

Quantum state analysis of few-photon-level light undergoing large, atom-mediated cross-phase modulation.

Authors

Steven Sagona-Stophel, Reihaneh Shahrokshahi, Mehdi Namazi, Bertus Jordaan, Eden Figueroa

Abstract

Strong photon-photon interactions are critical for analog quantum simulators, deterministic Bell state measurements, quantum networks, and linear quantum computing. While only recently such interactions have been directly measured at the single photon level,\(^1\) a number of breakthrough experiments have seen strong photon-mediated phase shifts.\(^2,3\) Additionally, few-photon-level $\pi$ phase shifts can be seen in double-lambda systems in cold atoms\(^4\) in which, unlike the Kerr Effect, the observed phase shift is independent of the powers of the input fields. While few-photon-level phase shifts have been observed for coherent state pulses for this double-lambda system, a fully-quantum characterization of the light fields has yet to be seen. Similar to our previous quantum characterization of a Kerr nonlinearity,\(^5\) we present a quantum characterization of few-photon-level light fields exhibiting large cross-phase modulation via a double-lambda system in a room-temperature atomic vapor. We use time-dependent homodyne tomography to obtain the phase-shift of the coherent state pulses. Unlike standard EIT systems, the phase shift of the closed-loop system is sensitive on the relative phases of the control fields. To observe this, we vary the phase of one of the control fields and observe the probe’s cross-phase modulation as a function of control-field phase. We observed $\pi$ phase shifts for 400ns long probe and signal pulses at the few photon level. Then, using the quadrature statistics of the phase shifted photons obtained via homodyne tomography, we use maximum likelihood estimation to observe the quantum state of the phase-shifted light fields in the Fock state basis.

Contextual advantage for state discrimination

David Schmid and Robert W. Spekkens

June 14, 2017

Finding quantitative aspects of quantum phenomena which cannot be explained by any classical model has foundational importance for understanding the boundary between classical and quantum theory. It also has practical significance for identifying information processing tasks for which those phenomena provide a quantum advantage. Using the framework of generalized noncontextuality [1] as our notion of classicality, we find one such nonclassical feature within the phenomenology of quantum minimum error state discrimination [2]. Namely, we identify quantitative limits on the success probability for minimum error state discrimination in any experiment described by a noncontextual ontological model. These constraints constitute noncontextuality inequalities [3] that are violated by quantum theory, and this violation implies a quantum advantage for state discrimination relative to noncontextual models. Furthermore, our noncontextuality inequalities are robust to noise and are operationally formulated, so that any experimental violation of the inequalities is a witness of contextuality, independently of the validity of quantum theory. Along the way, we introduce new methods for analyzing noncontextuality scenarios, and demonstrate a tight connection between our minimum error state discrimination scenario and a Bell scenario.

Link to the paper: arxiv.org/pdf/1706.04588.pdf

A key property of a random number generator is that its output should be unpredictable to an outside observer. For random number generators based on classical physics, it is fundamentally difficult to certify whether this property holds. However, the inherent unpredictability of quantum processes suggests that a quantum system can be used for random number generation. Here, we exploit the phenomenon of quantum nonlocality in a photonic loophole-free Bell test experiment similar to that described in [1] to obtain data containing randomness that cannot be predicted by any physical theory that does not also allow the sending of signals faster than the speed of light. To quantify the randomness, we develop an analysis protocol that is robust to potential memory effects and performs well in an experimental regime where the majority of the trials contain no photon pairs. Our analysis is device-independent in the sense that it does not require assumptions that characterize the quantum states being measured. In [2] we reported the extraction of 256 new random bits, uniform to within 0.001 of uniform, which was the first complete extraction of cryptographically secure bits from a fully device-independent system. In this talk I will describe improvements to our system that allow us to extract bits with higher security at a significantly faster rate, and move us closer to being able to integrate our setup into the public NIST Randomness Beacon [3].

FIG. 1. Bell test setup. (a) The locations of the Source (S), Alice (A), and Bob (B). Each trial, the source lab produces a pair of photons in the non-maximally polarization-entangled state $|\psi\rangle \approx 0.982|HH\rangle + 0.191|VV\rangle$, where $H$ ($V$) denotes horizontal (vertical) polarization. One photon is sent to Alice’s lab while the other is sent to Bob’s lab to be measured using fast, polarization switching, Pockels cells. Alice’s outcomes are outside the light cone of Bob’s measurement equipment and vice-versa.

Photons for quantum networks, macroscopic quantum effects, and neuroscience

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I will describe our work towards global quantum networks using quantum repeaters with satellite links, on the demonstration of entanglement between many large atomic ensembles in a solid, and on the possible existence of optical communication channels in the brain.

Global quantum networks with quantum repeaters, satellite links, and non-destructive photonic qubit detection: The first quantum communication satellite was recently launched in China. It is a low-earth orbit satellite carrying a source of entangled photon pairs. I will describe a proposal [1] how such satellites could be used as part of a relatively simple quantum repeater architecture to create entanglement over global distances. A key element of the proposed architecture is the non-destructive detection of photonic qubits, and I will describe a proposal and proof-of-principle experiment [2] for realizing such non-destructive detection with rare-earth ion doped crystals, which is attractive from the point of view of integration with quantum memories.

Entanglement between many large atomic ensembles in a solid [3]: I will describe a recent experiment in which we created a multi-partite entangled state by storing a single photon in a crystal that contained many large atomic ensembles with distinct resonance frequencies. The photon was re-emitted at a well-defined time due to an interference effect analogous to multi-slit diffraction. We derived a lower bound for the number of entangled ensembles based on the contrast of the interference and the single-photon character of the input, and we experimentally demonstrated entanglement between over two hundred ensembles, each containing a billion atoms. These results are the first demonstration of entanglement between many macroscopic systems in a solid.

The possible existence of optical communication channels in the brain [4]: It is well established that neurons can emit photons, which prompts the question whether these biophotons could serve as signals between neurons, in addition to the well-known electro-chemical signals. For such communication to be targeted, the photons would need to travel in waveguides. We showed, based on detailed theoretical modeling, that myelinated axons could serve as photonic waveguides, taking into account realistic optical imperfections, and we proposed experiments to test this hypothesis. Our results also raise the question whether photons could mediate long-range quantum entanglement in the brain.

References
Entangled photon LEDs and their application for quantum relays

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Two parties can share confidential information via quantum cryptography with the secrecy guaranteed by the laws of nature alone [1]. However, preservation of guaranteed secrecy over quantum communication networks poses a challenge, as classical receive-and-resend routing nodes can only be used conditional of trust by the communicating parties [2]. Fully quantum networks can be established by leveraging quantum entanglement to set up non-local correlations between measurements by end users, as employed in quantum relays [3]. Semiconductor quantum-dot based entangled-light sources are emerging as a promising platform for quantum teleportation and relay systems, due to the practical advantages of opto-electronic integration, and the fundamental benefit of emitting no more than a single entangled photon pair simultaneously.

Our first entangled-light-emitting diode (ELED) is based on InAs/GaAs quantum dots emitting at 900nm within a microcavity designed to enhance the light collection efficiency [4]. Based on such ELED we construct a quantum relay over 1 km of optical fiber and recover strong entanglement, with Bell’s parameter of 2.59±0.01, well above the classical limit of 2 [5]. Next, by using advanced growth techniques, we further extend the emission wavelength of the dots and demonstrate a working quantum relay in the telecom 'O' band around 1310 nm [6].

References
Dynamic shear suppression in quantum phase-space: quantum mechanics suppresses Liouvillian shearing, this can be quantified and used to identify special states

Short title:
– Dynamic shear suppression in quantum phase-space –

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(Dated: June 28, 2017)

As evolution time progresses, classical conservative systems stretch out probability distributions in phase space into ever finer structures. Quantum dynamics, instead, creates structures (of Wigner’s phase space distribution $W$) that saturate at Zurek’s phase space area scale $a_Z = \frac{h}{P L}$ [1]. Here, $h$ is Planck’s constant, and length $L$ and momentum $P$ represent the quantum state’s extent in phase-space.

How does quantum mechanics do this?

What is the mechanism that suppresses classical shear and is responsible for the saturation at the size scale $a_Z$ in quantum dynamics?

We investigate the time evolution of $W$ in the quantum Liouville equation

$$\partial_t W + \nabla \cdot J = 0$$

We find that Wigner’s phase space current $J$ [2] can become ‘viscous’ leading to the suppression of classical shear.

Quantum dynamics creates characteristic polarization patterns in phase space which represent quantum shear suppression of classical phase space shear.

When averaged over phase space this local polarization pattern leads to a global phase space polarization measure $\Pi(t)$ which drops over time while the dynamics settles the evolving quantum state towards structure formation at Zurek’s scale.

The measure $\Pi(t)$ reveals interesting aspects of the quantum dynamics. Its values can deviate from the average for settled states: at such deviation points, special quantum states have formed.

$\Pi(t)$ is a sensitive probe for the detection of dynamically created special states, such as revival states [3]. Interestingly, $\Pi(t)$ works without reference to abstract symmetries or reference states.


Control of quantum emitter dynamics near a plasmonic nanostructure

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We investigate theoretically the control of the emission dynamics, beyond the Markov approximation, of a degenerate V-type quantum emitter in the vicinity of a metallic nanostructure, a system that exhibits quantum interference in spontaneous emission due to the anisotropic Purcell effect. We calculate numerically the electromagnetic Green’s tensor and employ the effective modes differential equation method for calculating the quantum dynamics of the emitter population, with respect to the resonance frequency and the initial state of the emitter, its distance from the nanostructure, as well as the pulse excitation process. We find that the emitter population evolution varies between a gradually total decay and a partial decay combined with oscillatory population dynamics, depending strongly on the specific values of the above parameters. Under strong coupling conditions, coherent population trapping can be observed in this system. We compare our exact results with results when the flat continuum approximation for the modified by the metallic nanostructure vacuum is applied. We conclude that the flat continuum approximation is an excellent approximation only when the spectral density of the system under study is characterized by non-overlapping plasmonic resonances. Possible applications related to quantum information technologies are further explored.
A Noiseless Optical Quantum Memory at Room Temperature

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An optical quantum memory (QM) is a device that can store and release optical quantum states on demand. QMs are the key to solving the scalability problem of optical quantum networks which suffer from inherently probabilistic components and gates [1]. The key attributes for QMs for temporal multiplexing include large storage-time-bandwidth product, technical simplicity and noise-free performance. Several of these criteria have been met by realisations of QMs based on optical transitions in atomic systems [2-6], but no single system satisfies all the requirements simultaneously. The main remaining challenge is achieving a noise-free QM for genuine quantum operation.

Here we present a new QM protocol that overcomes this issue: the off-resonant cascaded absorption (ORCA) memory which is noise-free, technically simple and operates at room temperature. It is based on a two-photon ladder transition in a Caesium ensemble. We characterise the memory with weak coherent states, storing GHz-bandwidth pulses with $\eta=15\%$ efficiency and a storage time of $\tau=5.4\text{ns}$. We measure the noise level at the output as low as $8 \times 10^{-6}$ photons per pulse, giving a noise-to-efficiency ratio $\mu_1 \leq (39.4\pm0.2) \times 10^{-6}$, three orders of magnitude better than any memory to date.

We store GHz-bandwidth heralded single photons with an input $g^{(2)}=0.020 \pm 0.005$, and retrieve these photons with $g^{(2)}=0.028 \pm 0.009$ [7], demonstrating that the ORCA memory is inherently noise-free and preserves non-classical statistics. This result is the most significant violation of non-classical statistics of an on-demand memory to date, and represents a significant step towards large-scale photonic quantum technologies.

Fig. 1 (a) ORCA protocol in Cs level structure. (b) Coincidence histogram of storage and retrieval of heralded single photons. The blue (yellow) histogram represents the memory off (on), labelled Input (Output). (c) Log scale with Output and Noise (dark red histogram). The noise is several orders of magnitude below the retrieved signal.