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1 Conference Program

Quantum Communication, Measurement and Computing - Program at a Glance

Venue	Sunday, November 2		Monday, November 3		Tuesday, November 4		Wednesday, November 5		Thursday, November 6	
Hotel	08:00	Bus	08:15	Bus	08:15	Bus	08:15	Bus	08:15	Bus
Institute of Advanced Technology	08:45	Open ceremony	Chair	Nicolas Gisin	Chair	Jian-Wei Pan	Chair	Christophe Salomon	Chair	Reinhard Werner
	Chair	Giacomo M. D'Ariano	09:00	Christophe Salomon	09:00	Reinhard Werner	09:00	Eugene Polzik	09:00	Mikhail Lukin
	09:00	Cheng-Zhi Peng	09:45	Joerg Schmiedmayer	09:45	Nicolas Gisin	09:45	Eleni Diamanti	09:45	Shuai Chen
	09:45	Hoi-Kwong Lo	10:15	Margherita Mazzera	10:30	Coffee break	10:15	Mile Gu	10:15	Geza Toth
	10:15	Julien Laurat	10:35	Coffee break	Chair	Tim Ralph	10:35	Coffee break	10:35	Coffee break
	10:35	Coffee break	Chair	Matthias Troyer	11:00	Ping Xu	Chair	Nicolas Brunner	Chair	Tilman Pfau
	Chair	Mete Atature	11:00	Tim Ralph	11:20	Geoff Pryde	11:00	Chuan-Feng Li	11:00	Tracy Northup
	11:00	Jiang-Feng Du	11:30	Masahide Sasaki	11:40	Hyunseok Jeong	11:30	Tommaso Calarco	11:30	Lars S. Madsen
	11:30	Gerhard Rempe	11:50	Nicolas Gisin	12:00	Jietai Jing	12:00	Giulio Chiribella	11:50	Yongheng Huo
	12:00	Matthias Weidemüller	12:10	Valerio Scarani	12:20	Nathan Killoran	12:20	Hannes Bernien	12:10	Xiaoqi Zhou
	12:30	Lunch break	12:30	Lunch break	12:40	Lunch break	12:40	Lunch break	12:30	Lunch break
	Chair	Jiang-Feng Du	Chair	Masahide Sasaki	14:00	Poster session Size of poster board: 900 mm (Width)* 1200mm (Height)	Chair	Mile Gu	Chair	Shuai Chen
	14:00	Mike Thewalt	14:00	Stephanie Wehner			14:00	Giacomo M. D'Ariano	14:00	Tilman Pfau
	14:30	Fedor Jelezko	14:30	Andrew Doherty			14:30	Nicolas Brunner	14:30	Alexei Ourjoumtsev
	15:00	Tongcang Li	15:00	Norbert Lutkenhaus			15:00	Alex Retzker	14:50	Xiwen Guan
	15:20	Dirk Englund	15:20	Pascale Senellart			15:20	Michael Tobar	15:10	Peter Rabl
	15:40	Coffee break	15:40	Coffee break	15:40	Coffee break	15:40	Coffee break	15:30	Coffee break
	Chair	Fedor Jelezko	Chair	Joerg Schmiedmayer	16:10	Poster session | Parallel events: the meeting of the Steering Committee	Chair	Tommaso Calarco	Chair	Mikhail Lukin
	16:10	Mete Atature	16:10	Matthias Troyer			16:10	Arno Rauschenbeutel	16:00	Lev B. Levitin
	16:40	Michelle Simmons	16:40	Mark Saffman			16:40	Steven Prawer	16:20	Michael Vanner
	17:10	Glenn Solomon	17:10	Xianmin Jin			17:10	Luyan Sun	16:40	Saikat Guha
	17:30	Chih-Hwan Yang	17:30	Austin Lund			17:30	Jaromir Fiurasek	17:00	Wu-Ming Liu
	17:50	Bus	17:50	Bus	17:50	Bus	17:50	Bus	17:40	Bus
Hotel	18:30	Buffet dinner	18:30	Buffet dinner	18:30	Award Banquet Place: 3rd Floor Banquet Hall (三楼宴会厅)	18:30	Buffet dinner	18:20	Buffet dinner
			20:00	Chair: Chao-Yang Lu Evening special session: How to publish in ***Physical Review Letters***, ***Nature***, ***Nature Physics*** and ***Nature Photonics*** Place: 4th Floor Lecture Hall （四楼报告厅）			20:00	Social events: Chinese performance Place: 3rd Floor Banquet Hall （三楼宴会厅）		

Overview talk—45min	Prize talk—45min	Invited talk—30 min	Contributed talk—20min

2 Abstracts of Oral Presentations

09:00-09:45 Nov 2
Invited - **Actuality and Expectation of long distance quantum communication**
Cheng-Zhi Peng
University of Science and Technology of China
Abstract Quantum mechanics, which was established in the early 20th century, is the foundation of modern physics. Based on quantum mechanics, quantum information science was found in later 20th century. To date the quantum key distribution, verification of Bell's inequation, and quantum teleportation have become the frontier of scientific research in the field of quantum information science. Longer distance is always a significant goal of quantum communication, and also one of the strategic directions of quantum information science. Due to the absolute safety of quantum communication, getting longer and longer distance will eventually achieve a global wide-area quantum communication network which is very useful for information security. Besides, we can also perform some fundamental physics experiments such as testing the quantum mechanics at space scale. This report will summarize the research situations and future expectations of long-distance quantum communication at Excellence Center for Quantum Information and Quantum Physics of CAS.

09:45-10:15 Nov 2
Invited - **Foiling quantum hackers**
Hoi-Kwong Lo
Univ. Toronto
There is a big gap between the theory and practice of QKD. In principle, quantum key distribution (QKD) offers information-theoretic security. In practice, quantum hacking has allowed an eavesdropper, Eve to break the security of practical QKD systems by exploiting real-life imperfections. In this talk, we review recent practical methods to foil quantum hackers and re-establish the connection between the theory and practice of QKD. These include measurement-device-independent quantum key distribution (MDI-QKD) and loss-tolerant QKD. In particular, I will discuss about my group's recent experimental implementation of loss-tolerant QKD which, for the first time, takes state modulation flaws in QKD into account. References: 1) H.-K. Lo, M. Curty and B. Qi, Phys. Rev. Lett. 108, 130503 (2012); 2) Z. Tang, Z. Liao, F. Xu, B. Qi, L. Qian, and H.-K. Lo, Phys. Rev. Lett. 112, 190503 (2014); 3) K. Tamaki, M. Curty, G. Kato, H.-K. Lo, and K. Azuma, http://arxiv.org/abs/1312.3514 4) F. Xu, S. Sajeed, S. Kaiser, Z. Tang, L. Qian V. Makarov, H.-K. Lo http://arxiv.org/abs/1408.3667

10:15-10:35 Nov 2
Long-distance quantum networking based on optical hybrid resources
Julien Laurat
Laboratoire Kastler Brossel, UPMC, Ecole Normale Supéprieure
The optical hybrid approach of quantum information, which consists of mixing in a protocol both discrete and continuous degrees of freedom, has recently seen important developments. In this talk, I will illustrate how this approach can be used for long-distance quantum networks. After an overview of the hybrid framework, including a repeater architecture, I will first detail a protocol based on local homodyne measurements for witnessing single-photon entanglement. Robustness up to 80 km of fiber has been demonstrated, confirming its relevance as an operational test for networks relying on such entanglement. The second example will be the remote generation of hybrid entanglement, i.e. entanglement between particle-like and wave-like qubits located at distant places. Such entanglement enables to convert information from one space to the other via teleportation and therefore connect remote processors based upon different encodings. Beyond its fundamental significance for the exploration of entanglement and its possible instantiations, the realized circuit opens the promises for heterogeneous networks, where discrete and continuous-variable operations can be efficiently combined.

11:00-11:30 Nov 2
Invited - **Quantum control of electron / nuclear spins in solids**
Jiang-Feng Du
University of Science and Technology of China
The science of quantum control is at the heart of modern physics. Various applications of quantum control have emerged and we witness great development in recent years, such as quantum computation, quantum simulation, and quantum metrology, etc. Spins of electrons and nuclei are among the most promising physical systems that can perform reliable and robust quantum control. They have a major advantage since they protect quantum coherence very efficiently against outside noise, which represents the main challenge to the large-scale implementation of quantum control. My presentation will mainly focus

on our recent experimental study of quantum control over electron / nuclear spins in solids. We concern on several respects such as decoherence suppressing with dynamical decoupling, precise spin control, efficient realization of quantum algorithms and simulation, and ultrasensitive sensing with single spins in diamond.

11:30-12:00 Nov 2

Invited - **Single-Photon Rydberg Switches and Transistors**

Gerhard Rempe
MPQ

Modern information processing employs electronic devices on short distances and photonic devices on long distances. Efficient interfaces are rare, so that all-optical information processing is appealing. Classical light switches and transistors have been studied decades ago, but only for high intensities owing to the small optical nonlinearities which were available. We now perform experiments in the quantum regime by exploiting the giant optical nonlinearity provided by the Rydberg blockade mechanism. Specifically, an incoming gate photon is stored as a Rydberg excitation in an ultracold atomic gas using electromagnetically induced transparency. Blockade then suppresses the transmission of a subsequent target pulse. The stored gate photon can be retrieved afterwards, signaling successful storage with an extinction factor of 20 for the target light [1]. Recent improvements made it possible to observe gain of 20, thus realizing a single-photon transistor [2]. Such device offers interesting perspectives in quantum communication and quantum information processing. [1] S. Baur, D. Tiarks, G. Rempe, and S. Dürr, Phys. Rev. Lett. 112, 073901 (2014). [2] D. Tiarks, S. Baur, K. Schneider, S. Dürr, and G. Rempe, Phys. Rev. Lett. 113, 053602 (2014).

12:00-12:30 Nov 2

Invited - **Simulating dipolar energy transport with giant atoms**

Matthias Weidemüller
Univ. Heidelberg

Energy transport is an important theme in natural processes, e.g., chemical reactions and photosynthesis. There is ongoing debate on how the environment influences the efficiency of energy transfer in these systems and to which extent quantum mechanics plays a role. By interfacing electronically highly excited (Rydberg) atoms with laser light we simulate energy transfer dynamics in a controlled many-body system. In particular, Rydberg atoms experience quantum state changing interactions similar to Fürster processes in complex molecules, offering a model system to study the nature of dipole-mediated energy transport. The extension to multiple interacting excitations could enable elementary realisations of quantum spin models involving strong and long-range spin-dependent interactions. We report on a new imaging method, which we apply to monitor the migration of electronic excitations with high time and spatial resolution using a background atomic gas as an amplifier. Through precise control of interactions and the coupling to the environment via the laser fields, we find different mechanisms at work which shed new light on the nature of energy and spin transport in complex quantum systems.

14:00-14:30 Nov 2

Invited - **Highly enriched ^{28}Si - a 'semiconductor vacuum'**

Mike Thewalt
Simon Fraser Univ.

Kane's 1998 proposal to use the nuclear and electronic spins of donor impurities in Si as qubits led to widespread efforts to realize a scalable quantum information technology benefitting from the highly-developed Si materials science and nanofabrication capabilities, and long coherence times due to the possibility of a nuclear-spin-free host material. Even in natural Si, less than 5% of the host atoms have nonzero nuclear spin (^{29}Si with I=1/2). Si can be enriched to over 99.995% of the spin-free isotope ^{28}Si, resulting in large increases in the coherence times of superposition states of both the electron and nuclear spins, as measured by conventional ESR and ENDOR methods, as well as recent measurements on single 31P donors. However, highly enriched ^{28}Si has another unique property - the almost complete elimination of inhomogeneous broadening for a wide variety of optical transitions. The dominance of inhomogeneous broadening is an almost universal aspect of solid-state spectroscopy, and its near-elimination in ^{28}Si has led to this system being described as a 'semiconductor vacuum'. The ability to resolve the hyperfine splittings of donor bound exciton transitions in the near-infrared has led to new optical methods for measuring and preparing donor electronic and nuclear spins, resulting in the measurement of remarkable coherence times at both cryogenic and room temperatures.

14:30-15:00 Nov 2

Invited - **Qubits in diamond for sensing at nanoscale**

Fedor Jelezko
Institute of quantum optics, Ulm University
Recently, atom-like impurities in diamond (colour centers) have emerged as an exceptional system for quantum physics in solid state. In this talk I will discuss recent developments transforming quantum control tools into quantum technologies based on single colour centers. New applications of diamond qubits involving nanoscale magnetic resonance and force measurements will be shown. I will discuss single nanoscale NMR paving the way to ultrasensitive MRI and structure determination of single biomolecules. I will also report a combination of quantum error correction and sensing protocols.

15:00-15:20 Nov 2

Quantum spin-optomechanics of levitated nanodiamonds

Tongcang Li
Purdue University
Creating large Schrödinger's cat states with massive objects is one of the most challenging goals in quantum mechanics. We have previously achieved an important step of this goal by cooling the center-of-mass motion of a levitated microsphere from room temperature to millikelvin temperatures with feedback cooling. To generate spatial quantum superposition states with an optical cavity, however, requires a very strong quadratic coupling that is difficult to achieve. Here we propose to optically trap a nano-diamond with a nitrogen-vacancy (NV) center in vacuum, and generate large spatial superposition states and arbitrary phonon Fock states using the NV spin-optomechanical coupling with the assistance of a strong magnetic field gradient. The large spatial superposition states can be used to study objective collapse theories of quantum mechanics, which propose that the Schrödinger equation is only an approximate theory that breaks down when objects above a critical mass are delocalized over a critical distance [Rev. Mod. Phys. 85, 471 (2013)]. This system will also be great for force sensing because a levitated nanoparticle in vacuum have an ultrahigh mechanical quality factor.

15:20-15:40 Nov 2

Spin-Photon Interfaces Based on Spatially Targeted Nitrogen Vacancy Centers in Diamond Photonic Crystal Nanocavities

Dirk Englund
Massachusetts Institute of Technology
The nitrogen vacancy (NV) center in diamond has emerged as a promising, long-lived optically addressable solid-state qubit that could enable scalable quantum networks. A key challenge for rapid quantum entanglement over long distances requires a large flux of indistinguishable photons. This is particularly demanding for NV centers, as only about 3% of their emission is by the zero-phonon line (ZPL). We discuss NV coupling to photonic crystal nanocavities in single-crystal diamond with a sub-wavelength-cubed mode volume and quality factors as high as 10,000. NV centers are implanted with sub-wavelength resolution into the cavity field maximum. The spontaneous emission rate of the NV zero phonon line is enhanced by more than 50 times, and the ground state exhibits long spin coherence times. The integration of such cavities into scalable on-chip optical networks will be discussed.

16:10-16:40 Nov 2

Invited - **Quantum Optics with Solid-State Spins and Photons**

Mete Atature
University of Cambridge
Spins confined in solids, such as quantum dots and atomic impurities provide interesting and rich physical systems. Their inherently mesoscopic nature leads to a multitude of interesting interaction mechanisms of confined spins with the solid state environment of spins, charges, vibrations and light. Implementing a high level of control on these constituents and their interactions with each other creates exciting opportunities for realizing stationary and flying qubits within the context of spin-based quantum information science. I will provide a snapshot of the progress and challenges for optically interconnected spins, as well as first steps towards hybrid distributed quantum networks.

16:40-17:10 Nov 2

Invited - **Quantum Computing in Silicon with Donor Electron Spins**

Michelle Simmons
University New South Wales
Extremely long electron and nuclear spin coherence times have recently been demonstrated in isotopically pure ^{28}Si making silicon one of the most promising semiconductor materials for spin based quantum information. The two level spin state of single electrons bound to shallow phosphorus donors in silicon in particular provide well defined, reproducible qubits and represent a promising system for a scalable quantum computer in silicon. An important challenge in these systems is the realisation of an architecture, where we can position donors within a crystalline environment with 20-50nm separation, individually address each donor, manipulate the electron spins using ESR

techniques and read-out their spin states. We have developed a unique fabrication strategy for a scalable quantum computer in silicon using scanning tunneling microscope hydrogen lithography to precisely position individual P donors in a Si crystal aligned with nanoscale precision to local control gates necessary to initialize, manipulate, and read-out the spin states. During this talk I will focus on demonstrating electronic transport characteristics and single-shot spin read-out of precisely-positioned P donors in Si. Additionally I will report on our recent progress in performing a two qubit gate and initial characterization of transport devices with two and three single donors. The challenges of scaling up to practical 2D architectures will also be discussed.

17:10-17:30 Nov 2

Temporal variations in the nonclassical light properties from a single quantum-dot state

Glenn Solomon

Joint Quantum Institute, NIST and University of Maryland

We demonstrate time-resolved second-order correlation measurements (g(2)) of the photons emitted from a single exciton in an InAs quantum dot [1]. This measurement shows the dynamics of a nonclassical optical field, quantifying single-photon purity and coherence as a function of when in the excitation-decay cycle of the QD a photon is detected. For example, in above-band pumping, we observe that photons detected early with respect to the optical pump have reduced single-photon purity and coherence compared to those detected later. In typical g(2) measurements, a time invariant emission process is assumed, where the optical field properties depend only on the time difference of the two photon detections. However, in solid-state systems with non-resonant pumping and environmental coupling, the single photon statistics often depend not only on the time difference between detection events, but on when these events occur. The dynamical g(2) technique is important in characterizing the optical field, and can be used in determining the optimum gating of emitting photons for maximum single photon purity and coherence. [1] E. B. Flagg, et al., Phys. Rev. Lett. 109, 163601 (2012).

17:30-17:50 Nov 2

An addressable quantum dot qubit with fault-tolerant control fidelity

Chih-Hwan Henry Yang

The University of New South Wales

Exciting progress towards spin-based quantum computing has recently been made with qubits realized using nitrogen-vacancy centers in diamond and phosphorus atoms in silicon. While single-atom nanotechnologies have demonstrated long coherence times made possible by the presence of spin-free isotopes of carbon and silicon, lithographically defined quantum dots have an exchange coupling that can be precisely engineered. Here we combine the best aspects of both spin qubit schemes and demonstrate a gate-addressable quantum dot qubit in isotopically engineered silicon with a control fidelity of 99.6%, obtained via Clifford based randomized benchmarking and consistent with that required for fault-tolerant quantum computing. This qubit has orders of magnitude improved coherence times compared with other quantum dot qubits, with $T2^* = 120$ μs and $T2 = 28$ ms. By gate-voltage tuning of the electron g-factor, we can Stark shift the electron spin resonance (ESR) frequency by more than 3000 times the 2.4 kHz ESR linewidth, providing a direct path to large-scale arrays of addressable high-fidelity qubits that are compatible with existing manufacturing technologies.

09:00-09:45 Nov 3

Invited - **Quantum Simulation with Ultracold Gases**

Christophe Salomon

Laboratoire Kastler Brossel

In recent years, ultra-cold atoms have established a very fruitful connection with condensed matter physics, nuclear physics, and astrophysics. Thanks to the tunability of the atomic interactions offered by magnetic Feshbach resonances, Bose and Fermi gases can be brought to the strongly correlated regime and simulate outstanding problems in quantum many-body physics. In this talk, we will present recent studies on the thermodynamic equation of state (EoS) of Fermi gases. Expressing the EoS in the grand canonical ensemble enables a very simple connection with experimental quantities such as the in-trap position distribution. Precision measurements of the Equation of State of a tunable Fermi gas in the crossover between Bose-Einstein condensation of strongly bound pairs and traditional Cooper pairing for weak attractive interactions reveal several properties of the gas such as the superfluid phase transition, the Lee-Yang and Lee-Huang-Yang (LHY) beyond mean field effects or the properties of Fermi polarons. Quantitative comparisons with advanced many-body theories developed for a uniform gas can now be made at the few percent level. Next, using lithium 7 and lithium 6 isotopes, we will report on the production of a novel mixture of Bose and Fermi superfluids. We probe the collective dynamics of this system by exciting center-of-mass oscillations that exhibit extremely low damping below a certain critical velocity. Using high precision spectroscopy of these low-lying modes we observe coherent energy exchange and measure the coupling between the two superfluids. Our observations can be captured theoretically using a sum-rule approach that we interpret in terms of two coupled oscillators.

09:45-10:15 Nov 3
Invited - **Interferometry with Trapped Atoms**
Joerg Schmiedmayer
Vienna Univ. Tech.

We present two types of interferometer sequences for trapped Bose-Einstein Condensate: A Mach-Zehnder interferometer created be splitting into a double well and then recombining and a Ramsey interferometer by employing the first excited trap state. We have development of atom-optics analogy to beam splitters, phase shifters, and recombiners for trapped atoms. Integrating these elements into a single device we demonstrate a full Mach-Zehnder sequence with trapped Bose-Einstein condensates (BECs) confined on an atom chip. We exploit the non linearity coming from the atom-atom interaction to generate a non-classical state having reduced number fluctuations inside the interferometer and demonstrate coherence times a factor of three beyond what is expected for coherent states, highlighting the potential of entanglement as a resource for metrology. The Ramsey interferometer is usually implemented using internal states of atoms, molecules or ions. In a second set of experiments we demonstrate a two-pulse Ramsey-type interferometer for non-classical motional states of a Bose-Einstein condensate on an atom chip. The control sequences used to manipulate the condensate wave function are obtained from optimal control theory and are directly optimised to maximise the interferometric contrast. They permit a fast manipulation of the atomic ensemble compared to the intrinsic decay processes and many-body de-phasing effects. This allows us to reach an interferometric contrast of 92 % in the experimental implementation.

10:15-10:35 Nov 3
Coherent storage and on demand read-out of time-bin qubits in a spin wave solid state optical memory
Margherita Mazzera
ICFO-The Institute of Photonic Sciences

Rare-earth doped crystals are good candidates as quantum memories as they offer coherence times comparable to the atomic systems, but free of atomic motion. The research has been so far mostly focused on the mapping of photonic qubits to optical atomic excitations. This leads to short lived and/or predetermined storage times. We report the first demonstration of single photon level (SPL) qubit storage with on demand read out in a spin wave solid state optical memory. We use the full atomic frequency comb scheme in a Pr:YSO crystal. The spin wave storage (SWS) requires the transfer of optical excitations to spin excitations using strong control pulses. The main experimental challenge to implement SWS with SPL light is to suppress the technical noise created by the strong control pulses, especially in Pr:YSO where the splitting of the ground states is very small. Using spatial, temporal and narrowband frequency filtering, we achieve a SNR>10 for SPL inputs. Furthermore we demonstrate the coherent storage and on demand read-out of time bin qubits containing less than one photon per pulse with fidelities of around 85%. These results open the door to the SWS of quantum states of light.

11:00-11:30 Nov 3
Invited - **Enhancing Optical Quantum Channels**
Tim Ralph
Univ. Queensland

I will discuss various methods via which the transmission characteristics of optical quantum channels can be enhanced. These methods will range from simple post-selection protocols through to quantum repeaters. In the most general cases the channel is improved with respect to the transmission of arbitrary quantum states - i.e. the quantum information encoding protocol; discrete, continuous or hybrid, is unrestricted. I will present both theoretical and experimental results.

11:30-11:50 Nov 3
Quantum photonic network in Tokyo
Masahide Sasaki
National Institute of Information and Communications Technology

Quantum photonic network is an emerging platform to realize provably secure communications in efficient ways, approaching the optimal rate in secure bits/s/Hz/photon. The basic concept is to integrate QKD for the highest security, quantum communication for power-minimum maximum-capacity communications, and a new scheme of physical layer cryptography which merges the merits of these two to realize the secrecy capacity with the provable security into a network, so that the whole network can provide best solutions for various kinds of use cases. We first present the updated Tokyo QKD Network, consisting of GHz-clocked BB84 systems, continuous variable QKD systems, differential phase-shift-keying QKD system, and fiber-space hybrid entanglement link. Smart key management systems support variety of applications such as secure network switches, cipher systems, and secure smart phones. We then present free space quantum communication testbed, which pursues high capacity links in space with adaptive secure coding. Our challenges include an 8km inter-building laser link and satellite-ground links with SOCRATES which was launched in May 2014, and is now on the low earth orbit.

11:50-12:10 Nov 3
Experimental heralded amplification of time-bin qubits
Nicolas Gisin
University of Geneva
Quantum Communication (QC) protocols are based on qubits encoded on photons at telecommunication wavelengths, due to the high transmission efficiency in single mode optical fibres. However, above a certain distance, losses start to become significant also for telecom light. Protocols based on Device Independent Quantum Key Distribution (DIQKD) require a means to overcome transmission losses of quantum channels, in order to observe the violation of a Bell inequality free from the detection loophole. This task has been shown to be well performed by heralded qubit amplifiers. We present the realisation and characterisation of a heralded amplifier of time-bin qubits at telecom wavelengths. The setup is low-loss fibre based, allowing one to build a plug and play device with a fixed gain, suitable for DIQKD and other quantum communication technologies. Our source of pure photons and the simplicity of the fibre-based approach allow the realisation of a realistic scheme of QC, in which a time-bin qubit is sent through a lossy channel and then amplified in a probabilistic way with the aid of highly indistinguishable ancillary photons and efficient detectors.

12:10-12:30 Nov 3
Robust and versatile black-box certification of quantum devices
Valerio Scarani
Centre for Quantum Technologies, National University of Singapore
Device-independent certification has been studied for specific tasks: QKD, randomness, many-particle genuine entanglement. But one can be more ambitious and certify the state and the measurements that are being used (up to local isometries). Some perfect-case examples are known: CHSH=$2\sqrt{2}$ is only possible if the state is effectively a two-qubit singlet and the measurements on both sides are maximally complementary. Mayers and Yao reached the same conclusion with different statistics. Recent works have derived "robust" bounds that tolerate minor deviations from the ideal case (typically 10^{-5} and that are applicable only to CHSH or a few other examples. Our "swap" method, based on the NPA semi-definite relaxation of the quantum set, achieves a much higher robustness, well within experimentally observed values. Moreover, the recipe can be applied widely. Among the examples we studied are (i) the maximal violation of CGLMP certifies indeed a non-maximally entangled state of 2 qutrits; (ii) the certification of the three-qubits W state and its measurements.

14:00-14:30 Nov 3
Invited - **TBA**
Stephanie Wehner
TU Delft
TBA

14:30-15:00 Nov 3
Invited - **Real-time Estimation and Control for Spin Qubits**
Andrew Doherty
University of Sydney
Spin qubits, such as gate-defined quantum dots in GaAs, are a very promising experimental system for quantum information processing. In this system many theoretical ideas for quantum control can already be implemented in practice. For example, a lot of theoretical work has been done on various approaches to Hamiltonian parameter estimation in which one attempts to determine parameters of the Hamiltonian efficiently in terms of either the total time evolution required or the number of measurements that must be performed. I will describe an implementation of one approach to Hamiltonian parameter estimation for single qubits that is able to determine and compensate for the fluctuations of the magnetic field gradient between two quantum dots. Improvements of the qubit coherence time by a factor of 30 have been demonstrated in the laboratory. The approach is optimised for the fact that single-shot measurements of the qubit state, rather than the time taken for Hamiltonian evolution, dominate the time required for the estimation

procedure. It is possible to monitor slow fluctuations of the magnetic field gradient in this way and thereby probe the dynamics of the average magnetic field due to fluctuating nuclear spins. This work is in collaboration with M. D. Shulman, S. P. Harvey, J. M. Nichol, S. D. Bartlett, V. Umansky and A. Yacoby.

15:00-15:20 Nov 3

Could Gaussian regenerative stations act as quantum repeaters?

Norbert Lutkenhaus
University of Waterloo/ Institute for Quantum Computing

Authors: Ryo Namiki, Oleg Gittsovich, Saikat Guha, Norbert Lutkenhaus Higher transmission loss diminishes the performance of optical communication, be it the rate at which classical or quantum data can be sent reliably, or the secure key generation rate of quantum key distribution (QKD). Loss compounds with distance, exponentially in an optical fiber, and inverse-square with distance for a free-space channel. In order to boost communication rates over long distances, it is customary to introduce regenerative relays at intermediate points along the channel. It is therefore natural to speculate whether untended regenerative stations, such as phase-insensitive or phase-sensitive optical amplifiers, could serve as repeaters for long-distance QKD. The primary result of this paper is to rule out all Gaussian regenerative stations to be useful as QKD repeaters, which include phase-insensitive and phase-sensitive amplifiers as special cases, for any QKD protocol. We also delineate the conditions under which a Gaussian relay renders a lossy channel entanglement breaking, which in turn makes the channel useless for QKD.

15:20-15:40 Nov 3

Toward a quantum network based on semiconductor quantum dots

Pascale Senellart
CNRS- Laboratory for photonics and nanostructures

Cavity quantum electrodynamics is an efficient tool to implement a solid state quantum network based on semiconductor quantum dots (QDs). We control the spontaneous emission of a single QD through a deterministic coupling to a micropillar cavity. By engineering the Purcell effect, we fabricate ultrabright single photon sources where 0.79 photons are collected per pulse. The photons are also shown to have a high degree of indistinguishability, up to 92% . The potential of the sources is shown by demonstrating an entangling C-NOT gate . We also show that the Purcell effect enhances the indistinguishability of photons emitted by two remote QD sources. Symmetrically, reflectivity measurements on a QD-pillar device show an optical non-linearity with a threshold of only 8 incident photons. When inserting a single spin in the QD, the polarization of a photon sent on the device can also be rotated by $\pm 6^{\circ}$ depending on the single spin state. Finally, we have developped a novel photonic structure and a technology allowing the electrical control of the devices, a critical step for the scalability of a quantum network based on QDs.

16:10-16:40 Nov 3

Invited - **From analog to gate based quantum devices**

Matthias Troyer
ETH Zurich

The development of quantum devices follows similar paths as the history of classical computing devices. Like in classical computing, analog devices have been the first since they are easier to design and build. These range from simple devices like quantum random number generators and quantum key distribution systems to more complex many-body quantum devices such as quantum simulators using various hardware platforms (including ultracold atoms in optical lattices, ion traps, or superconducting qubits), and quantum optimizers (such as the D-Wave devices) have been the first devices built. Exploring, testing and validating these devices we find that while they work they are subject to the same limitations regarding calibration, scaling and flexibility as analog classical devices. I will show specific examples from validating quantum random number generators, quantum simulators and the D-Wave devices. "Digital" gate-model based quantum devices will be needed to overcome many of these limitations but - as for classical computers - take longer to develop. However, even for fast universal quantum computer it will be challenging to find real world applications where they outperform classical super computers. I will summarize what are in my view the currently most promising application areas and finish with a number of open questions.

16:40-17:10 Nov 3

Invited - **Towards scalable quantum computing with cold atoms and Rydberg blockade**

Mark Saffman
Univ. Wisconsin

We are exploring several different approaches towards scalable quantum computing based on neutral atom qubits with long range Rydberg blockade. Rydberg interactions can be used to entangle single atom qubits, to entangle ensemble qubits, and to establish hybrid entanglement between atomic and other qubits. Using a 2D array of atomic qubits we demonstrate high fidelity single qubit control together with entanglement of nearby qubits. The ratio of qubit coherence time to entangling gate time exceeds 1000. Progress towards hybrid atom-superconductor entanglement via a microwave mediated controlled phase gate will also be presented. Work supported by the NSF, AFOSR, ARL, IARPA, and Wisconsin Alumni Research Foundation.

17:10-17:30 Nov 3

Low-loss integrated photonic network for Boson sampling in large scale

Xianmin Jin
Shanghai Jiao Tong University

Boson sampling is one of quantum algorithms targeting to solve a specific problem. It can sample the output distribution resulting from multiphoton interference in a multimode interference device, which is a problem thought to be exponentially hard with classical computer even with known unitary operation matrix. A quantum Boson sampling machine will be able to beat the most powerful classical computer when operated number of photons and modes goes up to a few tens level. To achieve the require scale, it is crucial to develop a desirable device which must have very low loss, large number of modes and random inter-mode coupling. Here we present an all-fibre integrated coupler as a promising candidate. It has 15 input and output modes and can be scaled up to hundreds of modes by improving fabrication process. The intermode coupling is naturally random with asymmetric unitary operation matrix, therefore ensure Boson sampling realised inside nontrivial. Most importantly, such a large-scale device have a total loss as low as 1 dB, which is about one order lower than traditional silica chip. Our results may pave the way to implementation of large-scale quantum Boson sampling in the future.

17:30-17:50 Nov 3

Boson Sampling with Gaussian states

Austin Lund
University of Queensland

Boson Sampling is the problem of producing a sample from the distribution of photon detections from the output of a m-mode linear optical network when using n single photons as the input. This relatively straightforward situation was shown by Aaronson and Arkipov to not be efficiently computable by a classical computer. Here, we present two theoretical results of the Boson Sampling problem using Gaussian states as inputs. First, we show that a modified version of the Boson Sampling problem with two-mode squeezed states input into double the number of modes, where the extra modes are used to herald single photons, will also be a hard problem for a classical algorithm. Secondly, we show that if the linear optical network has an input of m thermal states, then the probability of obtaining particular Fock state detections is the matrix permanent of a positive definite matrix. We show that for the case of thermal state inputs, an efficient sampling algorithm exists based on the realisation of thermal states by a distribution over coherent states. Hence estimating the matrix permanent for positive definite matrices must lie within the polynomial hierarchy of complexity classes.

20:00-20:35 Nov 3

Invited - **Secrets of PRL**

Robert Garisto
Physical Review Letters

This will be a view inside of Physical Review Letters (PRL). I will describe how the review process works and how things have changed since we reaffirmed standards a year ago. I will also present some illuminating statistics and talk about journal metrics. If there is time, I will discuss how we pick our highlighted papers and give you some advice on how to succeed with your PRL submissions.

20:35-21:00 Nov 3. This is only the talk time.

Invited - **Nature and the changing landscape of scientific publishing**

Leonie Mueck
Nature

Ever since its launch in 1869, the multidisciplinary journal Nature has striven to publish the best science from around the world providing a communication platform for scientists to discuss and disseminate the latest results. I will explain the steps that a research paper takes from submission to publication with the aim to demystify the editorial process at Nature. This includes the pre-selection of papers by editors, the peer-review process and policy issues surrounding publishing. Additionally, I will focus on the trend towards more transparency in the dissemination of scientific results, which Nature and its sister journals embrace in several ways. This ranges from new possibilities to publish raw data to our initiative to enhance reproducibility in the life sciences. Although physics has not been shaken by as wide-ranging a reproducibility debate as biology, these trends offer many opportunities for physicists as well.

21:00-21:20 Nov 3. This is only the talk time.

Invited - **Impact or impact factor - choosing the right journal**

Iulia Georgescu
Nature Physics

Surely most people would agree that impact and impact factor are not equivalent, however very few authors take that at heart. The impact of research is hard to define and quantify, whereas the impact factor of a journal is a simple-to-calculate number. Despite the fact that impact factor is not a good measure for the 'worth' of a research paper, or for that matter a reliable means of evaluating researchers, the simplicity of relating to a number, inevitably gives impact factor a weight it does not deserve. At least in theory, we publish to be read by many of our peers, to communicate our results. High-visibility publications have a large and varied readership, but some communities focus on their favourite journals and may well miss a paper published in a top journal. So the question is where to publish to be read by many and by those who matter in your field? The quantum information community is inherently multi-disciplinary so it is blessed with a very wide choice of research outputs, but this makes it hard to choose the right journal to publish in. I argue that researchers need to carefully consider the nature of the results and the audience they wish to target before choosing a journal and submitting their research. Such thoughtful planning increases the chances of being published in an influential journal, enhances the quality of the paper and its value for the community, and reduces the time from submission to publication. In the NPG family there are several journals that publish quantum information and I will be talking about the difference between these publications and provide some guidelines to assessing which one is the most suitable for a particular type of research results. I will also be talking about the importance of writing meaningful titles and abstracts tailored for the specific readership of the journal rather than generic ones.

21:20-21:40 Nov 3. This is only the talk time.

Invited - **General criteria for publication in Nature Photonics**

Noriaki Horiuchi
Nature Photonics

The journal of Nature Photonics is specialized in research relevant to optical technique, opto-electronic device, fundamental study of light. Given the high number of published papers in Nature Photonics, the studies on quantum information, quantum communication and quantum metrology are very competitive with respect to other research fields of photonics. Studies making excellent use of state-of-the-art quantum technologies often excite scientists of photonics community, because they bring a new insight of physics or a novel device which would potentially make some real significant progress to other research fields. That's what Nature Photonics is looking for. In this talk, I will explain the general criteria for getting published in Nature Photonics.

21:40-22:00 Nov 3

Question time for the three invited talks on how to publish in Nature family

09:00-09:45 Nov 4

Invited - **Uncertainty relations**

Reinhard Werner
Leibniz Universität Hannover

Uncertainty relations are basic textbook material for every quantum mechanics course. To many this would appear to be a closed case if there ever was one. I will argue that the certainty about the topic which we carry from our student days is misleading, and prevents a fresh understanding of the subject. I will go back to the basics: The question what physical idea is to expressed by such relations, coming up with two conceptually different issues, which I call measurement and preparation uncertainty. I will then describe some mathematical techniques for getting explicit bounds, and exemplify this with the standard position-momentum case and new results on angular momentum uncertainty.

09:45-10:30 Nov 4

Invited - **TBA**

Nicolas Gisin
University of Geneva

TBA

11:00-11:20 Nov 4

Reconfigurable lithium niobate circutis for on-chip generation and manipulation of entangled photons

Ping Xu
Nanjing University

Photonic chips have been developed for the practical implementation of high-performance quantum information processing. However, strategic effort should still be devoted to developing the photonic chip's characteristics of low energy cost, high-efficiency internal photon sources, and fast and convenient phase modulation for enabling multiple high-fidelity quantum operations on a single chip. Lithium niobate (LN) belongs to one of the valuable substrate materials, owing to strong $\chi(2)$ nonlinearity, large piezoelectric, acousto-optic and electro-optic coefficients features, as well as the well-developed waveguide fabrication technique using either proton-exchange or titanium-indiffusion method. In this talk, we will present the on-chip generation and manipulation of entangled photons based on the LN circuits. The enhanced integration complexity of quantum chip will enable LN qualified for more complex quantum tasks, like peculiar quantum light sources, quantum walk, quantum algorithm etc..

11:20-11:40 Nov 4

Overcoming loss and verifying entanglement in remote entanglement sharing

Geoff Pryde
Griffith University

Photons are excellent for sharing entanglement between remote parties. For practical use, one must overcome the effects of loss and robustly verify entanglement in network scenarios. We experimentally demonstrated how noiseless-amplification techniques can be used to improve the transmission of a quantum channel, for dual-rail and single-rail qubits. Together with teleportation or entanglement sharing, which we also demonstrated, the channel can be used to transmit information or share correlations. Entangled measurements play a critical role in generating and using remote shared entanglement. We experimentally demonstrated a purely statistical approach to verifying entangled measurements in a semi-device-independent framework. Our technique is independent of imperfections in the state preparations and of the physical mechanism of the measurement. EPRS provides a method to verify remote entanglement between two parties, even in the presence of substantial loss, when one is trusted. We experimentally demonstrated a refereed quantum game which allows EPRS to be conducted without trust in either party or their apparatus, making the technique device-independent.

11:40-12:00 Nov 4

Entangling quantum and classical states of light

Hyunseok Jeong
Seoul National University

Entanglement between quantum and classical objects is of particular interest in fundamental studies of quantum theory and potential applications to quantum information technologies. In quantum optics, single photons are treated as light quanta while coherent states are considered as the most classical states among all pure states. Recently, entanglement between a single photon and a coherent state in a free-traveling field was identified to be a useful resource for quantum information processing that enables one to perform deterministic teleportation and gate operations. However, it was pointed out to be extremely difficult to generate such states since it requires a clean cross-Kerr nonlinearity. In this study, we devise and experimentally demonstrate a scheme to generate such hybrid entanglement by implementing a coherent superposition of two distinct quantum operations. The generated states clearly show entanglement between the two different types of states. Our work paves the way to generate hybrid entanglement of a larger size and to develop efficient quantum information processing using a new type of qubit. Reference [1] H. Jeong et al., Nature Photonics 8, 564 (2014).

12:00-12:20 Nov 4

Experimental generation of multiple quantum correlated beams from cascaded four-wave mixing processes

Jietai Jing
East China Normal University

Multipartite entanglement and correlations are important for both fundamental scientific significance and potential applications in quantum information. Here we report our experimental study of a scalable technique to create and measure quantum correlations among multiple beams produced by cascaded FWM processes in hot rubidium vapor. We have experimentally shown that quantum squeezing exists between the three beams but not between any two of them. Compared with the degree of intensity difference squeezing of the twin beams obtained with a single cell, the degree of intensity-difference squeezing of the triple beams has been enhanced from -5.5 /-4.5 dB to -7.0 dB. In this sense, our method for generating multimode quantum states offers significant advantages over other methods since the quantum correlations increase as the number of quantum modes increases. Furthermore, the phase insensitive nature of our system makes it possible to extend the configuration to a large number of beams, as it avoids the phase locking required by linear beam-splitting method. Reference: Z. Qin, L. Cao, H. Wang, A. M. Marino, W. Zhang and J. Jing*, Phys. Rev. Letts, 113, 023602 (2014)

12:20-12:40 Nov 4

Identical particles: an accessible source of entanglement

Nathan Killoran
Ulm University

One of the fundamental rules of quantum physics is that nature does not distinguish particles of the same type. Accordingly, the physical states of identical particles must always be (anti)symmetric with respect to the constituent particles. Because of this, nearly all identical particle systems appear to be highly entangled. However, the same principle responsible for this entanglement also fundamentally restricts its access, since we can never address the entangled subsystems. Hence, such entanglement is often viewed as a mathematical artifact, with no value for standard quantum information tasks. In this talk, we demonstrate that despite the fundamental limitations, such entanglement can nonetheless still be used as a resource for any standard task. We present a protocol which fully and faithfully extracts entanglement from inaccessible identical particles onto accessible modes using only elementary operations. This settles the long debate about the resource character of such entanglement, in particular for spin-squeezed states in Bose-Einstein condensates. As a bonus, our results offer fresh perspectives on the mechanisms for generating entanglement in passive optical networks.

09:00-09:45 Nov 5

Invited - **Beyond the Heisenberg uncertainty**

Eugene Polzik
Copenhagen Univ.

Some operations on quantum states are not restricted by the Heisenberg uncertainty principle. One example is teleportation, which allows for both the position and the momentum be transferred without added noise [1]. Perhaps even more surprisingly, a trajectory of an oscillator can be measured with an accuracy exceeding the Heisenberg uncertainty following the approach we have recently developed [2, 3]. The key feature is to monitor the oscillator trajectory in a quantized reference frame with a negative mass with which the oscillator is entangled. In the talk I will first present a oscillator with a negative mass and report the results of tracing the magnetic spin oscillator trajectory beyond the Heisenberg uncertainty. I will then describe progress towards tracing a trajectory of a mechanical oscillator with the precision not restricted by the Heisenberg uncertainty principle. Finally, I will outline perspectives for performing similar operations with an electrical oscillator [4]. References: 1.H. Kraute et al. Nature Phys., 9, 400 (2013). 2.E.S. Polzik and K. Hammerer, arXiv:1405.3067. W. Wasilewski et al. Phys. Rev. Lett., 104, 133601 (2010). 3.K. Hammerer, M. Aspelmeyer, E.S. Polzik, P. Zoller. Phys. Rev. Lett. 102, 020501 (2009). 4.T. Bagci et al. Nature 507, 81-85 (2014).

09:45-10:15 Nov 5

Invited - **Quantum cryptography using practical photonic systems**

Eleni Diamanti
Telecom Paris Tech.

In future quantum information networks, where individual parties will have the ability to communicate in a variety of ways with trusted and untrusted parties, several cryptographic protocols, inherently linked to fundamental features of quantum mechanics, will become essential. Here, we are interested in protocols that are at the heart of many advanced secure communication tasks, namely key distribution and coin flipping. We examine the implementation of these protocols using photonic systems, which provide an ideal physical support for quantum communications. We discuss how imperfections and limitations of practical systems affect the security of the protocols and how implementations offering high performance and strong security guarantees - superior to what classical communication alone could ever provide - are nevertheless achieved. These results, together with perspectives for novel integrated photonic components, offer a powerful toolbox for practical applications of secure quantum communications.

10:15-10:35 Nov 5

The Operational Significance of Discord: Theory, Applications and Experiments

Mile Gu
Tsinghua University

Coherent interactions that generate negligible entanglement can still exhibit quantum behaviour. This motivates a search beyond entanglement for a complete description of all quantum correlations. Quantum discord is a promising candidate. Here we show how discord between bipartite systems can be consumed to encode information accessible only via coherent quantum interactions [1]. We discuss how this allows discord to be used to test the entangling power of untrusted parties [2], and underpins why quantum illumination thrives in entanglement-breaking noise [3]. We demonstrate this framework with twin experiments in discrete and continuous variable optics [1, 2]. In either case, information is encoded within the discordant correlations some bipartite system. The amount of extra information recovered by coherent interaction is quantified and directly linked with the discord consumed. No entanglement exists at any point in either experiment. Thus we introduce and demonstrate an operational framework to use discord as a physical resource. [1] Nature Phys. 8, 671-675 (2012) [2] Phys. Rev. A 89. 042323 (2014) [3] arXiv:1312.3332; Highlighted in Nat. Phys. 10, 474 (2014)

11:00-11:30 Nov 5

Invited - **Experimental investigation of quantum entanglement network and fundamental quantum physics**

Chuan-Feng Li
University of Science and Technology of China

I will introduce our progress in constructing quantum entanglement network and investigating fundamental quantum physics with quantum technology. We have established four quantum systems, namely linear optics, man-made atomic system such as a single quantum dot, rare-earth-ion-doped crystal and ion trap. Among them, rare-earth-ion-doped crystal serves as storing node in the quantum network with the technique of atomic frequency comb etc., and ion trap serves as operating node implementing quantum operation, while linear optics and single quantum dot are used to generate entangled photon pair with spontaneous down conversion process and deterministic single photon source, respectively, to connect different nodes. And I will also briefly report our recent progresses in every single system. We have realized demon-like algorithmic quantum cooling process in linear optics system [Nature Photonics 8, 113 (2014)]. In single quantum dot system, we have used the deterministic single photon from InAs/GaAs quantum dot to realize quantum Wheeler's delayed-choice experiment and observe the wave-particle superposition state of photon [Nature Photonics 6, 600 (2012)]. In rare-earth-ion-doped crystal system, we have realized reliable solid-state quantum memory with Nd:YVO4 crystal for photonic polarization qubit with fidelity up to 99.9% [PRL108, 190505 (2012)]. Our ion trap system has just been established from last year. Now we can observe the Rabi oscillation of single Yb ion. Currently we focus on the interface between different systems. There are two key points to construct a basic entanglement network with the four systems. The first one is the match of wavelengths. The other one is the coupling between trapped ion and photon. In the year 2014, we have connected photon from spontaneous down conversion and single photon from self assembled quantum dot with solid state memory of Nd: YVO4 crystal, respectively.

11:30-12:00 Nov 5

Invited - **Steering many-body quantum dynamics**

Tommaso Calarco
University of Ulm

Quantum technologies are based on the manipulation of individual degrees of freedom of quantum systems with exquisite precision. Achieving this in a real environment requires pushing to the limits the ability to control the dynamics of quantum systems of increasing complexity. Optimal control techniques are known to enable steering the dynamics of few-body systems in order to prepare a desired state or perform a desired unitary transformation. I will present a recently developed optimal control method that allows doing so for a many-body quantum system undergoing e.g. a quantum phase transition in the non-adiabatic regime. This opens the way to a range ofapplications, from the suppression of defects in a superfluid-Mott-insulator transition with ultra-cold atoms in an optical lattice to the achievement of various quantum gates at the quantum speed limit. I will present detailed calculations we performed for different experimental scenario, together with the corresponding results obtained by experimental groups in different fields, from cold atoms to spin squeezing in atomic ensembles and diamond NV centers. Our control method also allows for exploring more general questions like the complexity of reversing quantum many-body dynamics, steering it back to its initial state even without the ability to revert the sign of the whole Hamiltonian. I will conclude by showing some recent results we obtained in this context, as well as further questions opened by our investigations.

12:00-12:20 Nov 5

Quantum replication at the Heisenberg limit

Giulio Chiribella
Tsinghua University

Quantum devices that achieve enhanced performances by operating probabilistically have received a great amount of interest in the past few years. They come in different forms, from weak values to probabilistic cloners and noiseless amplifiers, and have been investigated both theoretically and experimentally, with breakthrough demonstrations in quantum optics. Considering this vast landscape, some questions arise naturally: Can we find the general rules that apply to probabilistic devices? Is it always necessary to have a decaying probability of success in order to have probabilistic advantages? In this work we provide answers to these questions, establishing the ultimate limits that can be achieved probabilistic processes in a variety of relevant settings, exploring the optimal trade-off between performance and success probability, and providing new criteria that can be used to validate experimental demonstrations of probabilistic advantages. Based on: -G. Chiribella, Y. Yang, and A. C.-C. Yao, Nature Communications 4, 2915 (2013) -G. Chiribella and J. Xie, Phys. Rev. Lett. 110, 213602 (2013). -G. Chiribella and G. Adesso, Phys. Rev. Lett. 112, 010501 (2014).

12:20-12:40 Nov 5

Quantum networks based on diamond spins: from long-distance teleportation to a loophole-free Bell test

Hannes Bernien
Kavli Institute of Nanoscience

The realization of a highly connected network of qubit registers is a central challenge for quantum information processing and long-distance quantum communication. Diamond spins associated with NV centers are promising building blocks for such a network as they combine a coherent optical interface (similar to that of trapped atomic qubits) with a local register of robust nuclear spin qubits [1]. Here we present our latest progress towards scalable quantum networks. We have realized unconditional teleportation between long-lived qubits residing in independent setups [2]. The teleportation exploits entanglement between distant NV electronic spins that is generated through spin-photon entanglement and subsequent photon detection [3]. By encoding the source state in a separate qubit (a single nuclear spin) we realize a Bell state measurement that distinguishes between all four outcomes in a single shot. Analysis shows that the obtained fidelities are in principle high enough for a loophole-free violation of Bell's inequalities. [1] T. H. Taminiau et al., Nature Nanotechnology 9, 171 (2014). [2] Pfaff et al., Science 345, 532 (2014). [3] H. Bernien et al., Nature 497, 86 (2013).

14:00-14:30 Nov 5

Invited - **Foundations of Quantum Theory and Quantum Field Theory in the light of Quantum Information**

Giacomo Mauro D'Ariano
University of Pavia

The experience in Quantum Information has led the community of foundations to look at Quantum Theory under a completely new angle, regarding Quantum Theory as a "theory of information". Few years ago this has lead to an axiomatization of Quantum Theory in information-theoretic terms. The need of addressing also the mechanical nature of the quantum systems, has shifted the focus toward Quantum Field Theory. In my talk I will briefly review the information-theoretical principles of Quantum Theory, along with the new additional informational principles for Quantum Field Theory. The network-connectiveness inherent in the informational framework leads to assuming a discrete description at some scale, leading to a quantum cellular automata theory of quantum fields. Free Quantum Field Theory is recovered in the relativistic limit of small wave vectors, without using relativity theory, but with Lorentz covariance emerging in the relativistic regime, whereas in the ultra-relativistic regime a more general covariance (Doubly special relativity of Camelia-Smolin-Maguejo) holds. The Maxwell field emerges in fashion similar to neutrino theory of radiation (a la De Broglie), with small deviations from the Maxwell dynamics in terms of a longitudinal polarization component and dispersive effects. Also some GR effects arise in the automaton description, as e.g. a bound for the inertial mass of the Dirac particle due solely to unitarity, with flat dispersion relations reminiscent of a mini black hole. The main lines of the derivation and the modifications of the usual quantum field dynamics will be presented, along with some computer simulations, and discussing possible visible effects, e.g. from radiation of ultra deep-space sources.

14:30-15:00 Nov 5

Invited - **Certifying quantum dimensions and randomness**

Nicolas Brunner
University of Geneva

The Hilbert space dimension of an uncharacterized quantum system can be tested in a device-independent manner. Specifically a lower bound on the dimension can be obtained from measurement data only, without requiring a detailed knowledge of the devices used in the experiment. Moreover, these ideas find applications in quantum information processing. In particular, they lead to a self-testing quantum random number generator, which allows the user to monitor in real time the entropy of the output data.

15:00-15:20 Nov 5

Increasing sensing resolution with error correction

Alex Retzker
The Hebrew University

The signal to noise ratio of quantum sensing protocols scales with the square root of the coherence time.

Thus, increasing this time is a key goal in the field. Dynamical decoupling has proven to be efficient in prolonging the coherence times for the benefit of quantum sensing. However, dynamical decoupling can only push the sensitivity up to a certain limit. In this talk I will present a new approach to increasing the coherence time further through error correction which can improve the efficiency of quantum sensing beyond the fundamental limits of current state of the art methods.

15:20-15:40 Nov 5

Ultrahigh Q Bulk Acoustic Wave Cavities at the Quantum Limit

Michael Tobar
The University of Western Australia

The combination of ultrahigh quality factors and considerable photon-phonon coupling makes piezoelectric BAW devices an alternative to photon cavities in many low-frequency, low-power experiments. The advantages of acoustic devices is the ease of operation and integration into higher-order electronic systems, compact size, natural way of combination of mechanical motion and electromagnetic environment, as well as artificial lattice impurities. In particular, phonon trapping BAW devices are intended to be used as parts of quantum hybrid systems in miliKelvin temperatures integrating quantum circuit electrodynamics and cavity elastodynamics providing the extremely long coherence times. Moreover, unlike nano-scale mechanical resonators, acoustic cavities are a macroscopic objects of considerable effective mass varying from a few milligrams at tents of MHz to a few milligram at hand reds of MHz. This fact can be a promising experiment on unifying quantum mechanics and general relativity in a single experiment. Apart from applications to fundamental physics, cryogenic acoustic cavities are used for building ultra-stable frequency sources.

16:10-16:40 Nov 5

Invited - **Breaking the mirror symmetry of spontaneous emission via spin-orbit interaction of light**

Arno Rauschenbeutel
Vienna Univ. Tech.

The fundamental guided mode in an optical nanofiber exhibits a significant polarization component that points in the direction of propagation of the light. In contrast to paraxial light fields, the corresponding intrinsic angular momentum of the light field is position-dependent - an effect referred to as spin-orbit interaction of light. Remarkably, the light's spin can even be perpendicular to the propagation direction. I will show that the interaction of emitters with such light fields leads to new and surprising effects. In particular, the intrinsic mirror symmetry of the emission of light by gold nanoparticles as well as by atoms near a silica nanophotonic waveguide is broken. This allowed us to realize chiral nanophotonic interfaces in which the emission direction of light into the waveguide is controlled by the polarization of the excitation light [1] or by the internal state of the atoms [2]. References [1]J. Petersen et al., Science 346, 67 (2014). [2]R. Mitsch et al., arXiv:1406.0896 (2014).

16:40-17:10 Nov 5

Invited - **Quantum information processing with diamond**

Steven Prawer
Univ. Melbourne

Diamond is an exceptional platform for quantum information processing. Fundamental demonstrations of single and multiple qubit operations have become almost routine, based mostly around the properties of the NV optical centres in diamond which offers room temperature spin readout and control. In this talk, I will review some of the more applied applications of diamond technology which take advantage of these remarkable properties. These include single photon sources for secure communications, imaging single spins in live cells and the fabrication of a bionic eye to restore vision to patients suffering from retinal diseases.

17:10-17:30 Nov 5

Tracking photon jumps with repeated quantum non-demolition parity measurements

Luyan Sun
Tsinghua University

Quantum error correction (QEC) is required for a practical quantum computer because of the fragile nature of quantum information. A measurement-based QEC requires the measurement of error syndromes in a quantum non-demolition (QND) way and at a rate which is faster than errors occur. In a 3D circuit quantum electrodynamics architecture, we realize a parity measurement of a microwave field by mapping its parity onto an ancilla qubit. The projective nature of the parity measurement onto a degenerate parity eigenspace, the cat states, is confirmed by Wigner tomography after a single parity measurement, showing 83% fidelity to ideal cats. The parity can therefore serve as an error syndrome for a recently proposed QEC scheme [Leghtas et.al. PRL (2013)]. We then demonstrate a tracking of quantum jumps of this error syndrome by repeated parity measurements. We conclude by showing our protocol to be 99.8% QND per measurement and to be highly sensitive to parity jumps. Such levels of performance can already increase the lifetime of a quantum bit of information, and thereby present a promising step towards realizing a viable QEC scheme [Sun et.al. Nature 511, 444 (2014)].

17:30-17:50 Nov 5

Experimental demonstration of perfect orthogonalization of partly unknown quantum states of light

Jaromir Fiurasek
Palacky Univesrity

It is well known that a universal quantum NOT gate that would transform any input pure qubit state onto an orthogonal state is forbidden by the laws of quantum physics. However, recently it has been shown that perfect probabilistic quantum state orthogonalization becomes feasible provided that we possess some a-priori information about the input state. In particular, it suffices to know a mean value of some quantum operator and apply a suitable quantum filter to the input state. We report on experimental implementation of this protocol in a linear optics setting. In particular, we demonstrate orthogonalization of partly unknown polarization states of single photons and entangled photon pairs. We prove that the conditional orthogonalization outperforms the best deterministic strategy, and we show that perfect orthogonalization of partly unknown two-qubit entangled states can be performed by a local operation, where the quantum filter is applied to one of the qubits only.

09:00-09:45 Nov 6

Invited - **New interface between quantum optics and nanoscience**

Mikhail Lukin
Harvard Univ.

We will discuss recent developments at a new scientific interface between quantum optics, nanoscience and quantum information science. Specific examples include the use of quantum optical techniques for manipulation of individual atom-like impurities at a nanoscale and for realization of hybrid systems combining ultracold atoms with nanophotonic devices. We will discuss how these techniques and systems can be used for realization of quantum networks, magnetic resonance imaging with single atom sensitivity and nanoscale sensing in biology.

09:45-10:15 Nov 6

Invited - **Exploration of the Spin-Orbit coupled Bose Gas**

Shuai Chen
University of Science and Technology of China

We report the experiment of quantum simulations with synthetic spin-orbit coupled Bose gas. Raman coupling technique is applied to generate spin-orbit (SO) coupling in 1D with ultracold Bose gas of ^{87} Rb. It also leads to many new phenomena of boson superfluidity and various condensate phases. We experimentally determine the phase diagram of SO coupled Bose gas at finite temperature, including the critical temperature, the phase transition and phase boundary between density striped (ST) phase and magnetized plane wave (MG) phase, as well as the temperature that the magnetic order is established. Furthermore, Bragg spectroscopy is applied to study the excitation of SO coupled BEC. "Roton" mode and its softening is observed in the excitation spectrum, which only short range and weak atom-atom interactions is presented. The softening of phonon modes is also observed, which give us some new understanding of the superfluidity in SO coupled Bose gas. Our study shows the true power of quantum simulation.

10:15-10:35 Nov 6

Optimal detecton of multipartite entanglement close to symmetric Dicke states in cold atomic ensembles

Geza Toth
University of the Basque Country UPV/EHU

We present a criterion detecting multipartite entanglement in an ensemble of two-state atoms close to symmetric Dicke states. The criterion is given in terms of the expectation values and variances of collective observables, which makes it applicable in systems where the spins cannot be addressed individually. The criterion is optimal in the sense that it detects all the states that can be detected based on the measured quantities. Our criterion is has been used in an experiment with a cold atomic ensemble of 8000 atoms. Experimentally, a Dicke-like state has been produced using spin dynamics in a Bose-Einstein condensate. Our criterion proves that the quantum state prepared contains at least genuine 28-particle entanglement. We also present a spin squeezing parameter, that is the generalisation of the original spin squeezing parameter. We infer a parameter value of -11.4(5) dB. [1] B. Lücke, J. Peise, G. Vitagliano, J. Arlt, L. Santos, G. Toth, and C. Klempt, Detecting multiparticle entanglement of Dicke states, Phys. Rev. Lett.

112, 155304 (2014); Editors' suggestion; synopsis at physics.aps.org.

11:00-11:30 Nov 6
Invited - **Entanglement as a resource for a cavity-based quantum interface**
Tracy Northup
Univ. Innsbruck
Entanglement can enhance the coherent interaction of light and matter at a quantum interface, enabling information transfer within future quantum networks. Here, our interface consists of calcium ions trapped within an optical cavity. First, I will describe how we transfer a qubit from a single ion onto a photon, for distribution over quantum channels. Next, we replace the ion by two ions in a maximally entangled state, in which a logical quantum bit is encoded. The phase of the entangled state determines the collective interaction of the ions with the cavity mode, that is, whether the emission of a single photon into the cavity is suppressed or enhanced. The latter case corresponds to a superradiant state of the ion-cavity system, for which we demonstrate that quantum information transfer onto a single photon is improved. By constructing an interface based on collective effects, one can thus relax the technical requirements for the faithful mapping of quantum information.

11:30-11:50 Nov 6
Atom-mechanical coupling in a tapered fibre trap
Lars Skovgaard Madsen
University of Queensland
Hybrid systems of cold atoms and micro-mechanics form a novel basis to study quantum interactions. The two systems are coupled with light serving as a coherent messenger(1). We recently showed theoretically that this type of coherent control allows remote cooling of mechanical oscillators to their quantum ground state, in regimes where neither resolved-sideband cooling nor measurement-based feedback cooling are possible (2). We are constructing a hybrid setup where atoms are trapped around a tapered optical fibre in a far-detuned dual-colour dipole trap (3). Recently it has been proposed that the major decoherence mechanism of this type of trap is coupling to a torque mode in the tapered fibre (4). In this presentation we will experimentally investigate the coupling between the torsional mode of the tapered fibre and the atoms. We study this by controlling the tension of the tapered fibre and the depth of the dual-colour trap. We are also investigating the mechanical properties of the vibrational mode, to test whether it should be avoided or if it is suitability for coherent quantum dynamics.

11:50-12:10 Nov 6
Quantum Dots for Semiconductor-Atomic Interfaces
Yongheng Huo
Institute for Integrative Nanosciences, IFW Dresden
Y. H. Huo, E. Zallo, and O. G. Schmidt Quantum dots (QDs) are considered as promising single- and entangled- photon sources. In order to perform as practical flying qubits in a quantum network, photons generated by QDs should have the same colors as quantum memories, generally proposed to be atom ensembles [1]. Here we will introduce our recent work of fabrication of QDs having the same emission wavelengths of widely used atoms, such as Rubidium (Rb) and Cesium (Cs). First, we will talk about GaAs/AlGaAs QDs [2-4] with emissions at ∼780 nm and ∼795 nm, in resonance with the D1 and D2 lines of ^{87}Rb, respectively. Then, we will show the indium-flushed growth of In(Ga)As/GaAs QDs [5] emitting in resonance with the Cs D1 transition (∼894.6 nm). Finally we will demonstrate how strain is used to finely tune the emission wavelengths. [1] H. J. Kimble, Nature 453, 1023 (2008). [2] S. Kumar, et al., Appl. Phys. Lett. 99, 161118 (2011). [3] Y. H. Huo, et al., Appl. Phys. Lett. 102, 152105 (2013). [4] Y. H. Huo, et al., Nat. Phys. 10, 46 (2013). [5] R. Trotta, et al., , Phys. Rev. Lett. 109, 147401 (2012).

12:10-12:30 Nov 6
Quantum-enhanced tomography of unitary processes
Xiaoqi Zhou
University of Bristol
Quantum process tomography (QPT) is the standard method in determining how a process acts on quantum mechanical states. For example, QPT can be used to characterise multi-qubit processors and quantum communication channels. However, the precision of QPT is limited by the fact that measurements with single-particle probes are subject to unavoidable shot noise. In situations where measurement resources are limited, for example, where the process is rapidly changing or the time bandwidth is constrained, it becomes essential to overcome this precision limit. Here we devise and demonstrate a scheme for tomography which exploits non-classical input states and quantum interferences; unlike previous QPT methods our scheme capitalises upon the possibility to use simultaneously multiple photons per mode. The efficiency—quantified by precision per photon used-scales with

larger photon-number input states. Our demonstration uses four-photon states and our results show a substantial reduction of statistical fluctuations compared to traditional QPT methods-in the ideal case one four-photon probe state yields the same amount of statistical information as twelve single probe photons.

14:00-14:30 Nov 6

Invited - **Coupling a single electron to a Bose-Einstein condensate**

Tilman Pfau
Univ. Stuttgart

We study the interaction of a single localized electron with a Bose-Einstein condensate (BEC) and show that it can excite phonons and eventually set the whole condensate into a collective oscillation [1]. We find that the coupling is surprisingly strong as compared to ionic impurities due to the more favourable mass ratio. The electron is held in place by a single charged ionic core forming a Rydberg bound state. This Rydberg electron is described by a wavefunction extending to a size comparable to the dimensions of the BEC, namely up to 8 micrometers. In such a state, corresponding to a principal quantum number of up to n=202, the Rydberg electron is interacting with several tens of thousands of condensed atoms contained within its orbit. We observe surprisingly long lifetimes and finite size effects due to the electron exploring the wings of the BEC. Based on our results we anticipate future experiments on electron orbital imaging, investigation of phonon mediated coupling of single electrons, applications in quantum optics and possibly on ion atom interactions. References [1] J. B. Balewski, A. T. Krupp, A. Gaj, D. Peter, H. P. Büchler, R. Löw, S. Hofferberth, T. Pfau, Nature 502, 664 (2013)

14:30-14:50 Nov 6

Quantum optics with an intracavity Rydberg gas

Alexei Ourjoumtsev
CNRS, Institut d'Optique

Our project aims at creating strong dispersive interactions between optical photons using an interacting Rydberg gas trapped inside an optical cavity, in order to perform quantum logic operations between optical photons and deterministically create non-classical states of light. After observing a dispersive non-linear response of the gas in the classical regime, we have shown that our experimental system allowed us to create single heralded excitations in the atomic gas and efficiently extract them as single-mode free-propagating photons presenting strongly non-classical, negative Wigner functions. Our current theoretical and experimental efforts focus on reaching a regime where Rydberg interactions are strong enough to create such non-classical states deterministically.

14:50-15:10 Nov 6

Exactly solvable models of large spin cold atoms

Xiwen Guan
Wuhan Institute of Physics and Mathematics, CAS

Interacting bosons and fermions with high mathematical symmetries greatly expand our understanding of many-body physics. In this talk, I will briefly review recent theoretical and experimental developments of one-dimensional (1D) integrable quantum gases of cold atoms with high spin symmetries. In particular, I will discuss universal low energy physics of 1D interacting bosons and fermions with large spins through the Luttinger paramters, Wilson ratio and Contact. These universal parameters build up a precise description of quantum liquids in 1D interacting many-body systems with high spin symmetries.

15:10-15:30 Nov 6

Implementation of the Dicke lattice model in hybrid quantum system arrays

Peter Rabl
Atominstitut, TU Wien

Generalized Dicke models can be implemented in hybrid quantum systems built from ensembles of nitrogen-vacancy (NV) centers in diamond coupled to superconducting microwave cavities. By engineering cavity assisted Raman transitions between two spin states of the NV defect, a fully tunable model for collective light-matter interactions in the ultra-strong coupling limit can be obtained. Our analysis of the resulting non-equilibrium phases for a single cavity and for coupled cavity arrays shows that different super-radiant phase transitions can be observed using existing experimental technologies, even in the presence of large inhomogeneous broadening of the spin ensemble. The phase diagram of the Dicke lattice model displays distinct features induced by dissipation, which can serve as a genuine experimental signature for phase transitions in driven open quantum systems.

16:00-16:20 Nov 6

A classical-quantum communication channel with an image as the input

Lev B. Levitin
Boston University

A classical-quantum communication channel is considered where the input is an image obtained by observation of a surface in reflected or transmitted natural (i.e., fully thermalized light), or by observation of an object emitting incoherent (thermal) radiation. The discreteness of the degrees of freedom and the statistical properties of thermal radiation are taken into account. We derive the maximum amount of information that can be retrieved from the object. This amount is always finite and is proportional to the area of the object, the solid angle under which the entrance pupil of the receiver is seen from the object, and the time of observation. An explicit expression for the information in the case where the information recorded by the receiver obeys Planck's spectral distribution is obtained. The amount of information per photon of recorded radiation is a universal numerical constant, independent of the parameters of observation.

16:20-16:40 Nov 6

Non-linear optomechanical measurement of mechanical motion

Michael Vanner
The University of Queensland

A current major goal of quantum optomechanics is to perform non-Gaussian quantum state preparation of the motion of a macroscopic mechanical resonator. Experimentally exploring the behaviour of such states will increase our empirical understanding of quantum decoherence, test the feasibility of mechanical elements for quantum information/metrology applications, and may even reveal potential quantum-gravitational phenomena. In this work we report the first demonstration of mechanical position squared measurements and utilise this to conditionally prepare bimodal states of motion. Our setup uses a high-Q optical microsphere resonator that evanescently couples to the position of a SiN nanostring oscillator. The effective position-squared coupling is achieved by exploiting the intrinsic non-linearity of the radiation pressure interaction. After state preparation we use a linear measurement to reconstruct the phase-space distribution and demonstrate feature sizes well below 100 pm. With future technical improvement to our setup this approach provides one of the most feasible routes to generate non-classical quantum superposition states in a massive mechanical system.

16:40-17:00 Nov 6

Bridging the gap to the Holevo limit

Saikat Guha
Raytheon BBN Technologies

I will give an overview of various progress made during the last two years with collaborators at BBN, MIT, LSU, and NICT, on investigating structured receivers and codes to bridge the gap between the Shannon capacities of conventional optical receivers, viz., homodyne, heterodyne and direct-detection, and the ultimate limit to the capacity of classical communication on an optical channel–the Holevo limit [1, 6]. I will explain four distinct quantum-limited joint-detection measurements [2, 3, 4, 5]—the slicing receiver, sequential vacuum-or-not, USD measurement, and the successive-cancellation receiver, each of which in principle can attain the Holevo limit, and the optical resources (devices and detectors) that may be needed for structured realizations of each. I will explain the construction of the quantum polar code and decoder, the first explicit and linear code (as opposed to random codes used in Holevo's proof) that can provably attain the Holevo capacity. Finally, I will describe our recent results on the capacity performance when the joint-detection receiver is restricted in complexity, i.e., to jointly detect up to N optical symbols. I will conclude with open questions. References: [1] S. Guha, Structured optical receivers to attain superadditive capacity and the Holevo limit, Physical Review Letters, 106, 240502 (2011). [2] M. P. da Silva, S. Guha, Z. Dutton, Achieving minimum-error discrimination of an arbitrary set of laser-light pulses, Phys. Rev. A, 87, 052320 (2013). [3] M. Wilde, S. Guha, S.-H. Tan, S. Lloyd, Explicit capacity achieving receivers for optical communication and quantum reading, Proc. IEEE International Symposium on Information Theory, MIT, Cambridge, (2012). [4] M. Takeoka, H. Krovi, S. Guha, Achieving the Holevo Capacity of a Pure State Classical-Quantum Channel via Unambiguous State Discrimination, Proceedings of the IEEE International Symposium on Information Theory (ISIT), Istanbul, Turkey (2013). [5] M. Wilde and S. Guha, "Polar codes for classical quantum channels," IEEE Transactions on Information Theory, vol. 59, no. 2, pages 1175-1187 (February 2013). [6] M. Takeoka and S. Guha, "Capacity of optical communication in loss and noise with general Gaussian receivers," Physical Review A, 89, 042309 (2014). [7] H. Krovi, S. Guha, Z. Dutton, and M. P. da Silva, "Optimal Measurements for Symmetric Quantum States with Applications to Optical Quantum Communication," Proceedings of the 2014 IEEE International Symposium on Information Theory (ISIT), Honolulu, Hawaii, June 29 - July 4 (2014).

17:00-17:20 Nov 6

Quantum phase transition of spin-orbit coupling Fermi gases

Wu-Ming Liu
Institute of Physics, Chinese Academy of Sciences

I will review our research on quantum phase transition of spin-orbit coupling Fermi gas. We find that a strong spin-orbit coupling can considerably reduce the critical interaction strength for itinerant ferromagnetism transition, which provides a new and efficient mechanism to realize this long sought state. These novel phenomena could be detected by current experimental techniques such as speckle imaging [1]. We investigate the fidelity susceptibility of a two-dimensional spin-orbit-coupled Fermi superfluid and the topological phase transition driven by a Zeeman field in the perspective of its ground state wave function. The topological phase transition can be detected by measuring the momentum distribution in cold atom experiments [2]. We obtain the collective modes in the spin-orbit-coupled Fermi gas with repulsive s-wave interaction. We also propose an experimental protocol for detecting these collective modes and discuss corresponding experimental signatures in the ultracold Fermi gases experiment [3]. We get the normal-state properties of spin-orbit-coupled Fermi gases with repulsive s-wave interaction, in the absence of molecule formation, i.e., in the so-called "upper branch" [4]. We investigate a two-component atomic Fermi gas with population imbalance in the presence of Rashba-type spin-orbit coupling. As a competition between spin-orbit coupling and population imbalance, the finite-temperature phase diagram reveals a large variety of new features, including the expanding of the superfluid state regime and the shrinking of both the phase separation and the normal regimes [5]. References [1]. S. S. Zhang, J. W. Ye, W. M. Liu, Itinerant ferromagnetism in repulsively interacting spin-orbit coupled Fermi gas, arXiv:1403.7031. [2] X. B. Luo, K. Z. Zhou, W. M. Liu, Z. X. Liang, Z

3 Abstracts of Poster Presentations

A1 - **On the Reality of the Quantum State**
Shan Gao
Institute for the History of Natural Sciences, Chinese Academy of Sciences

The physical meaning of the quantum state is an important problem in the foundations of quantum mechanics. A long-standing question is whether a pure state relates only to an ensemble of identically prepared systems or directly to the state of a single system. Recently, Pusey, Barrett and Rudolph (PBR) demonstrated that under a preparation independence assumption, the quantum state is a representation of the physical state of a single quantum system. This poses a further interesting question, namely whether psi-ontology can be argued without resorting to nontrivial assumptions. In this presentation, we will show that the reality of the quantum state can be demonstrated in terms of protective measurements, by which one can measure the expectation values of observables on a single quantum system (Aharonov and Vaidman 1993; Aharonov, Anandan and Vaidman 1993). This result is independent of nontrivial assumptions, and it is stronger than the PBR theorem.

A2 - **Nonlinear Entanglement and its Application to Generating Schrodinger Kittens**
Yong Shen
National University of Defense technology

The Einstein-Podolsky-Rosen (EPR) paradox, which originally argued for the incompleteness of a quantum mechanical description of reality, has since metamorphosed into the very essence of quantum information science. The EPR entanglement describes the strength of linear correlations between two objects in terms of a pair of conjugate observables in relation to the Heisenberg uncertainty limit. We propose that entanglement can be extended to include nonlinear correlations between pairs of conjugate observables. Being more than a new phenomenon, nonlinear entanglement extracts a richer set of behaviour from a quantum system. We examine a system of two driven harmonic oscillators that exhibits quadratic-like nonlinear entanglement which, after a projective measurement on one oscillator, collapses the other into a Schrodinger kitten state of tunable size. We shows that this specific quadratic-like entanglement can be realized optically with current third-order nonlinear materials and micro-cavity technology.

A3 - **Physics above and below the Bell horizon: re-examining quantum foundations and glimpsing the post-quantum world via photonics.**
Martin Ringbauer
School of Mathematics and Physics
Fifty years ago John Bell formulated the framework which is now the basis for the study of many foundational questions in quantum mechanics. His theorem not only made a testable prediction for quantum mechanics, but also provided a horizon which delineated quantum from post-quantum theories. In this talk I will shine some light on one of longest standing open questions, which Bell's local-causality framework helped to formulate: what is the nature of the quantum wavefunction? Does it correspond to an element of reality, or is it a representation of information, or knowledge of reality? We demonstrate experimentally, that if there is some underlying reality, then the quantum wavefunction must itself be part of this reality. I will then edge above the Bell horizon with two post-quantum phenomena: an experimental protocol which allows to create stronger-than-quantum correlations-and thus explore the principle of information causality in the quantum and post-quantum regime; and a quantum simulation of closed-timelike curves—quantum mechanics in regions of extreme gravitational effects.

A4 - **A time-domain benchmark for discriminating between electromagnetically induced transparency and Autler-Townes splitting**
Xiaogang Lu
The Institute of Physics, Chinese Academy of Sciences
The threshold for the transition between electromagnetically induced transparency (EIT) and Autler-Townes (AT) splitting is studied from the time-domain viewpoint. The AT splitting appears when there is coherent Rabi oscillation of the populations between states which are coupled by the coupling field. By contrast, in the EIT regime the relaxation suppresses the coherent oscillation of the populations when the coupling field is weak, thus no splitting can occur. In this case, the role of the coupling field is simply to induce weak transitions between states, and the transparency window can be explained as being due to the gain of a four-wave mixing process. This interpretation provides a simpler physical picture and a more direct way

of understanding EIT than the conventional Fano interference. Experiments performed in cold rubidium atoms, where both the absorption and dispersion were measured, show that EIT can be discriminated from AT splitting through Fourier transformation of the spectra.

A5 - **Multipartite Einstein-Podolsky-Rosen steering in optical and hybrid quantum systems**
Qiongyi He
Peking University
We develop the two concepts of genuine and collective N?partite Einstein- Podolsky-Rosen (EPR) steering. This nonlocality is the natural multipartite extension of the original EPR paradox. Useful properties emerge that are not guaranteed for multipartite entangled states. In particular, there is a close link with the task of one-sided device-independent quantum secret sharing. We derive inequalities to demonstrate multipartite EPR steering for Gaussian continuous variable (CV) states in loophole-free scenarios. We show that it is possible to obtain genuine and collective multipartite EPR steering in very different sorts of systems to those so far predicted for multipartite Bell nonlocality. We have formalized the meaning of genuine and collective multipartite EPR steering, and derive criteria to detect them, respectively. Here, we show how to verify N-partite steering for continuous variable Gaussian systems both in optical systems and in multimode hybrid optomechanical systems, giving efficiency bounds to do so conclusively.

A6 - **Fermionic one way quantum computing**
Yun Shang
Academy of mathematics and system sciences
This paper studied fermionic generalization of one-way quantum computation model. It aims to give universal fermionic resource states and computational schemes for one-way quantum computation model. By using the similar encoding scheme with Chiu's, we have reformulated the computational model of the one-way computer in the framework of fermions. It is proved that fermionic cluster states are reliable universal resource state. Furthermore we have shown that universal fermionic cluster states can be created only by measurements on at most four modes with $|+\rangle_f$(fermionic Bell state) as free.

A7 - **The Possibility to Experimentally Verify General Bell's Inequality Violation**
George Rytikov
M.V.Lomonosov MSU and I.Fedorov MSU of Printing Arts
Discussing the fundamental problems of nonclassical correlations and microscopic entanglement experimental observation for multiphoton quantum light beams, we propose the concept of Bell inequality violation generalization and represent the results of the theoretical investigation of the possibility to its experimental verification for P-scalar light. We have found the critical relation between the quantum efficiency and the parametric gain coefficient which confirms that in order to observe nonclassical behavior of light one should be able to resolve its photonic structure.

A8 - **Robust test of Bell's inequality with amplified N00N states**
Falk Toppel
Max Planck Institute for the Science of Light
Although our understanding of Bell's theorem and experimental techniques to test it have improved over the last 40 years, thus far all Bell tests have suffered at least from the detection or the locality loophole. Most optical Bell tests rely on inefficient discrete-outcome measurements, often provided by photon counting detection. One possible way to close the detection loophole in optical Bell tests is to involve efficient continuous-variable measurements instead, such as homodyne detection. Here, we propose a test of the Clauser-Horne-Shimony-Holt (CHSH) inequality that applies photon counting and homodyne detection on amplified two-photon N00N states. The scheme suggested is remarkably robust against experimental imperfections and suits the limits of current technology. It may therefore constitute an alternative platform for a loophole-free Bell test or other important quantum-technological applications. Furthermore, as experimentally accessible macroscopic quantum states of light are considered, our work also contributes to the exploration of entangled macroscopic quantum systems.

A9 - **Information complementarity: A new paradigm for decoding quantum incompatibility**
Huangjun Zhu
Perimeter Institute for Theoretical Physics
We introduce an information theoretic paradigm together with an intuitive geometric picture for understanding a number of foundational issues in quantum mechanics, starting from two simple ideas: Every observable can only provide limited information and information is monotonic under data processing. By virtue of quantum estimation theory, we introduce a family of universal criteria for detecting incompatible observables (observables that cannot be measured

simultaneously) and a natural measure of incompatibility, which are applicable to arbitrary number of arbitrary observables. Based on this framework, we derive a family of universal measurement uncertainty relations, provide a simple information theoretic explanation of quantitative wave–particle duality, and offer new perspectives for understanding Bell nonlocality, contextuality, and quantum precision limit. Our study is of interest to researchers from diverse fields, such as information theory, quantum estimation theory, quantum metrology, and quantum foundations (arXiv:1406.6898).

A10 - **Discord and Information Capacity - Storing Information within Non-Classical Correlations**

Jiajun Ma
Tsinghua University

Non-classicality can persist beyond entanglement, motivating other candidates to fully understand quantum correlations. Quantum discord is a prominent candidate. Here we report a new operational interpretation of quantum discord from the perspective of quantum information storage-the potential for a quantum state to be manipulated unitarily to store and retrieve information. We study a bipartite distributed quantum system, and evaluate how much less information it is able to store under three communication restrictions between the bipartitions: no communication, one-way classical communication and quantum communication. We find that progressively more powerful communication methods can harness progressively more powerful correlations. In particular, the advantage of quantum over one-way classical communication exists if and only if the quantum memory initially has non-zero quantum discord. Thus we conclude quantum discord, rather than entanglement, characterizes the purely ''quantum' component of a quantum information storage. This work is done jointly with Mile Gu.

A11 - **Generation of squeezed surface-plasmon-polariton state through quadratic nonlinear interactions**

Yang Ming
Nanjing University

Quantum plasmonics presents a new sight into quantum photonic science and technology. There is a rapidly growing interest in studying the quantum properties of surface plasmon polariton (SPP). In this work, we investigate the generation of squeezed SPP state through parameter down conversion. Due to intrinsic losses of SPP, the situation is quite different from the squeezing process in traditional bulk optics. The role of loss in the squeezing process is not completely negative. From certain aspects, loss has a positive effect upon squeezing. Moreover, an actually achievable plasmonic structure is proposed to show the squeezing results. The squeezing degree of the generated nonclassical SPP state could reach about 6 dB with a propagation length of only tens of micros in a single path. The compact feature of this device is significant for constructing integrated quantum photonic circuits, which is of great value in practical quantum information applications such as quantum communication, cryptography and metrology.

A12 - **Tripartite quantum correlations of polar molecules in pendular states**

Jin-Ming Liu
East China Normal University

By employing the pendular states of polar molecules as qubit, we investigate the properties of three types of tripartite quantum correlations for three linear polar molecules and numerically analyze the relation of tripartite negativity, measurement-induced disturbance (MID), and tripartite quantum discord (TQD) depending on three unitless reduced variables involving the external field strength, dipole moment, rotational constant, dipole-dipole coupling, and temperature. The study shows that if the values of the other parameters are fixed, the three quantum correlations decrease with the increase of the field strength, as well as the three quantum correlations first increase to their respective maximum and then diminish gradually as the dipole-dipole coupling becomes larger. Moreover, both tripartite negativity and TQD become small as the temperature increases. In addition, the three quantum correlations of polar molecules in pendular states can be manipulated by tuning the values of the external electric field strength, dipole-dipole coupling, and temperature.

A13 - **Bell inequality tests using asymmetric entangled coherent states**

Chae-Yeun Park
Seoul National University

We study Bell-Clauser-Horne-Shimony-Holt (Bell-CHSH) inequality tests using an asymmetric form of two-mode entangled coherent state (ECS) where the two local amplitudes have different values. It is shown that the asymmetric ECSs are useful to obtain larger violations of the Bell-CHSH inequality compared to the symmetric ones when the same resource requirements are assumed. We also study the effects of asymmetric lossy environments where the only one local part suffers loss effects, together with detection inefficiencies in the Bell-CHSH inequality tests. In asymmetric lossy environments, we could get the larger violation of the inequality with the asymmetric ECSs compared to the symmetric ones by lessening the local amplitude of the part in which the decoherence occurs. We could also obtain larger violations of the inequality with the asymmetric ECSs when the detection inefficiencies are considered.

A14 - **Cooperativity and collective shifts in a superradiant system**

Guin-Dar Lin
National Taiwan University

We study a dense ensemble of radiating particles where many-body coherence alters their spontaneous decay behavior. The dipole-dipole interaction plays a subtle role, contributing to enhancement of the radiation and meanwhile suppressing it if the particles' permutation symmetry is broken. We use an effective master equation to describe such as system taking account this subtlety. Along with change of decay rates, certain energy shifts are also observed. We compute the frequency chirping effect based on our formalism.

A15 - **Replicating time travel's power without past self-interactions**

Yuan Xiao
CQI, IIIS, Tsinghua University

The iconic grandfather paradox highlights a controversial feature of general relativity-closed timelike curves (CTCs) that allow an objects to travel back in time and interact with their past self. In the quantum regime, the resolution of such paradoxes led to novel predictions - the availability of otherwise impossible operations that have remarkable computational benefits: The efficient solution of NP-complete problems, and the cloning of unknown quantum states. These computational benefits of CTCs, are thus instinctively associated with the rather paradoxical nature of past self-interactions. Here, we demonstrate that past self-interactions are not required. In sending one arm of an entangled state back in time, we can solve NP-Complete problems, and clone arbitrary quantum states; even when the said time-traveling system interacts with nothing in the past. Thus, we establish that the computational benefits are CTCs can be fully replicated, even when the paths all time-travelling particles remain open. Such effects may be operationally similar to gravitational time delay, and significantly improve the practicality for testing the exotic computational benefits of time-travel.

A16 - **Information theoretical Bell's inequality for two-photon diffraction**

Kiyoung Cho
Korea Institute fo Advanced Study

Method to figure out the non-locality in propagation or spatial diffraction of momentum-position entangled photon pair is one of the important topics in quantum optics. Debate on the quantumness of ghost imaging and ghost interference is the representative example. Information theoretical Bell's inequality, devised by Braunstein and Caves, is a promising method to test non-local property of two-photon propagation because it can be applied to the continuous variable entangled state. We will formulate an information theoretical Bell's inequality with transverse positions of photons on the cross-sections of the photon. Because the inequality is based on joint probability of transverse positions, its violation means that photons does not have definite paths and local realistic theory of two-photon diffraction fails.

A17 - **Quantifying the non-locality of experimental qutrits**

Bänz Bessire
University of Bern

Non-local quantum correlations require some amount of classical communication between two parties to be simulated. It is therefore natural to define as a measure of non-locality the minimal amount of classically shared information to simulate the correlation between the two quantum systems. We call this measure the non-local capacity which has the property to directly quantify non-locality as a resource for information processing. Whereas the non-local capacity does not rely on a specific Bell inequality, we consider, as a further measure of non-locality, the distance to the local polytope thereby taking into account all possible Bell inequalities. By applying both measures to experimental data, we quantify the non-locality content of two qutrits with a variable degree of entanglement. The involved two-qutrit states are generated and manipulated by a spatial light modulator in the frequency domain of broadband energy-time entangled photons. This method is highly versatile to encode high-dimensional qudit states which are of importance for fundamental tests of quantum mechanics as well as for quantum key distribution.

A18 - **Single photons from defects in two-dimensional atomic layer**

Yuming He
University of Science and Technology of China
The fluorescence of defects on monolayer WSe2 was observed under above band optical excitation. The observation of photon antibunching in photoluminence from defects demonstrated the non-classical nature of radiation. Magneto-photoluminescence revealed an unprecedented large excited state Zeeman splitting parameter in defects. Temperature spectra showed a growing linewidth as a function of Temperature. These results proved that a single defect on monlayer WSe2 can be a single photon emitter, acting like an artificial atom.

A19 - **Quantum Dot Spin-Photon Network**
Yu He
University of Science and Technology of China
Firstly, we realized all-optically tunable and highly indistinguishable single Raman photons from a driven single quantum dot spin. The frequency, linewidth and lifetime of the Raman photons are tunable by varying the driving field power and detuning. Hong-Ou-Mandel interference is demonstrated between two single photons emitted from remote, independent quantum dots with an unprecedented visibility of 0.87(4).This is useful for implement the DLCZ quantum repeater based on quantum dot. Secondly, we demonstrated the spin-photon entanglement between emitted photon and stationary electron from a quantum dot. A three qubit-two partite GHZ entanglement is demonstrated. Thirdly, we encoded polarization qubit on the flying qubit of the quantum dot, and by utilizing teleportation to remotely prepare the spin qubit state. All these results constitute the main building blocks in the quantum dot based spin-photon network protocol.

A20 - **Deterministic Solid-State Single Photons with Near-Unit Indistinguishability**
Yujia Wei
University of science and technology of China
Single photon sources based on semiconductor quantum dots offer distinct advantages for quantum information, including a scalable solid-state platform, ultrabrightness, and interconnectivity with matter qubits. A key prerequisite for their use in optical quantum computing and solid-state networks is a high level of efficiency and indistinguishability. We demonstrate deterministic generation of high quality pulsed resonance fluorescence single photons from a single InGaAs quantum dot embedded in a microcavity by using the method of Rabi rotation and rapid adiabatic passage. Comparative study is performed with transform-limited, negatively chirped and positively chirped pulses, identifying the last one to be the most robust against fluctuation of driving strength. The generated single photons from a transform-limited or positively chirped pulses driven quantum dot are background free, have a vanishing two-photon emission probability. Two-photon Hong-Ou-Mandel interferences between these photons is observed with a visibility approaching one.

A21 - **Quantum Computing for Big Data**
Xindong Cai
University of Science and Technology of China
A major challenge in the "big data" age is that the data size grows exponentially faster than the growth of classical computing resources. Therefore, a large number of computation tasks are rendered intractable for classical computers. Quantum computers promise to provide an exponential speedup over their classical counterparts for certain tasks. We report first experimental demonstrations of solving entanglement-based supervised machine learning tasks and solving linear systems of equations, both fundamental in science and engineering, on a photonics quantum computer with four photons entangled state. The ability of manipulating large vectors and matrix shown in our work, combined with other techniques, such as Hamiltonian simulation, may provide a useful quantum toolkit for dealing with the "big data". 1. X.-D. Cai, C. Weedbrook, Z.-E. Su et al., Experimental quantum computing to solve systems of linear equations. Phys. Rev. Lett. 110, 230501 (2013) 2. X.-D. Cai, D. Wu, Z.-E. Su et al., Experimental quantum machine learning, arxiv:1409.7770 (2014)

A22 - **High-Dimensional Quantum Teleportation**
Xi-Lin Wang
University of Science and Technology of China
Quantum teleportation provides a "disembodied" way to transfer quantum states of an object over arbitrarily long distance, without physical travelling of the object itself. A single quantum particle can possess various degrees of freedom-internal and external-and with coherent coupling among them. Yet, all the previous experiments were limited to teleportation of a single degree of freedom only. A fundamental open challenge is to simultaneously teleport multiple, or all, degrees of freedom that fully describe an object, thus truly teleporting it intactly. Here, we demonstrate the first quantum teleportation of both polarization (spin) and orbital angular momentum of a single photon, in the form of spin-orbit hybrid entangled states. We

use spin-orbit hyper-entangled photon pairs as quantum channel, and develop a new technique to discriminate hyper-entangled Bell state exploiting quantum non-demolition measurement. This work demonstrates an enhanced capability for quantum communications, and moves a step toward complete teleportation of complex quantum systems. More detail: Arxiv 1409.7769

A23 - **Observation of Geometric Phases in Three-State Systems for Two-Photon Polarization**

Kazuhisa Ogawa
Department of Electronic Science and Engineering, Kyoto University

The geometric (Berry) phases defined by three discrete states (three-vertex geometric phases) in three-state systems play the fundamental roles as minimal building blocks of any geometric phases. We focus on the three-vertex geometric phases for polarization states of photon pairs, which forms a three-state system. We found that the three-vertex geometric phases for polarization-entangled photon pairs exhibit drastic changes by 2π twice associated with the variation of one constituent state. The phase shifts are essentially different from that for one-photon polarization, which exhibits only one drastic change, and can be interpreted as the variation of the areas of two spherical triangles on the Bloch sphere [PRA 84, 052114 (2011)]. We also experimentally demonstrated the two drastic changes of the geometric phases for polarization-entangled photon pairs. The measurements of geometric phases were conducted by using the time-reversed version of a two-photon interferometer, which can be constructed in a classical optical system. We observed the two drastic changes in the geometric phases with high signals.

A24 - **Mathematical Structure of a Three-Slit Experiment**

Sascha Agne
Institute for Quantum Computing

Interference is a phenomena that distinguishes quantum from classical physics and as a consequence of Born's rule, it can only appear between pairs of alternatives, i.e., according to quantum mechanics, there should be no interference between three or more paths. A three-slit experiment by Sinha et al. bounds higher interference terms to less than 10^{-2} [1]. In this paper we identify a three-slit experiment with a group, analyse its consequences and demonstrate its significance for the interpretation of the experiment. [1] Sinha U, Couteau C, Jennewein T, Lafl amme R and Weihs G 2010 Ruling Out Multi-Order Interference in Quantum Mechanics, Science, vol 329, 418

A25 - **Experimental violation of a d-dimensional Bell inequality for various quantum states with energy entangled photons**

Sacha Schwarz
Institute for Applied Physics, University of Bern

Entangling two qudits, d-dimensional Bell inequalities can be derived, delivering an extended insight into the non-locality of Nature beyond qubit-based systems. We encode qudits in the energy spectrum of entangled photons by defining frequency bins within their spectra. Broadband entangled photons are generated by continuous wave spontaneous down-conversion and detected in coincidence by sum frequency generation. By means of experimental methods used for shaping fs-laser pulses, frequency bins can be addressed in the photons spectra. Furthermore, controlling each frequency component individually allows to manipulate and characterize the quantum states. Within this framework, we perform Bell-type experiments on bipartite two- and three-level systems. We investigate sets of quantum states which contain all corresponding Schmidt decompositions. We experimentally study the violation of the CGLMP inequality, and characterize its non-trivial behavior with respect to variable degrees of entanglement. In order to achieve a maximal violation for each quantum state configuration, we numerically optimize the required measurement settings of SU(d) generalized projective measurement bases.

A26 - **Experimental demonstration of quantum interference in phase space**

Yinghong Xue
East China University of Science and Technology

In this report, we experimentally observed the oscillation photon number distribution of a squeezed state, which was generated from a single-pass degenerated optical parametric amplifier. The results show that the oscillatory photon statistics depends on both the amplitude of incidence coherent laser and parameter of squeezed state. This is regarded as quantum interference in phase space. To our knowledge, this is the first directly experimental demonstration of quantum interference in phase space .

A27 - **Generation of tripartitle quantum correlation among intenstiy squeezing states by frequency doubling in a dual-port resonator**

Yun Zhang
The University of Electro-communications
We present a new technique for generation of tripartitle quantum correlated amplitude squeezed light beams, using a singly resonnant frequency doubler with two output ports. The two output second harmonic beams are both nonlineraly coupled to the common fundamental beams even though they have no direct interation. The nonlinear coupling produces noise reduction of intensity for each beams and quantum correlations among three beams. In our first experiment, we measured amlitude squeezing of 0.6 dB, 0.8 dB and 0.6 dB for the fundamental beams, upward SH beam and downward SH beam, respectively. Meanwhile, quantum correlation of 0.6 dB between the two amplitude squeezed SH beams and quantum anticorrelation of 0.8 dB between the squeezed fundmental beam and each of SH beams were observed around the range of optimum conversion efficiency. This opens a new way to produce tripartile quantum correlated systems.

A28 - **Highly efficient sub-μs spin state detection of single trapped atoms for a loophole-free test of Bell's inequality**
Norbert Ortegel
Faculty of Physics, LMU Munich
Bell's inequality allows to test the validity of local hidden variable theories by local measurements on a bipartite system. In a conclusive test a large fraction of all created particle pairs must be read out (detection loophole) and space-like separation of the measurements on the particles must be assured (locality loophole). We aim at a test of Bell's inequality with both loopholes closed simultaneously. Our system consists of a pair of Rb87-atoms which are independently trapped at a distance of 400m. Using entanglement swapping we create heralded entanglement between the atoms which allows closing the detection loophole. Recently we successfully implemented a ultra-fast readout of a single trapped atom based on Zeeman-state selective ionization and subsequent detection of the ionization fragments with channel electron mulitpliers. Including random choice of the measurement basis the overall duration of the readout will be below 1μs. For the given distance between the atoms this will allow to close the locality loophole. With a detection efficiency of the ionization fragments of above 98% we achieve a fidelity for the state readout of a single atom of ~95%.

A29 - **Multipartite nonlocality of high-dimensional systems and its applications.**
Wonmin Son
Sogang Univ.

A30 - **Highly Retrievable Spinwave-Photon Entanglement for Loophole-Free Bell Tests**
Sheng-Jun Yang
University of Science and Technology of China
All experimental tests of Bell inequalities so far suffer from loopholes, such as the locality loophole and the detection loophole. Here we present a source of spinwave-photon entanglement which can be used as an essential element to close the locality and the detection loophole simultaneously. The spin-wave qubit is stored in an atomic ensemble quantum memory with cavity enhancement. Retrieval efficiency of the spinwave is measured to be 76(4)%, which surpasses the detection threshold to close the detection loophole. Storage lifetime of the spinwave is measured to be $25.2(4)\mu$s, which allows entanglement distribution over several kilometers to close the locality loophole. Thus our work pave the way towards a loophole-free Bell inequality test with atomic ensemble and linear optics, and may also find important applications in device-independent quantum key distribution and scalable quantum networks.

A31 - **Multi-mode Entanglement is Detrimental to Lossy Optical Quantum Metrology**
Paul Knott
University of Leeds
In optical interferometry multimode entanglement is often assumed to be the driving force behind quantum enhanced measurements. Recent work has shown this assumption to be false: single mode quantum states perform just as well as their multimode entangled counterparts. We go beyond this to show that when photon losses occur - an inevitability in any realistic system - multimode entanglement is actually detrimental to obtaining quantum enhanced measurements. We specifically apply this idea to a superposition of coherent states, demonstrating that these states show a robustness to loss that allows them to significantly outperform their competitors in realistic systems. A practically viable measurement scheme is then presented that allows measurements close to the theoretical bound, even with loss. These results promote a new way of approaching optical quantum metrology, using single mode states, that we expect to have great implications for the future.

A32 - **Experimental verification of quantum precision limit in adaptive qubit state**

tomography

Guoyong Xiang
University of Science and Technology of China

Quantum state tomograpy is a primitive of various quantum information processing tasks, such as quantum computation, communication, and cryptography. The precision limit in quantum state estimation is of great interest not only to practical applications but also to foundational studies. However, little is known about this subject in the multiparameter setting even theoretically. In the case of a qubit, the theoretic precision limit was determined by Hayashi as well as Gill and Massar, but attaining the precision limit in experiments has remained a challenging task. Here we report the first experimental verification of this precision limit in adaptive quantum state tomography on optical polarization qubits. Our study may have significant implications for multiparameter quantum estimation problems, such as quantum metrology. Meanwhile, it may promote our understanding about the complementarity principle and uncertainty relations from the information theoretic perspective.

A33 - **High precise temporal and spectral quantum properties in a single-photon frequency comb state**

Changliang Ren
Chong Qing institute of green and intelligent technology, Chinese Academy of Sciences

We analyzed the quantum properties of a single photon that prepared in a time-energy state described by a frequency comb. Such single-photon frequency comb state combines high precision in time with precisely defined photon energies. It is shown that simultaneous suppression of time and energy uncertainties can be described by a separation of scales. We compare this with the suppression of uncertainties in the two-particle correlations of an entangled state. To illustrate the sensitivity of the frequency-comb states to small shifts in time and frequency, we consider the Hong-Ou-Mandel dips observed in two-photon interference when both time and frequency shifts between the input photons are varied. It is shown that the interference of two photons in equivalent frequency-comb states results in a two-dimensional Hong-Ou-Mandel dip that is narrow in both time and frequency, while the corresponding entangled photon pairs are only sensitive to temporal shifts. Frequency-comb states thus represent an alternative approach to quantum operations beyond the uncertainty limit.

A34 - **Adaptive Quantum State Estimation of an Entangled Qubit State**

Stefan Lerch
Institute of Applied Physics, University of Bern

We report on the experimental demonstration of adaptive quantum state estimation (AQSE) on entangled photon pairs. By means of a spatial light modulator (SLM) we realize entangled two qubits state by discretizing the frequency spectrum of broadband energy-time entangled photons into frequency bins. In addition the SLM allows to rapidly set different projection measurements, thus enables AQSE with a minimal deadtime. We present further a non-adaptive procedure that allows a comparison of the two estimation methods. We experimentally demonstrate the consistency and efficiency of AQSE and show the effective ability of to outperform the non-adaptive estimation scheme.

A35 - **Complete Temporal Characterization of Single Photons**

Adarsh Shankar Prasad
Institute for Quantum Science and Technology, University of Calgary

Precise information about the temporal mode of optical states is crucial for optimizing their interaction efficiency between themselves and/or with matter in various quantum communication devices. Here we propose and experimentally demonstrate a method of determining both the real and imaginary components of a single photon's temporal density matrix by measuring the autocorrelation function of the photocurrent from a balanced homodyne detector at multiple local oscillator frequencies. We lay the theoretical foundation for our work and describe the experimental methods involved in detail. We show the results of testing our method on single photons heralded from biphotons generated via four-wave mixing in an atomic vapor. We develop an appropriate theoretical model for our experimental settings and describe the involved calculations explicitly. The obtained experimental results show excellent agreement with theoretical predictions for the various settings involved.

A36 - **Quantum interferometry with binary-outcome measurements**

Guang-Ri Jin
Physics Department of Beijing Jiaotong University

Optimal measurement scheme with an efficient data processing is important in quantum-enhanced interferometry. Here we prove that for a general binary-outcome measurement, the simplest data processing based on inverting the average signal can saturate the Cramer-Rao bound. This idea is illustrated by binary-outcome homodyne detection, even-odd photon counting (i.e., parity detection), and zero-nonzero photon counting that have achieved super-resolved interferometric fringe and shot-noise limited sensitivity in coherent-light Mach-Zehnder interferometer. The roles of phase diffusion are investigated in these binary-outcome measurements. We find that the diffusion degrades the fringe resolution and the achievable phase sensitivity. Our analytical results confirm that the zero-nonzero counting can produce a slightly better sensitivity than that of the parity detection, as demonstrated in a recent experiment.

A37 - **Qubit readout by using the estimator-correlator formula**

Shi Lin Ng
National University of Singapore

The measurement of a quantum two-level system, or a qubit in modern terminology, often involves an electromagnetic field that interacts with the qubit, before the field is measured continuously and the qubit state is inferred from the noisy field measurement. During the measurement, the qubit may undergo spontaneous transitions, further obscuring the initial qubit state from the observer. Taking advantage of some well known techniques in stochastic detection theory, here we propose a novel signal processing protocol that can infer the initial qubit state optimally from the measurement in the presence of noise and qubit dynamics. Assuming continuous quantum-nondemolition measurements with Gaussian or Poissonian noise and a classical Markov model for the qubit, we derive analytic solutions to the protocol in some special cases of interest using It-o calculus. Our method is applicable to multi-hypothesis testing for robust qubit readout and relevant to experiments on qubits in superconducting microwave circuits, trapped ions, nitrogen-vacancy centers in diamond, semiconductor quantum dots, or phosphorus donors in silicon.

A38 - **Optomechanical Parameter Estimation**

Shan Zheng Ang
National University of Singapore

We propose a statistical framework for the problem of parameter estimation from a noisy optomechanical system. The Cramer-Rao lower bound on the estimation errors in the long-time limit is derived and compared with the errors of radiometer and expectation-maximization (EM) algorithms in the estimation of the force noise power. When applied to experimental data, the EM estimator is found to have the lowest error and follow the Cramer-Rao bound most closely. Our analytic results are envisioned to be valuable to optomechanical experiment design. The presented framework is valid for quantum systems described by a Gauss-Markov model. This makes our study, in particular, the EM algorithm with its ability to estimate most of the system parameters, relevant to optomechanical sensing, atomic magnetometry and fundamental tests of quantum mechanics.

A39 - **Multimode Kapitza-Dirac interferometry with trapped Cold Atoms**

WeiDong Li
Institute of theoretical physics

We present one novel suggestion to realize a multimode interferometer with cold atoms confined in a harmonic trap. A first Kapitza-Dirac pulse creates several spatially addressable modes which are coherently recombined by the harmonic potential and mixed again by a second Kapitza-Dirac pulse. A phase shift among the mode is estimated by fitting the density profile or by measuring the number of atoms in each output mode. The expected sensitivity is rigorously calculated with the Fisher information and the Cramer-Rao lower bound. For the measurement of the gravitational acceleration g we predict, with typical parameters of a compact setup, a temperature independent sensitivity which can exceed by different order of magnitudes the sensitivity of current atomic interferometers.

A40 - **Experimental study of Mach-Zehnder interferometer with squeezed and EPR entangled optical fields**

Wei Li
Institute of Opto-Electronics

We present experimental study of Mach-Zehnder(M-Z) interferometer with two types of input optical fields with the continuous-variable nonclassical optical fields, i.e., the two squeezed states and the Einstein-Podolsky-Rosen (EPR) entangled states. The interference patterns of M-Z interferometer vary periodically as the relative phase of the two arms of the interferometer is scanned, and are measured by the balanced homodyne detection system. It shows that there are different interference patterns and periodicity for two cases which depend on the relative phase of input optical fields. This work will has the important applications in quantum estimation and metrology of quantum transformations and states.

A41 - **Cavity-assisted, quantum-limited atomic magnetometer**

Heng Shen
Niels Bohr Institute, University of Copenhagen

We report on a quantum-noise limited, radio-frequency magnetometer based on the optical read-out of atomic Cesium vapors at room temperature.The atomic medium is is contained in an alkene-coated, glass cell with dimensions 300micrometer*300micrometer*10mm, providing submillimiter spatial resolution. The cell is located inside a standing wave optical cavity to enhance the coherent light-matter interaction.We demonstrate a magnetic field sensitivity of 158fT/sqrt(Hz), corresponding to the projection noise limit of detection by using stroboscopic modulation for back-action evasion. We also show the generation of a 3 dB squeezed spin state conditioned on the measurement result, which indicates multipartite entanglement and metrological advantage.

A42 - **Ultra-sensitive mass spectrometer via dynamical decoupling**

Nan Zhao
Beijing Computational Science Research Center

We propose an ultra-sensitive mass spectrometer based on a coupled quantum-bit-oscillator system. Under dynamical decoupling control of the quantum bit (qubit), the qubit coherence exhibits a comb structure in time domain. The time-comb structure enables high precision measurement of oscillator frequency, which can be used as an ultra-sensitive mass spectrometer. Surprisingly, in ideal case, the sensitivity of the proposed mass spectrometer, which scales with the temperature T as $T^{-1/2}$, has better performance in higher temperature. While taking into account qubit and oscillator decay, we show that the optimal sensitivity is independent on environmental temperature T. With present technology on solid state spin qubit and high-quality optomechanical system, our proposal is feasible to realize an ultra-sensitive mass spectrometer in room temperature.

A43 - **Binary projective measurement onto an arbitrary superposition of coherent states.**

Shuro Izumi
National Institute of Information and Communication Technology

Quantum measurement plays an essential role in Quantum Information Processing (QIP). One of the experimental challenges in optical QIP is to implement non-trivial quantum measurements which cannot be described by usual physical observables e.g. quadrature amplitudes or photon numbers. An example of that includes the projection measurement onto a superposition of coherent states (SCS). SCS is a macroscopic quantum superposition and thus often regarded as a 'Schrodinger cat state'. Its generation in optical regime has been successfully demonstrated by several groups though the projection measurement onto the SCS bases had not been explored extensively. We show that the SCSs projection measurement is approximately realizable by the measurement process consisting of a displacement operation and photon-number- resolving detection. By optimizing amplitude and a phase of the displacement operation, the SCSs measurement with arbitrary superposition coefficients can be implemented. Our scheme is worth not only for fundamental quantum physics but also for applications such as the SCS based optical quantum computation.

A44 - **Generation of continuous-wave 194 nm light with elliptical Gaussian beams**

Hongxin Zou
National University of Defense Technology

We report in this paper the generation of over 1 mW line-narrowed continuous-wave radiation at 194 nm in a Beta Barium Borate (BBO) crystal via sum frequency mixing (SFM). The two source beams, which are at 718 nm and 266 nm, respectively, are mixed under critically phase matched condition (CPM). Considering the walk-off effect in CPM crystals, the source beam waists are designed to be elliptical so that the conversion efficiency can be promoted. The 266 nm beam produced by frequency doubling of 532 nm laser is shaped close to the diffraction limit to achieve better mode matching. Frequency stabilization techniques such as saturated absorption spectrum and optical cavity are adopted to reduce the linewidth of the 194 nm beam to 2 MHz.

A45 - **The precision of weak measurement**

Liang Xu
Nanjing University

Weak measurement, which reveals partial information about a quantum state without "collapsing" it, has drew increased interest in precision metrology. When the interaction between the quantum system and the measurement apparatus is small, with proper pre-and post-selection on the quantum system, the result of the measurement can be dramatically amplified proportional to the 'weak value'. Unfortunately, the amplified outcomes tend to occur with highly suppressed probabilities due to the post-selection. Yet the overall signal-to-noise ratio as well as the measurement precision does not increase. Here, we compare the conditions to maximize the total information in the post-selected state with those to maximize the weak value, i.e. the displacement of the apparatus. Our results reveal the complex relation between the measurement precision and the amplifying effect in weak measurement. The study will shed new light on the design of new protocols of precision metrology. References: [1] Lijian Zhang, Animesh Datta, Ian A.Walmsley, arXiv: 1310.5302(2013) [2] X.Zhu, Y,Zhang, S.Pang, C.Qiao, Q.Liu, and S. Wu, Phy. Rev. A84, 052111(2011). [3] J.Combes, C.Ferrie, Z.Jiang, and C.M.Caves, Phys. Rev. A 89, 052117(2014)

A46 - **Precision Measurements Utilizing Squeezed Spin States via Two-axis Counter Twisting Interactions**

Emi Yukawa
National Institute of Informatics

Squeezed spin states exhibit intrinsic quantum properties such as entanglement and reduced quantum spin fluctuations below the standard quantum limit. These properties have proved instrumental in quantum precision measurements. The minima of achievable quantum spin fluctuations have been well investigated; however, the optimal precisions of measurements utilizing squeezed spin states, which are defined by the quantum Cramer-Rao inequality, have not been fully analyzed. In this presentation, we show that the two-axis counter twisting interaction squeezes a coherent spin state into three states of interest in precision measurements in addition to the well-known Heisenberg-limited state of quantum spin fluctuations: the twin-Fock state, the equally-weighted superposition state, and the state that achieves the minimum optimal sensitivity. Similarly to the recently demonstrated case of squeezed spin states via the one-axis twisting interactions, the optimal sensitivities of all these states satisfy the Heisenberg limit for the sensitivity.

A47 - **Effects of Dzyaloshinskii-Moriya interaction on entanglement and fidelity intrinsic decoherence in quantum spin system**

Meng Qin
PLA University of Science and Technology

By investigating the Milburn equation, we study the entanglement and fidelity dynamics properties of the spin system with Dzyaloshinskii-Moriya interaction and magnetic field. The effects of Dzyaloshinskii-Moriya interaction, anisotropic parameter and the initial state on entanglement and fidelity are discussed. The initial state greatly affects the entanglement. The dependence of entanglement and fidelity behave periodicity on the angle of initials state. We can select optimal initial state for different condition according to requirement.

A48 - **Experimental Quantum Speed Up of Field Evolution in an Optical Cavity QED System**

Zhihui Yan
University of Maryland

The quantum speed of the evolution of a state is an important parameter in quantum information. We have experimentally measured the quantum speed of the field in an optical cavity QED system in the intermediate coupling regime under weak driving. We focus our measurements on the cavity field coupled to an atomic polarization (N two-level atoms), that we treat as a tunable environment. Changing the number of atoms changes the quantum speed of state evolution of the optical cavity field as measured by the second order correlation function of the intensity escaping the cavity. Our results open the possibility to control and manipulate the quantum speed by tailoring the environment. Work supported by the NSF of USA.

A49 - **Optimization of shortcuts to adiabaticity**

Xi Chen
Shanghai University

Quantum adiabatic processes are very useful for the manipulation and control of quantum states. However,they take typically a long time, which is problematic because of decoherence and noise. "Shortcuts to adiabaticity", to accelerate slow adiabatic processes without final excitation, are alternative protocols for the manipulation and control of quantum systems. In this talk, we will focus on the optimization of the stability of shortcuts protocols versus different sources of errors or fluctuations. Main two settings are considered: shortcuts to adiabatic transport of a particle in a trap, and shortcuts to adiabatic population inversion of the internal state of an atom. In both settings, we will examine the stability of the shortcuts versus noise and systematic error. The goal will be always to optimize the stability of these quantum control schemes.

A50 - **Suppressing decoherence and unwanted interactions in coupled quantum systems efficiently by driving fields of constant amplitudes**

Zhenyu Wang
Institute of Theoretical Physics, Ulm University

We provide an explicit procedure to construct continuous or pulsed dynamical decoupling (DD) for multi-level systems (qudits) coupled to their environment.The resulting DD control can be implemented by driving fields of constant amplitudes and does not require field switching. Arbitrary decoherence and unwanted coupling between the qudits can be suppressed. We show how to retain desired qudit-qudit interactions while suppressing qudit decoherence, e.g., for coherence-protected two-qudit quantum gates or for quantum simulations. We also provide a construction to implement coherence-protected single-qudit quantum gates. Explicit simplifications on the control overheads are given for realistic systems. For example, for qubits with two-body qubit-qubit interactions, quadratical increase $O(n^2)$ on the maximal field amplitude is sufficient, where $n \leq N$ is the number of indirectly interacting sets of qubits and can be much smaller than the total number N of qubits with near-neighbor interactions, and for dephasing models, the scaling of the overheads becomes linear $O(n)$.

A51 - **14N nitrogen vacancy centers as three-qubit systems**

Burkhard Scharfenberger
National Institute of Informatics

We investigate quantum control of a 14NV- nitrogen vacancy color center in diamond using simulated microwave- and radio-frequency pulses with a view towards using the full 9 dimensional Hilbert space for quantum information tasks. Both (ground state) NV electronic spin and nitrogen nuclear spin of the a 14NV- center, the variety most commonly found in nature, are S=I=1. Here, we numerically investigate which encoding of three qubits in this 9 dimensional Hilbert space gives the fastest and most reliable implementation of the basic gate set required for quantum computation in a quantum repeater. There, three qubit nodes have the advantage of allowing basic error correction on lower fidelity links (correcting either phase or bit flip errors) or holding two links at the same time in a nuclear spin memory (e.g. a link to the left and right in a central node). We find, that this is provides a promising way simplifying application of NV centers, as lengthy searches for NVs with the proper environment (13C carbon spins) become unnecessary. This is a particular handicap in isotopically purified (13C depleted) samples, which are the ones showing the best coherence times.

A52 - **Quantum control of spinor Bose-Einstein condensates**

Shi Wang
National Institute of Informatics

Spinor Bose-Einstein condensates (BECs) on atomic chips are potential candidates for quantum memories as they have long coherence times and have been shown to be coherently controlled. Unlike most candidates for quantum memories which are genuine or effective single particle systems, BECs are a many-body system where the quantum information is stored as a spin coherent state involving typically 10^4 atoms. It is therefore a non-trival task to extend standard quantum control methods to the BEC case. The objective of this work is to design a control law to steer an unknown state of a spinor Bose-Einstein condensates (BECs) into a desired state. We propose a controller design method using the stochastic stability theory, quantum filtering theorem and weak measurements. Here, we use weak measurements to delay the process of quantum state reduction. During the delay period, we can apply our control laws to different axes to manipulate the BECs according to control purposes. Several simulations are given to illustrate our methods.

A53 - **Optimal transport of cold atoms in anharmonic traps**

Qi Zhang
Shanghai University

Efficient transport of cold atoms in harmonic trap has been proposed by using shortcuts to adiabaticity, based on Lewis-Riesenfeld dynamics invariants. In this paper, we design optimal trajectories to transport cold atoms in anharmonic traps, combining an invariant-based inverse engineering with optimal control theory. Since the actual optical traps are Gaussian but not harmonic, we bound the relative displacement between the trap center and the center of the mass of transport mode, and find the optimal trajectories for minimizing the anharmonic perturbation energy with high fidelity.

A54 - **Experimental single-qubit open-system simulation**

Chang Liu
University of Science and Technology of China

Quantum control is the central in quantum information science, and leads to novel applications, such as quantum computation, quantum cryptography and quantum simulation. Such control in closed system has been achieved in atomic physics, quantum optics, and so on. However, the precise and complete control in an open-system has not been extensively studied, even for single particle. Here, we first experimentally realize the quantum control in a single-qubit open-system with photons. With the help of one ancillary photon and one-qubit two-qubit unitary gate, we illustrate our ability to simulate arbitrary dissipative process with high fidelity of 90%. By using this quantum architecture, we simulate the process of superposition protection via weak measurement and the universal transpose of a quantum state based on structural physical approximation. Besides being of an effective method to simulate arbitrary single qubit channel, our work opens up the avenue towards universal quantum computation based on dissipative resource.

A55 - **Implementing the single-photon-added coherent source in practical quantum key distributions**

Qin Wang
Nanjing University of Posts and Telecommunications

We propose new schemes on implementing the single-photon-added coherent source in the quantum key distributions. We apply the source in either the standard BB84 protocol or the new proposed measurement-device-independent quantum key distribution. We compare its performance with the case of using other existing sources, e.g., the weak coherent source or the heralded single-photon source, giving out numerical simulations. Our simulation results demonstrate that in both protocols the single-photon-added coherent source can irresistibly defeat all other existing sources. Moreover, even when taking statistical fluctuation into account, we can still achieve a high key generation rate at long distance with our new schemes. Besides, the single-photon-added coherent source can be generated with current technology. Therefore, it has a promising prospect in the field of quantum communications in the near future.

A56 - **Reference-Frame-Independent Quantum-Key-Distribution Server with a Telecom Tether for an On-Chip Client**

Pei Zhang
Xi'an Jiaotong University

We demonstrate a client-server quantum key distribution (QKD) scheme. Large resources such as laser and detectors are situated at the server side, which is accessible via telecom fiber to a client requiring only an on-chip polarization rotator, which may be integrated into a handheld device. The detrimental effects of unstable fiber birefringence are overcome by employing the reference-frame-independent QKD protocol for polarization qubits in polarization maintaining fiber, where standard QKD protocols fail, as we show for comparison. This opens the way for quantum enhanced secure communications between companies and members of the general public equipped with handheld mobile devices, via telecom-fiber tethering.

A57 - **Continuous-Variable Measurement-Device-Independent Quantum Cryptography Using Practical Squeezed States**

Yichen Zhang
Beijing University of Posts and Telecommunications

We report a continuous-variable measurement-device-independent quantum key distribution protocol using practical squeezed states, where the two legitimate partners send practical Gaussian-modulated squeezed states to an untrusted third party. Security analysis shows that the protocol can not only defend all detector side channels but also attain higher secret key rates and transmit longer distance than coherent-state based protocol. Such protocol with a small variance allows one to directly use the EPR state as the source in a practical experiment. If Alice and Bob do use EPR sources, they could completely outplay side-channel attacks in their private spaces which makes the continuous-variable measurement-device-independent quantum key distribution protocol more secure.

A58 - **Direct Counterfactual Communication with Single Photons**

Zhu Cao
Tsinghua University

Intuition in our everyday life gives rise to a belief that information exchanged between remote parties has to be carried by physical particles. Surprisingly, by recent theoretical studies, quantum mechanics allows counterfactual communication even without actual transmission of physical particles. Using a single photon source, we experimentally demonstrate counterfactual communication and successfully transfer a monochrome bitmap from one location to another by employing a nested version of the quantum Zeno effect. Besides of its fundamental interest, our experimental scheme is applicable to other quantum technologies, such as imaging and state preparation.

A59 - **Quantum Communication with Coherent States and Linear Optics**

Juan Miguel Arrazola
Institute for Quantum Computing

We introduce a general mapping for encoding quantum communication protocols involving pure states of multiple qubits, unitary transformations, and projective measurements into another set of protocols that employ coherent states of light in a superposition of optical modes, linear optics transformations, and measurements with single-photon threshold detectors. This provides a general framework for transforming protocols in quantum communication into a form in which they can be implemented with current technology. To illustrate the power of this mapping, we make use of it to construct new protocols for quantum fingerprinting, the hidden matching problem and quantum digital signatures, all of which can be implemented with existing techniques. Our work thus has the potential of bringing a wide class of quantum communication protocols closer to their experimental demonstration. Additionally, our results are useful for analysing the properties of quantum-optical protocols employing coherent states and linear optics, as well as in understanding the fundamental connection between entanglement and non-orthogonality

A60 - **More Randomness from the Same Data**
Jean-Daniel Bancal
Center for Quantum Technologies
Randomness is a resource for numerous applications, and the violation of a Bell inequality can certify the generation of private randomness. However, for given Bell test statistics, different Bell inequalities can certify various amounts of randomness. Here, by quantifying randomness directly from correlations, we show how an optimal Bell inequality can be derived to certify the largest possible rate of randomness generation. Our analysis assumes an adversarial scenario relevant for a practical realization of the protocol – it is similar to the one used for practical quantum key distribution (QKD). In this context, we elucidate how randomness can be generated while an initial random seed is needed, e.g. to choose settings for the Bell test. We also demonstrate that, in this context, extracting randomness from all measurement settings restricts the power of the adversary. The applicability of our method is illustrated by several examples.

A61 - **Experimental quantum key distribution with source flaws and tight finite-key analysis**
Feihu Xu
University of Toronto
Decoy-state quantum key distribution (QKD) is a standard technique in current quantum cryptographic implementations. Unfortunately, existing experiments have two important drawbacks: the state preparation is assumed to be perfect without errors and the employed security proofs do not fully consider the finite-key effects for general attacks. These two drawbacks mean that existing experiments are not guaranteed to be secure in practice. Here, we perform an experiment that for the first time shows secure QKD with imperfect state preparations at long distances and achieves rigorous finite-key security bounds for decoy-state QKD against general quantum attacks in the universally composable framework. We implement both decoy-state BB84 and three-state protocol on top of a commercial QKD system and generate secure keys over 50 km standard telecom fiber based on a recent security analysis that is loss-tolerant to source flaws. Our work constitutes an important step towards secure QKD with imperfect devices.

A62 - **Demostration of Quantum Communications in Satellite Downlinks**
Paolo Villoresi
University of Padova
Quantum Communications (QC) on planetary scale require complementary channels including ground and satellite links. The former have progressed up to commercial stage using fiber-cables. It is then very actual the study of links for space QC and eventually the demonstration of protocols such as quantum-key-distribution (QKD) and quantum teleportation along satellite-to-ground or intersatellite links. In this work we report on the faithful transmission of qubits from Space to ground by exploiting satellite corner cube retroreflectors acting as transmitter in orbit. We demonstrate the achievement of QBER of 3.7% (LARETS) and 6.7 % (STARLETTE), suitable for QKD applications. From the link budget, the mean photon number of the state leaving the satellite has been estimated to be of the order of unity. A novel synchronization procedure was introduces, that allows for sub-nanosecond qubit arrival identification, necessary for noise suppression. Finally, on the base of the findings, we envisage a two-way QKD protocol exploiting modulated retroreflectors that necessitates a minimal payload on satellite, thus facilitating the expansion of Space QC and Quantum Physics tests in Space.

A63 - **Security analysis of quantum cryptography system**
Linmei Liang
national university of defense technology
Quantum cryptography is secure based on quantum physics and one-time pad, but real quantum cryptography system consist of real optical and electrical equipments, and there exists security loophole in those real equipments. In order to obtain secure quantum cryptography system, it is necessary to examine those security loopholes. We propose several attack and defense protocols with regard to the system which is encoded in discrete and continuous variable , including Passive Faraday mirror attack, Partially random phase attack, Single-photon-detector attack,

Wavelength-selected PNS attack, random phase module against PRP attack, Wavelength attack on CV-QKD with a heterodyne protocol etc. Eve can make use of those security loopholes to obtain full secure key without being detected. Those attacks remind people to design more secure quantum cryptography system.

A64 - **Proof of Principle Experiment for Plug and Play Measurement-Device-Independent Quantum Key Distribution**

Yong-Su Kim
Center for Nano and Quantum Information, KIST

We propose and experimentally demonstrate the proof of principle experimental on an improved scheme for MDI-QKD, named Plug and Play MDI-QKD or P&P MDI-QKD. Our scheme does not need any tricky method to match up. The P&P MDI-QKD looks like the original one in that there are three parties, Alice, Bob, and Charlie. The difference is that Charlie has both a source and detectors, and Alice (Bob) has only modulation devices. This is why the proposed architecture does not need any complex active control. The detailed protocol is as in the following. Charlie sends weak coherent pulses to Alice and Bob. Then Alice (Bob) randomizes phase of the pulse in order to remove the first-order interference, and encodes information on polarization or phase, and reflects it back to Charlie. A variable optical attenuator can be added to implement decoy protocol before sending the pulse to Charlie. Alice and Bob carry out this procedure independently. Finally, Charlie does Bell state measurement for the reflected pulses and announces the coincidence results. After post-processing, Alice and Bob can share secret keys. Detailed protocol and experiental results will be presented.

A65 - **Tampering with source harms the security of quantum cryptography**

Shihai Sun
National University of Defense Technology

Due to the measurement-device-independent quantum-key distribution (MDI-QKD), the source is the last exploitable region for a potential eavesdropper in quantum cryptography. Most commercial and experimental QKD systems use semiconductor laser diode (S-LD) as emitter of signal photons due to the unavailability of single photon source. Although the source based on S-LD contains potential loopholes, the security is still attainable by carefully precharacterizing the source. However, in this letter we propose and experimentally demonstrate, for both commercial and homemade pulse lasers based on S-LD, that Eve can actively and temporarily tamper with parameters of these sources by infusing photons into S-LD from channel. For example, when pulse lasers are illuminated by a bright controlling light, the phase of each pulse is related, which is random without controlling light, then the phase randomization assumption of decoy state QKD is broken and the security of systems are compromised by exploiting some known quantum hacking strategies.

A66 - **Quantum bit commitment combining with BB84 protocol**

Linxi Zhang
Xidian University

We proposed a new quantum bit commitment scheme in which secret key need not to be provided by other quantum key distribution system. We can get the bit commitment with probability p by adding a waiting time in a frame during operating the BB84 protocol. Then the measurement outcomes can be encrypted by one-time pad with the key generated by BB84 protocol. We can also obtain the redundant secret keys to encrypt other information in this quantum key distribution system. The new scheme can be used to perform routing operation by which the source can be made sure that the virtual circuits it chosen doesn't influence on other relay routes in a large-scale trusted relay-based quantum network.

A67 - **General framework for alignment-free quantum communication: beyond covariant noise**

Mehdi Ahmadi
University of Nottingham

In quantum communication protocols the existence of a shared reference frame between two spatially separated parties is normally presumed. However, in many practical situations we are faced with the problem of misaligned reference frames. In previous studies it has been shown that misalignment of reference frames is equal to a noisy quantum channel and that encoding information in decoherence-free subspaces (DFS) allows us to be able to communicate in spite of covariant noise, i.e. the type of noise that commutes with the encoding channel. In this paper, we present a general framework in order to devise optimal encoding and decoding operations for alignment-free communication protocols. This framework is applicable to both cases of covariant and non-covariant noise. In particular, we find that the existence of decoherence-free subsystems is not necessary in the presence of non-covariant noise. This is as opposed to the case of covariant noise where encoding information in DFS is the absolute necessity.

Moreover, we present an operational measure for the efficiency of alignment-free communication schemes. Finally, we show that decreasing the amount of correlation between the generators of the noisy channel and the encoding channel amounts to increasing the quality of communication when Alice and Bob do not share a common reference frame.

A68 - **Orthogonal Frequency Division Multiplexing in Trusted-Node Quantum Key Distribution Networks**

Mohsen Razavi
University of Leeds

Orthogonal frequency division multiplexed (OFDM) quantum key distribution (QKD) links are proposed and theoretically analysed. OFDM offers a spectrally efficient technique for multiplexing. Its combination with QKD facilitates high-rate flexible secure key exchange. Such links are of interest at the core of trusted-node QKD networks, which constitute the first generation of quantum communication networks. In such networks, the key-exchange traffic is much higher at the internal core nodes than that of access nodes and high-rate QKD links are desirable. Moreover, to share the infrastructure among multiple service providers, without requiring them to trust each other, multiplexing techniques need to be used. Here, we consider two possible setups for all-optical OFDM and evaluate their suitability for QKD applications. It turns out that the existing passive OFDM decoders are not fit for the main purpose of increasing the key rate. We therefore propose an active setup that resolves the inherent loss issue. We also consider time-misalignment errors, which are key impediments in OFDM systems, and propose a time-gating solution to alleviate this problem. Full version soon on the arXiv.

A69 - **Analysis of underwater free space quantum key distribution**

Yong-jian Gu
Ocean University of China

Driven by the communication requirements of underwater sensor networks, submarines and underwater vehicles, underwater wireless communication has been developing rapidly in recent years, for which underwater quantum key distribution (QKD) can provide absolute security. In this research, based on Ocean Optics, Mie scattering theory and the vector radiative transfer theory, we carry out the simulation of the transmission of polarized photons in seawater channel with the Monte Carlo method, and then analyze the effects of the seawater channel, the background noise and the optical detection system on quantum key distribution. Our results show that in the night when background noise is weak, it is theoretically feasible to achieve absolute security underwater QKD within a hundred meters range in the clear ocean waters.

A70 - **Quantum Communications Improvement Using A Distributed Phase-Sensitive Amplifier**

Anjali Agarwal
Applied Communication Sciences

We demonstrate a novel quantum communications transmission system where information is encoded onto one of two non-orthogonal entangled photon-pair states and then transmitted through a 5-km long distributed optical phase-sensitive amplifier (PSA). The PSA is configured to affect each input state equally and improves the state transmission probability compared to direct transmission. The states are characterized at the input and output of the PSA and, to within measurement error, have the same quality. This demonstrates that the PSA supports transmission of both non-orthogonal states. Much like collective decoherence can be mitigated by encoding in a specific state, these results suggest that effects of loss may be reduced by encoding quantum information in a higher dimensional Hilbert space designed to benefit from transmission through a PSA. In the experiment, telecom-wavelength time-bin entangled photon pairs are generated by spontaneous four wave mixing in a dispersion shifted fiber (DSF) cooled in liquid nitrogen. The entangled pair output is encoded to create two non-orthogonal states: $(e^{\pm i\pi/8}|ee\rangle + e^{-\times \pm ipi/8}|ll\rangle)/\sqrt(2)$, where |ee> and |ll> denote the early and late time-bins, respectively. The states are sent to a 5-km long DSF-based PSA configured to have maximal gain for the sum of the two non-orthogonal states. This results in a slightly smaller, though equal, gain for each input state. After the PSA, the entangled pairs are analyzed using stabilized time-bin interferometers and single-photon detectors. The raw fringe visibility after the cooled DSF source is 81% $\pm$ 5% for each non-orthogonal state and is 86% $\pm$4% and 81% $\pm$4% after PSA transmission. The input coincidence counting rate maximums per 300 s for the two states are 85$\pm$9 and 86$\pm$9, while the output counting rates are 99$\pm$10 and 104$\pm$10. Transmission through the 5-km PSA preserves not only the state quality ...

A71 - **Demonstration and risk analysis of practical Trojan-horse attacks on**

continuous-variable quantum key distribution systems

Imran Khan
Max Planck Institute for the Science of Light

Trojan-horse attacks are a class of side-channel attacks on quantum key distribution (QKD) systems, first conceived by Bethune et al. in 2000. Eve sends a bright pulse into either Alice or Bob and analyzes its back-reflections to read out the modulator used to encode/decode the quantum states in protocols such as BB84, SARG04, G02 or B92. We present the results of such attacks on a home-built and a commercial continuous-variable QKD system. We experimentally demonstrate the first successful Trojan-horse attack on a CVQKD system, showing success rates of >99% (BPSK) for the discrimination of the originally modulated quantum states, thus providing access to the raw key. For Alice and Bob, it is of primary interest to install safeguards that prevent such attacks. To this end, the wavelength used by Eve to attack the system is critical. We found two attack regimes in the 1300 nm and the 1700 nm range that may allow Eve to bypass these safeguards and perform a successful attack. We discuss possible countermeasures and provide a detailed security analysis, which should be taken into account for the design of future QKD systems.

A72 - **Intracity free-space quantum communication using continuous variables**

Christian Peuntinger
Max Planck Institute for the science of light

Free space quantum communication has great potential for establishing quantum links to moving objects or in intracity environments in future quantum networks. We investigate the distribution of coherent and squeezed states through a turbulent atmospheric channel of 1.6km length in an urban environment. Both the squeezing and the prepared coherent states are encoded in the polarization degree of freedom and analyzed at the receiver using Stokes measurements. By using intense polarized light beams the system is immune to stray light. Our results show the successful distribution of 1.08dB of squeezing at a channel transmission of 62%. Furthermore, the data acquired from the distribution of four strongly overlapping coherent states is interpreted using the framework of effective entanglement. We found an entanglement distribution rate of 2.2×10^6 logarithmic negativity units per second. In both experiments, fast PIN photo diodes were used for the detection. The results highlight the opportunities provided by continuous variable quantum communication in free space.

A73 - **QKD in free space: security analysis in the finite-key regime and channel characterization.**

Davide Bacco
University of Padova

In QKD implementations, each session is typically chosen long enough so that the secret key rate approaches its asymptotic limit. This choice may be constrained by the physical scenario, as in the perspective with satellites, where the passage is restricted to a few minutes. We experimentally evaluate the robustness of a recent finite-key tight bound ensuring secrecy against the most general quantum attacks. The relevance of the proposed analysis is mainly directed to practical QKD and, in particular, to scenarios where the number of exchanged qubits is limited by physical constraints, where channel losses and visibility play a major role in limiting the quantum link. For what concern the channel characterization we introduce a method to exploit the atmospheric turbulence as a resource for QKD. An Adaptive Real Time Selection technique at the receiver allows to take advantage of the fluctuating transmissivity of the channel, giving rise to an increase of the secure key rate.This method is based on the sampling of a probe classical beam sent on the same channel of the quantum bits. In this way it is possible to select in real time the best time slots of high channel transmissivity.

A74 - **Truly random number generation based on one single photon detector optimized by polarization scrambling**

Zhengyong Li
Beijing Jiaotong University

Recently we have proposed and demonstrated a relatively simpler scheme composed of only one SPD while a polarization scrambler is used to enhance the randomness. In our experiment, the semiconductor laser source (1550 nm) is triggered by a pulse generator (100 MHz), and then the pulsed light goes through a polarization scrambler before attenuated to single photon stream. A polarization beam splitter is employed to route the single photons with one arm delayed 25 ns, which are further combined by a polarization beam coupler into a SPD gated by synchronized trigger pulses. The output signals are purified by a timing filter and band-pass filters. Finally, the random numbers "1" and "0" are achieved by logic "AND" processing between the output and the trigger pulses and 25-ns delayed trigger respectively. Our experimental random data pass both ENT and DIEHARD pseudo-random number test program, while further analysis show that polarization scrambling can significantly improve the randomness (15%) especially the serial correlation coefficient (up to 36%).

A75 - **Experimental quantum key distribution with classical optical communication based on Fabry-Perot lasers**

Liujun Wang
University of Science and Technology of China

We demonstrate quantum key distribution (QKD) with classical optical communication based on Fabry-Perot (FP) lasers using wavelength division multiplexing (WDM). We have designed a WDM scheme for the multi-longitudinal-mode FP lasers, employing multistage band-stop filtering. This multiplexing scheme ensures enough isolation and low loss of classical light simultaneously. Fiber distances up to 45 km are achieved when we transmit all optical signals via only one ber. Our results show that QKD has potential to be multiplexed into passive optical network where cost-effective FP lasers are widely used by the end users.

A76 - **Several Issues in Quantum Logic Circuits Synthesis**

Xiaoyu Li
University of Electronic Science and Technology of China

Researchers have made plenty of work about physical implementation of quantum logic gates. Construction and implementation of universal quantum logic gates are necessary conditions for the implementation of quantum computation and quantum computer. The details of the research work and innovations are as following: (1) Based on the group theory, our work presents four logic circuits synthesis algorithms with minimum quantum cost. Experimental results show that the logic synthesis ability of Peres gate is better than Toffoli gate. (2) Quantum ternary logic synthesis and hybrid-logic synthesis. Combined with the methods of classical logic circuits synthesis creatively, the irreversible logic can be transformed into a reversible logic. Then, it is extended to the issue of ternary logic synthesis. Based on the SNT gate library, it presents a synthesis algorithm called STNC, which uses minimum qutrits. (3) The construction and application of quantum increment gates. It proposes a class of quantum increment gates innovatively, including three topological types (N: 0), (N: N-1: RE) and (N: N-1: RD).

A77 - **Tree size complexity of quantum states**

Yu Cai
Centre for Quantum Technologies

It is likely that the origin of the "speed up" quantum computers offer over classical computers lies in the quantum states. There are many evidences that if the state in a quantum computation is simple, it can be simulated efficiently with classical computers. Hence complexity of quantum states plays a role in the power of quantum computation. Tree size (TS) is an interesting measure of complexity for multiqubit states: not only is it in principle computable, but one can obtain lower bounds for it. In this presentation, we would like to: 1.define what tree size is, the properties of tree size; 2.show how to find bounds on tree size, with some example of a class of states with superpolynomial tree size in the number of qubits; 3. show some properties of tree size of few-qubit states, the most complex few-qubit states; 4.draw some relation between tree size and usefulness of states for quantum computing.

A78 - **Teleportation of macroscopic states**

Tim Byrnes
National Institute of Informatics

Macroscopic quantum states, such as Schrodinger cat states, are notoriously sensitive to decoherence which make their observation all but impractical on a large scale. Teleportation of macroscopic states is limited for the same reason, as macroscopically entangled states tend to decohere on a very fast timescale. We introduce a novel teleportation protocol that overcomes this limitation by using a new type of entangled state. Unlike cat-like entangled states which decay exponentially with the system size, the entangled state decays as a power law. This means that relatively large sized systems can be entangled in practice. The teleportation protocol can teleport spin coherent states, which are N-fold duplicates of a qubit state. The scheme goes beyond the standard continuous variables approach for teleporting spin coherent states, as realized in atomic ensembles or Bose-Einstein condensates. Classical bounds corresponding to a limited communication channel and quantum state estimation are shown to be beaten. The scheme is designed to be within reach of current technologies.

A79 - **Spinor Bose-Einstein Condensate Quantum Gates Using Stimulated Raman Adiabatic Passage**

Andreas Thomasen
National Institute of Informatics

Spinor Bose-Einstein condensates (BECs) have been proposed for a variety of quantum information applications, from quantum metrology to quantum computing. Currently coherent control of spinor BECs are produced by microwave/RF pulses, which has the problem of addressability and being relatively slow. While optical Raman passages offer a natural solution to these problem, due to highly enhanced spontaneous emission, this has also been problematic to date. We propose the use of stimulated Raman adiabatic passage (STIRAP) to offer a fast, reliable, and highly addressable method of controlling spinor BECs on atom chips. Using STIRAP one adiabatically controls the spinor BEC state avoiding spontaneous emission. The method is applied to the implementation of quantum gates on BECs using this approach. The effects of various sources of decoherence are modelled into the systems considered.

A80 - **multiparty quantum state remote preparation**

Ping Zhou
Guangxi University for Nationalities

we presented two schemes for multiparty quantum state remote preparation. The first one is a scheme for joint remote preparation of the GHZ-class state by using a pure entangled state as the quantum channel. It has the advantage of transmitting less particles. The second one is a protocol for multiparty joint remote preparation of an arbitrary m-qudit state via pure entangled states. All the senders share the information of the prepared state, the receiver can probabilistic reconstruct the original state by performing corresponding unitary operations on his particles. The positive operator valued measurement is given and the relation between the success probability and the entanglement of quantum channel is also discussed.

B1 - **Robust self testing of the 3-qubit W state**

Xingyao Wu
Centre for Quantum Technologies

Self-testing is a device independent method which can be used to determine the nature of a physical system or device, without knowing any detail of the inner mechanism or the physical dimension of Hilbert space of the system. The only information required are the number of measurements, number of outputs of each measurement and the statistics of each measurement. Earlier works on self testing restricted either to two parties scenario or multipartite graph states. Here, we construct a method to self-test the three-qubit W state, and show how to extend it to other pure three-qubit states. Our bounds are robust against the inevitable experimental errors.

B2 - **Discrete-variable entanglement distillation with continuous-variable quantum teleportation and Gaussian post-selection**

Rémi Blandino
University of Queensland, Centre for Quantum Computation and Communication Technology

We present a probabilistic purification of non-Gaussian states requiring only Gaussian operations. Our protocol is based on continuous-variable quantum teleportation and Gaussian post-selection, which allows to virtually implement a noiseless linear amplification, and correct the loss introduced by a quantum channel. We first show that the global post-selected transformation is equivalent to an effective system composed of a noiseless amplification (or attenuation), and an effective quantum channel, which can in theory be made arbitrarily close to an identity channel. This result is independent of the input state, and could find many applications in quantum communications. As a concrete exemple, we consider a discrete-variable entangled state degraded by loss, such that it does not violate a CHSH inequality. Using our protocol, we show that this state can be arbitrarily well purified and violate the CHSH inequality. We also show that its entanglement measured by the concurrence can in theory be increased up to the value of a maximally entangled state.

B3 - **Modularity in Quantum Computation**

Jayne Thompson
Centre for Quantum Technologies, National University of Singapore

Modularity allows complex technology to be constructed from prefabricated components. Without this feature each user would need a detailed understanding of how every individual component was synthesized and its internal mechanisms. Here we formalize the concept of modular quantum algorithms, which allow subroutines to be outsourced to an oracle, while remaining blissfully ignorant of the exact implementation. We develop a general no-go result qualifying when such modularity is strictly impossible. This earmarks many quantum algorithms ranging from deterministic quantum computing with a single pure qubit to factoring as non-modular - forcing their circuit implementation to be individually tailored to specific problems, such as the number being factored. We introduce a work-around for restoring modularity and apply it to enhance existing quantum factoring algorithms; reducing their complexity, and the extent to which they need to be tailored to factor specific numbers. Thus, we highlight a natural property of classical information that fails in the advent of quantum logic; and simultaneously demonstrate how to mitigate its effects in practical situations. Based on [arXiv:1310.2927].

B4 - **Pure Quantum State Tomography and fidelity estimation via Phaselift**
Yiping Lu
Beijing Institute of Technology
The experiments of multi-photon entanglement have been performed by several groups, including Pan's group. Obviously, an increase in the photon number for fidelity estimation and quantum state tomography causes a dramatic increase in the elements of positive operator valued measures (POVMs), which results in a great consumption of time and settings in measurements. From a practical point of view, we wish to obtain a good estimation of fidelity and quantum states through as few measurements as possible for the multiphoton entanglement. Phaselift provides such a possibility to estimate fidelity and pure states based on a less amount of data. In this paper, we would like to show how the Phaselift works for six qubits in comparison to the data given by Pan's group, we use a fraction of the data as an input to estimate all the rest of the data. This estimate of the rest of the data is based on the obtained density matrix and thus goes beyond the simple fidelity analysis. And the fidelity bound is gain for general SC state. Based on the fidelity bound, we propose a optimal measurement approach which could both cut the copies and keep the fidelity bound small. All these result allow us to conclude that the Phaselift can help reduce the measured elements of POVMs for six qubits. Our conclusion is based on the priori that a pure state is the target state prepared by experiments.

B5 - **Hybridized Photon-Magnon interaction with Ultra-Strong Coupling due to Cavity with Focused Resonant Magnetic Field**
Michael Tobar
The University of Western Australia
Recent work at UWA has consisted of coupling photons to spins in novel high-Q cavities at mK tempaerature. This includes paramagnetic and rare-earth ions in various low loss crystal hosts, which shows strong coupling. More recently, we have investigated a ferrite sub-mm sized YIG sphere mounted in a 3D microwave cavity. This work demonstrates ultra-strong coupling between magnon and photon modes in the system at millikelvin temperatures. The cavity is designed to focus the resonant magnetic field into the sub-millimetre YIG crystal to achieve the highest filling factor possible at any desirable microwave frequency (patent pending). This is possible with large magnetic filling factor despite the fact that the smallest resonant frequency of the YIG crystal itself is of the order of 100 GHz. Coupling strength of 2 GHz is achieved for a bright cavity mode (about 10% of the photon energy). Also, a three-mode strong coupling regime is observed between a dark cavity mode and two magnon modes, where the photon-magnon and magnon-magnon couplings are ∼143 MHz and ∼12.5 MHz respectively. Multiple magnon modes of the YIG sphere are observed with bandwidths approaching 0.5 MHz.

B6 - **Transfer of different types of qubits in free-traveling fields over lossy environments**
Hoyong Kim
Seoul National University
We compare the effect of photon losses on direct transmission and quantum teleportation for three different types of qubits. Qubits using the vacuum and the single-photon (VSP) states, polarized single-photon (PSP) qubits, and coherent-state qubits are considered. We find that VSP qubits are the most efficient for both the direct transmission and teleportation under photon loss effects when considering fidelities and success probabilities. On the other hand, PSP qubits are relatively sensitive to photon losses. Our analysis also shows that the teleportation scheme outperforms the direct transmission for most of cases as far as fidelities are concerned. Our results provide useful information for the development of practical optical quantum information processing particularly in the context of hybrid architectures.

B7 - **Quantum Estimation Theory of Quantum Statisitical Mechanics**
Susumu Osawa
Hokkaido University
We construct the estimation theory of canonical ensembles in which density operators are descried by

$$\rho = (\mathrm{Tr} e^{-\beta \tilde{H}})^{-1} e^{-\beta \tilde{H}},$$

where β denotes inverse temperature, $\tilde{H}$ the Hamiltonian of the canonical ensemble. We consider the system to which generalized external fields are added. In this case, the Hamiltonian is

$$\tilde{H} = H + \sum_{j=1}^{n} h_j X_j,$$

where H denotes the Hamiltonian of a canonical ensemble without external fields, $h_j s$ generalized external fields, and $X_j s$ conjugate observable. When $[\tilde{H}, X_j] = 0$ holds for any j on a dense subspace of countably infinite dimensional Hilbert space and we suppose some assumptions, we have $L_{h,j}^s = \frac{kT}{2}\Delta X_j$ on the subspace, where $L_{h,j}^s$ denotes the symmetric logarithmic derivative (SLD), k the Boltzmann constant, and T temperature and ΔX_j is defined to be $\Delta X_j := X_j - \mathrm{Tr}\rho X_j$. Corresponding quantum Fisher information matrix elements are

$$J_{ij}^s = \frac{1}{(2kT)^2}\mathrm{Tr}\rho(\Delta X_i \Delta X_j + \Delta X_j \Delta X_i)$$

$$= \frac{1}{(2kT)^2} \cdot \frac{1}{2}(\chi_{ij} + \chi_{ji}),$$

where χ_{ij} is defined to be

$$\chi_{ij} := \frac{\partial}{\partial h_j}\mathrm{Tr}\rho X_i.$$

When $[\tilde{H}, X_j] \neq 0$, but $i[\tilde{H}, X_j]$ is a self-adjoint operator which is strong commuting with both the $\tilde{H}$ and X_j for any j, SLD and corresponding Fisher information matrix are the same as above-mentioned case with some assumptions. When density operator is regular, that Fisher information matrix elements are

$$J_{ij}^s = \frac{1}{(2kT)^2}\mathrm{Tr}\rho(\Delta X_i \Delta X_j + \Delta X_j \Delta X_i)$$

$$= \frac{1}{(2kT)^2} \cdot \frac{1}{2}(\chi_{ij} + \chi_{ji})$$

and that $L_{h,j}^s = \frac{kT}{2}\Delta X_j$ for any j are equivalent.

B8 - **Quantum communication in the presence of a horizon**

Daiqin Su
University of Queensland

One important task of relativistic quantum information is to investigate how relativistic motion and gravitational fields affect the storage, transfer and processing of quantum information. Based on homodyne detection, we discuss how the presence of an event horizon affects quantum communication between an inertial partner, Alice, and uniformly accelerated partner, Rob. We showed that there exists a low frequency cutoff for Rob's homodyne detector that maximizes the signal to noise ratio and it approximately corresponds to the Unruh frequency. In addition, the low frequency cutoff which minimizes the conditional variance between Alice's input state and Rob's output state is also approximately equal to Unruh frequency. Thus the Unruh frequency provides a natural low frequency cutoff in order to optimize quantum communication of both classical and quantum information between Alice and Rob.

B9 - **A better teleportation scenario than the original protocol.**

Quan Quan
Institute of Modern Physics, Northwest University

We investigate a new scenario based on Bell measurement for optimal teleportation. Picture of the scenario is put forward and we give the quantum channel Λ about it. A corresponding general expression of the transmission fidelity is also presented, which turns out to be a function of the newly defined fully entangled fraction (NFEF). And the concise form of the NFEF we define is proved to be an invariant under local unitary transformation. Moreover, we prove that hermitian witness operators which can distinguish unknown states useful for the new scenario is exist. The most important discovery is that the fidelity of our new scenario is no less than that of the original teleportation protocol, and for some circumstance, it is even strictly greater than the optimal fidelty of the original scheme. Examples about it are also given. What's more, copies of bound entangled states(BES) along may be found useful for quantum communication when the new scenario is taken. In the end, we also give the experimental scheme of the new scenario.

B10 - **On the adiabatic equivalence between the Deutsch and Deutsch-Jozsa problems**

Jie Sun
Huazhong University of Science and Technology

In this Letter, we show why the Deutsch and Deutsch-Jozsa problems are also equivalent in the framework of adiabatic evolution, although the equivalence between them is known in the quantum circuit model. That is, when there is an efficient adiabatic evolution for the Deutsch problem, there will also exist an efficient adiabatic algorithm for the Deutsch-Jozsa problem. The other direction also holds. This may help explain why Z. Wei et al. [Z. Wei, M. Ying, Phys. Lett. A 354 (2006) 271] can improve the algorithm complexity of S. Das et al.'s [S. Das, R. Kobes, G. Kunstatter, Phys. Rev. A 65 (2002) 062310] to $O(1)$.

B11 - **A universal quantum information processor for scalable quantum communication and networks**

Xihua Yang
Shanghai University

We present a proposal to efficiently and conveniently achieve a universal quantum information processor (QIP) via atomic coherence in an atomic ensemble. The atomic coherence, produced through electromagnetically induced transparency (EIT) in the Lambda-type configuration, acts as the QIP and has

full functions of quantum beam splitter, quantum frequency converter, quantum entangler, and quantum repeater. By employing EIT-based nondegenerate four-wave mixing processes, the generation, exchange, distribution, and manipulation of light-light, atom-light, and atom-atom multipartite entanglement can be efficiently and flexibly achieved in a deterministic way with only coherent light fields. This method greatly facilitates the operations in quantum information processing, and holds promising applications in realistic scalable quantum communication and quantum networks.

B12 - **Formula of channel matrix for covariant signal set with respect to a direct product of groups**

Tsuyoshi Usuda
Aichi Prefectural University

In classical-quantum channels, the square-root measurement (SRM) is well known to be an optimum or asymptotically optimum quantum measurement minimizing the average probability of error. Moreover, the capacity of a certain channel is attained by the SRM. We showed an analytical expression of the channel matrix by the SRM for a narrow sense group covariant signal set with respect to an arbitrary Abelian group [1]. The expression is referred to as a formula of a channel matrix. However, some covariant signal sets, e.g. a symmetric informationally complete (SIC) set (e.g. [2]), are not narrow sense covariant, so that generalization of the formula is desired. In this paper, we derive a formula of a channel matrix for a covariant signal set with respect to the direct product of groups G_1 and G_2 by decomposing the Gram matrix for the signal set into a tensor product. As an example of such a signal set, there is a Weyl-Heisenberg covariant state set. Then we calculate the channel matrix for the state set and show that the channel matrix is a different type of that for the narrow sense group covariant.

[1] T.S. Usuda and K. Shiromoto, QCMC2010. [2] C.A. Fuchs, QCMC2010, Prize Talk.

B13 - **Quantum circuit for accurate simulation of qudit channels**

Dongsheng Wang
Institute for Quantum Science and Technology

The quantum simulation of quantum open-system dynamics and quantum channels is important for the study of, e.g., quantum state generation, quantum measurement and instrument, and dissipative quantum computing and algorithms. In this work, we construct a classical algorithm that designs quantum circuits for algorithmic quantum simulation of arbitrary qudit channels within a pre-specified error tolerance with respect to diamond-norm distance. The classical algorithm is constructed by decomposing a quantum channel into a convex combination of extreme channels by optimization of a set of nonlinear coupled algebraic equations. The resultant circuit is a randomly chosen extreme-channel circuit whose run-time is efficient with respect to the error tolerance and quadratic with respect to Hilbert space dimension, achieving the circuit lower bound. The circuit also requires only a single ancillary qudit plus one classical dit, instead of two ancillary qudits according to standard approach based on Stinespring dilation theorem, thus significantly reduces the circuit complexity and pushes the quantum dynamics simulation one more step closer to experimental implementation.

B14 - **Topological phases in spin-orbit coupled dipolar lattice bosons**

Ho-Tsang Ng
Institute for Interdisciplinary Information Sciences, Tsinghua University

We study the topological phases in spin-orbit coupled dipolar bosons in a one-dimensional optical lattice. The magnetic dipolar interactions between atoms give rise to the inter-site interactions. In the Mott-insulating regime, this system can be described by the quantum XYZ spin model with the Dzyaloshinskii-Moriya interactions in a transverse field. We focus on investigating the effect of dipolar interactions on the topological phase. We find that the dipolar interaction can broaden the range of parameters of spin-orbit coupling and transverse field for exhibiting the topological phase. We study a parameter, which is the sum of spin correlations between the two nearest neighbouring atoms, to indicate the topological phase. This parameter may be useful for detecting topological phases in experiments.

B15 - **Quantum simulation of edge state and local convertibility**

Heng Fan
Institute of Physics, Chinese Academy of Sciences

In 1982, Richard Feynman conjectured that a quantum machine can predict the outcome of a general quantum evolution and pioneered the notion of a universal quantum simulator: a device capable of processing quantum information that potentially supersedes any classical computer in simulating quantum systems. However, quantifying to what extent a given quantum simulation could outperform classical method is problematic. We employ the example of the Ising chain, displaying an order-disorder quantum phase transitions. Employing both analytical and numerical methods, we compute entanglement Renyi entropies for various system's bipartitions and consider ground states with and without Majorana edge states. We find that ground state of disordered phase show non-local convertibility. In contrast, the ordered (symmetry breaking) ground state is always locally convertible. This result points out that non-local convertibility is a necessary condition for a universal quantum simulator.

B16 - **Creating topological edge states with controllable spin-orbit coupling and inversion-symmetric potential in 1D optical lattice**

Wei Nie
Centre for Quantum Technologies

Spin-orbit coupling is quite important to produce topological quantum state. Recently, cold atoms driven by Raman lasers are used to create synthetic spin-orbit coupling in optical lattice. Some proposals have been suggested to explore topological states based on different spin-orbit coupling schemes. Here, we consider the influence of lattice structure. We find that the lattice structure will make significant change in the topological state in this system.

B17 - **Frustrated spin-spin interactions between trapped ions using longitudinal and transverse phonon modes**

Yanli Zhou
NUDT

We present a scheme of quantum simulation of many-body interactions with trapped ions via the exchange of virtual phonons, where the motion from both the longitudinal and the transverse directions is considered. By tuning the detunings of Raman lasers, the long-range and locally tunable interaction is easily obtained between different spins. We show that the competing spin-spin couplings mediated by all motion modes can give rise to higher levels of frustration and richer phase transitions than the conventional approaches based on the longitudinal or the transverse phonon modes alone.(???Phys. Rev. A 89, 052318)

B18 - **Quantum phase transition of light in a 1-D photon-hopping-controllable resonator array**

Chun-Wang Wu
National University of Defense Technology

We give a concrete experimental scheme for engineering the insulator-superfluid transition of light in a one-dimensional (1-D) array of coupled superconducting stripline resonators. In our proposed architecture, the on-site interaction and the photon hopping rate can be tuned independently by adjusting the transition frequencies of the charge qubits inside the resonators and at the resonator junctions, respectively, which permits us to systematically study the quantum phase transition of light in a complete parameter space. By combining the techniques of photon-number-dependent qubit transition and fast read-out of the qubit state using a separate low-Q resonator mode, the statistical property of the excitations in each resonator can be obtained with a high efficiency. An analysis of the various decoherence sources and disorders shows that our scheme can serve as a guide to coming experiments involving a small number of coupled resonators.

B19 - **Simulating unidimentional gases using cavity QED systems**

Aizar Enciso Dominguez
Imperial College

Modern technologies allow ever increasing accuracy and control in quantum optics experiments, and in turn have given rise to candidate quantum simulators for the study of many body systems. Furthermore, the many-body variational wave functions known as Continuous Matrix Product States (CMPS) can be used to describe the low energy states of quantum field theories like the Lieb Liniger (LL) gas model, which typically require hundreds of variables. Recently (Phys. Rev. Lett. 110, 090501 2013) these states have been shown to naturally arise in cavity QED, and offer analog simulation of LL models, in the process greatly reducing the number of variables needed. Our work seeks to exploit common structure between contact interactions and the Jaynes-Cummings dynamics of the cavity in order to better describe strongly interacting field theories. Moreover by considering the cavity as a mediator of the interactions among photons we demonstrate that judicious choices of Hamiltonian for the cavity can reproduce a broad range of dynamics for the bosonic gas. Finally, we also discuss the viability of two-photon absorption and anti-Jaynes-Cummings models as alternative simulation candidates.

B20 - **The Effectiveness of Quantum Simulated Annealing in Tunneling through High Energy Barriers**

Mingkai Deng
Shenzhen Middle School

We explore the ability of the classical simulation of quantum annealing in solving a discrete n-bit optimization problem featuring high energy barrier. By studying the behavior of simulated quantum annealing on a classical spin model representing the problem, we find numerical results about the scaling of approximation parameters needed to capture the quantum effects expected in the physical quantum hardware. We reach a better understanding of the differences among simulated annealing, quantum annealing and simulated quantum annealing.

B21 - **Quantum Storage of Orbital Angular Momentum Entanglement in an Atomic Ensemble**

Dong-Sheng Ding
University of Science and Technology of China

Constructing a quantum memory for a photonic entanglement is vital for realizing quantum communication and network. Besides enabling the realization of high channel capacity communication, entangled photons of high-dimensional space are of great interest because of many extended applications in quantum information and fundamental physics fields. Photons entangled in a two-dimensional space had been stored in different system, but there have been no any report on the storage of a photon pair entangled in a high-dimensional space. Here, we report the first experimental realization of storing an entangled orbital angular momentum (OAM) state through a far off-resonant two-photon transition (FORTPT) in a cold atomic ensemble. We reconstruct the matrix density of an OAM entangled state postselected in a two-dimensional subspace with a fidelity of 90.3%±0.8% and obtain the Clauser, Horne and Shimony and Holt inequality parameter S of 2.41±0.06 after a programmed storage time. All results clearly show the preservation of entanglement during the storage. Besides, we also realize the storage of a true-single-photon via FORTPT for the first time.

B22 - **An opto-magneto-mechanical quantum interface between distant superconducting qubits**

Keyu Xia
Macquarie University

A quantum internet, where widely separated quantum devices are coherently connected, is a fundamental vision for local and global quantum information networks and processing. Superconducting quantum devices can now perform sophisticated quantum engineering locally on chip and a detailed method to achieve coherent optical quantum interconnection between distant superconducting devices is a vital, but highly challenging, goal. We describe a concrete opto-magneto-mechanical system that can interconvert microwave-to-optical quantum information with high fidelity. In one such node we utilize the magnetic fields generated by the supercurrent of a flux qubit to coherently modulate a mechanical oscillator that is part of a high-Q optical cavity to achieve high fidelity microwave-to-optical quantum information exchange. We analyze the transfer between two spatially distant nodes connected by an optical fibre and using currently accessible parameters we predict that the fidelity of transfer could be as high as ,80%, even with significant loss.

B23 - **Quantum network of superconducting qubits through opto-mechanical interface**

Zhangqi Yin
Tsinghua University

We propose a scheme to realize quantum networking of superconducting qubits based on the opto-mechanical interface. The superconducting qubits interact with the microwave photons, which then couple to the optical photons through the opto-mechanical interface. The interface generates a quantum link between superconducting qubits and optical flying qubits with tunable pulse shapes and carrier frequencies, enabling transmission of quantum information to other superconducting or atomic qubits. We show that the scheme works under realistic experimental conditions and it also provides a way for fast initialization of the superconducting qubits under 1 K instead of 20 mK operation temperature.

B24 - **Effects of multimode pump on distinguishability of photon pairs in a periodically poled KTiOPO4**

Hee Jung Lee
Pusan National University

Two-photon quantum interference is a key element of quantum metrology and quantum information processing. Through Hong-Ou-Mandel (HOM) interference, the spatio-temporal purity, or distinguishability, of single photons can be investigated. Photon pair sources based on a long periodically poled (PP) crystal have an advantage of high generation efficiency, however, due to their narrow operation bandwidth they tend to be vulnerable to instability of a pump laser. This work reports the dependence of the HOM interference visibility on longitudinal modes (LMs) of a pump laser that is used for parametric down-conversion in a bulk PPKTP crystal. Our experiment was performed under a type-II collinear phase matching condition, where the pump laser diode was designed to be single longitudinal mode. The measured interference visibility was varied from 0.53 to 0.99 for different LM configuration. By comparing with the theory, the variation in the HOM signals could be understood in terms of decomposition of the LMs into a principal and side modes caused by the LM instability of the pump diode.

B25 - **Generation and evaluation of the physical random number using a gain-switched semiconductor laser**

Takahisa Seki
Hokkaido Graduate School of Information Science and Technology

Random number is the heart of the modern cryptography. To satisfy the demands for high speed communication, fast and high quality random number generation is necessary. In particular, to achieve the information theoretical security, the random number must be generated from a physical process. We apply spontaneous emission in semiconductor laser medium as a source of randomness. Since a laser pulse is generated by amplified spontaneous emission seed, the phase between the optical pulses should be completely random. We generated the physical random bits from the interference signals between the optical pulses from a gain-switched semiconductor laser at the clock frequency of 625 MHz. Stable interference was obtained using the planar lightwave circuit technology. We examined the obtained random number by hypothesis testing. The present setup can be integrated into current quantum key distribution equipment with only a few additional components (a mirror, a photodetector, and a decision circuit.)

B26 - **Narrow bandwidth photon pairs preparation at telecom band with triple resonance configuration**

Zhi-Yuan Zhou
University of Science and Technology of China

we report on the preparation of a narrow bandwidth photon source at the telecom wavelength using spontaneously parametric down-conversion in a type II PPKTP crystal inside an optical cavity. Simultaneous resonances of the pump and the two down-converted fields are achieved by special design of the cavity. This triple resonances optical parametric oscillator operates far below threshold, generating photon pairs at the wavelength of 1560 nm with a bandwidth of 8 MHz. A coherence time of 27.7 ns is estimate by a time correlation measurement, and the estimated production rate of the photon pairs is 134 /s.MHz.mW. As a photon pair in the telecom regime is suitable for long-distance transmission, this source is desirable for the demands of quantum communication.

B27 - **Generation of optical hybrid entanglement and its application to loophole-free Bell inequality tests**

Hyukjoon Kwon
Seoul National University

We suggest a generation scheme for hybrid entanglement between a single-photon polarization qubit and a free-traveling coherent field. Optical hybrid states can be obtained by a non-deterministic method for which a polarization entangled photon pair, a superposition of coherent states, beam splitters, the displacement operation, and single-photon detectors are required as the resources. Remarkably, the fidelity of the heralded state can be achieved arbitrarily high even if realistic photodetectors and imperfect initial states are assumed. We also show that a loophole-free Bell's inequality test may be realized using the hybrid entanglement. The Bell violation occurs until the efficiency of the photodetectors becomes as low as 67% even though the degree of violation becomes small as the detection efficiency degrades.

B28 - **Single-mode photon pairs from a crystalline whispering gallery mode resonator**

Michael Förtsch
Max Planck Institute for the Science of Light

Over the past ten years the interest in resonator assisted spontaneous parametric down-conversion (RA-SPDC) has increased significantly. This interest originates from the possibility of these systems to efficiently generate narrow-band heralded single photons, which are directly compatible with atomic transitions. One still remaining challenge with RA-SPDC based systems is the efficient photon generation in exactly one spatiotemporal mode, which up to now has typically required additional complex filtering setups. Here we experimentally demonstrate a pulsed, narrowband RA-SPDC source based on a crystalline whispering gallery mode resonator, which allows the detection of photons in exactly one mode. The unique phasematching conditions allow for easy experimental realization of single mode operation and result, to the best of our knowledge, in the highest reported singlemode pair-detection rate. In combination with the wide wavelength and bandwidth tuning possibilities, our setup is ready to serve as the heralded single photon source in a large variety of proposed quantum-repeater networks.

B29 - **Generation of genuine 2-photon N00N states in non-linear coupled waveguides**
Regina Kruse
Applied Physics / University of Paderborn
Integrated optics have revolutionised the application of photonic circuits in quantum information science. Still, the potential of coupled structures in non-linear materials has not been explored. Here, we combine non-linear generation with passive manipulation via a periodically poled beam splitter in lithium niobate, following [1,2]. We show, theoretically and experimentally, that this simple geometry allows for the generation of a genuine 2-photon N00N state [3]. By pumping only one input port with an ultrafast pump pulse, we create our quantum state in the telecom regime at room temperature without any need for phase control. Both the easy implementation and the intrinsic stability and coherence of this device make it a desirable candidate for scalable applications in quantum information networks. [1] PRL 108 023601, 2012 [2] NJP 15 083046, 2013 [3] PRL 85 2733, 2000

B30 - **Cross-phase modulation in Gradient Echo Memory using stationary light**
Pierre Vernaz-Gris
Centre for Quantum Computation and Communication Technology - Australian National University
Cross-phase modulation of the order of 10e-5 rad has been achieved via the ac-Stark effect in atomic media with Electromagnetically-Induced Transparency [1]. However these techniques suffer from a trade-off between non-linearity and efficiency in addition to a 50% limit on storage efficiency [2]. Single-pass cross-Kerr proposals are limited by the saturation of the Kerr effect and require some kind of light storage that allows for multiple interactions [3]. Stationary light-which is fully optical and is distinct from "stopped light", stored, to some extent, as an atomic coherence-allows for enhanced non-linearity without the aforementioned detriments [4]. Quantum memories have yielded promising results [5]. An even augmented interaction has been proven using stationary light. Here we present a model of stationary light in a three-level system using off-resonant coupling fields and the experimental implementation of stationary light on top of a Gradient Echo Memory scheme in a warm vapour of rubidium atoms. We show how one can store a weak coherent pulse, convert it into stationary light and maximise the achievable cross-phase modulation with a second stored coherent pulse.References: [1] H.-Y. Lo et al. Electromagnetically-induced-transparency-based cross-phase-modulation at attojoule levels. Phys. Rev. A, 83(4):041804, 2011. [2] J. Gea-Banacloche. Impossibility of large phase shifts via the giant Kerr effect with single-photon wave packets. Physical Review A, 81(4):043823, 2010. [3] B. Fan et al. Breakdown of the cross-Kerr scheme for photon counting. Phys. Rev. Lett., 110:053601, 2013. [4] A. Andé ret al. Nonlinear Optics with Stationary Pulses of Light. Phys. Rev. Lett., 94:063902 2005. [5] M. Hosseini et al. Memory-enhanced noiseless cross-phase modulation.Light: Science & Applications, 1(12):e40, 2012.

B31 - **Entanglement distillation with photonic metamaterials**
Motoki Asano
Osaka University
Authors: M. Asano, M. Bechu, M. Tame, D. O. Guney, S. K. Ozdemir, R. Ikuta, T. Yamamoto, L. Yang, M. Wegener, N. Imoto Metamaterials have been actively studied to control the electric and magnetic field responses at the macroscopic level by constructing and arranging sub-wavelength structures in a specified way. So far, the field of photonic metamaterials has mainly focused on manipulating and controlling the propagation of classical fields of light. Here we report on the ability of photonic metamaterials to manipulate quantum states of light, and present an experimental demonstration of an entanglement distillation protocol, which plays a crucial role in quantum information processing, using a metastructure formed by an array of gold nanoantennas.

B32 - **Hexapartite entanglement and full characterization of optical parametric oscillators - Versatile tool for multicolor teleportation**
Marcelo Martinelli
IFUSP
Optical parametric oscillators have been the workhorse of quantum information processing with continuous variables, enabling deterministic implementation of many communication protocols in the continuous variable domain-like teleportation, quantum networks, and cluster states, to mention a few. They are robust and versatile in the shaping of the generated states. Nevertheless, they strong tunability was not used, up to the moment, as a resource for quantum communication. This work will discuss the intrinsic multicolor nature of the entanglement produced by the OPO operating above threshold, detailing the role of the sidebands of the central carrier

in the complex entanglement structure, and the differences between this system and the more frequent sub-threshold counterpart. Although departing from a trilinear Hamiltonian, we will present strong support for its Gaussianity, enabling a complete reconstruction of the quantum state from second order moments. Finally, we will discuss the use of the tunability of the OPO twin beams, entangled to its pump field, as a powerful tool to swap the quantum information over the electromagnetic spectra.

B33 - **Manipulation of Trapped Ions in a Chip Trap**
Mang Feng
Wuhan Institute of Physics and Mathematics, CAS
Ultracold ions confined in ion traps are promising for quantum information processing. We report our recent experimental works in a home- built planar electrode chip trap. The chip trap can confine hundreds of ions in a cloud phase, and move 37 ion crystals under full control, which are the prerequisite for trapped-ion quantum information processing. By changing the trapping parameters, we have observed configuration phase transitions, depending on the conformation of the ion crystals, the number of the ions involved and the confining potential of the trap. With the ions cooled down to micro-Kelvin, the configuration phase transition will get into quantum regime. Meanwhile, Tavis-Cummings model can be realized by a line of trapped ions, where quantum phase transition from normal state to superradiant state is available with current experimental techniques.

B34 - **Bulk induced phase transition in driven diffusive systems**
Yu-Qing Wang
University of Science and Technology of China
This paper studies a weakly and asymmetrically coupled three-lane driven diffusive system. A non-monotonically changing density profile in the middle lane has been observed. When the extreme value of the density profile reaches rho=0.5, a bulk induced phase transition occurs which exhibits a shock and a continuously and smoothly decreasing density profile which crosses rho=0.5 upstream or downstream of the shock. The existence of double shocks has also been observed. A mean-field approach has been used to interpret the numerical results obtained by Monte Carlo simulations. The current minimization principle has excluded the occurrence of two or more bulk induced shocks in the general case of nonzero lane changing rates.

B35 - **Carrier-free Raman manipulation of trapped neutral atoms**
Lothar Ratschbacher
University of Bonn
We experimentally realize an enhanced Raman control scheme for neutral atoms that achieves an intrinsic suppression of the two-photon carrier transition, but retains the coupling to motional sidebands [1]. The method is based on the simultaneous use of a blue detuned light field, both as a standing wave dipole trap for the neutral atoms, and as one field in the two-photon Raman coupling. Its improved ratio between cooling and heating processes during resolved sideband cooling and the need for only minimal additional resources make the configuration applicable to experiments with unconventional optical potentials and challenging optical access. This is highlighted by our implementation for atoms strongly coupled to an optical cavity. We demonstrate ground state cooling as well as the coherent manipulation of the atomic motion and determine the heating rate of atoms in the standing wave optical trap formed by the high-finesse optical cavity. We furthermore show how the cooling technique improves the collective coupling of two atoms to the cavity mode. In particular, we study collective Rayleigh scattering that is sensitive to the relative atom-field coupling phase and for which both cooperative effects and the cavity backaction are relevant [2]. Our results are an important step towards the realization of phase-sensitive cQED protocols, such as the cavity-mediated entanglement of two atoms."

B36 - **High-fidelity cluster state generation of ultracold atoms in an optical lattice**
Yuuki Tokunaga
Nippon Telegraph and Telephone Corporation
We propose a method for generating high-fidelity multipartite spin entanglement of ultracold atoms in an optical lattice in a short operation time with a scalable manner, which is suitable for measurement-based quantum computation [1]. To perform the desired operations based on the perturbative spin-spin interactions, we propose to actively utilize the extra degrees of freedom (DOFs) usually neglected in the perturbative treatment but included in the Hubbard Hamiltonian of atoms, such as, (pseudo-)charge and orbital DOFs. Our method simultaneously achieves high fidelity, short operation time, and scalability by overcoming the following fundamental problem: enhancing the interaction strength for shortening the operation time breaks the perturbative condition of the interaction and inevitably induces unwanted correlations

among the spin and extra DOFs. [1] K. Inaba, Y. Tokunaga, K. Tamaki, K. Igeta, and M. Yamashita, Phys. Rev. Lett., 112, 110501 (2014)

B37 - **Hong-Ou-Mandel interference between photons from a single atom and an atomic ensemble**

Alessandro Cere
Centre for Quantum Technologies - NUS

Many proposed all-optical quantum-photonic networks are based on single photons carrying information between atomic nodes and interacting with one another. This requires the generation of indistinguishable photons form different physical processes [1-3]. We demonstrate the compatibility of two different sources of single photons: a single atom and four-wave mixing in a cold cloud of atoms. A single ^{87}Rb atom is trapped in an optical dipole trap and can be excited with high probability using a short (3 ns), intense pulse, emitting a single photon by spontaneous decay. A large numerical aperture collects 4% of the total fluorescence [5]. A four-wave mixing process in a cloud of cold ^{87}Rb generates time correlated photon pairs. We use a cascade level scheme that ensures that the idler photons temporal envelope is an exponential decay, matching the spontaneous decay one, except for the shorter coherence time caused by the collective effects in the atomic cloud [6]. The signal photon heralds the idler one and triggers the excitation of the single atom and the generated photons are interfered in a HOM setup. We observe a visibility of 70±0.04%, well above the classical limit of 50%.

B38 - **Antiresonance in a Strongly-Coupled Atom-Cavity System**

Christoph Hamsen
Max-Planck-Institute of Quantum Optics

The strongly-coupled atom-cavity system has proven useful for the observation of fundamental quantum effects. Recently, it has found application as a building block for more complex structures in elementary quantum circuits for quantum information processing. Moreover, large networks of strongly-coupled systems have been proposed for simulation of quantum phase transitions. However, due to the strong coupling these compound systems cannot be treated perturbatively, but require a holistic analysis of all constituents making characterization a challenging task. Here, we provide a way to address this challenge. It is based on an experiment where, by heterodyne detection of the light transmitted through a cavity containing a single atom, we see a hitherto unobserved negative phase shift which is associated with an antiresonance. The linewidth and frequency of this antiresonance are solely determined by the atom. The corresponding phase shift can be optically controlled via the AC Stark shift and reaches values of up to 140° - the largest ever reported for a single emitter. We explain how this opens up new routes towards characterization of complex quantum circuits.

B39 - **Convenient and Reliable Fabrication of High Surface Quality Tungsten Elecrodes for Ion Trap**

Zhao Wang
University of Science and Technology of China

We present a new electrochemical etching method for mass-production of tungsten tips as ion trap electrodes, which can also be employed for fabricating nanoscale probes and fiber micro-lens for Atomic Force Microscopy(AFM), Scanning Tunneling Microscopy(STM) and Microelectromechanical Systems (MEMS). Using inexpensive, convenient material and equipment in the process, a simple procedure yields sharp, uniformly shaped and robust tips. Furthermore, the shape and size are tweaked by selecting appropriate electrolyte solution concentration and voltage to produce tips with arbitrary shape. We also explore optimal parameters to create consistent tungsten tips for Ion-Trap experiments. This technique paves the way for the mass-production of ion trap based quantum computer systems.

B40 - **Arbitrary Rotation of a Single Spinwave Qubit in an Atomic-Ensemble Quantum Memory**

Yan Jiang
University of Science and Technology of China

We report the first experimental realization of single-qubit manipulation for single spinwaves stored in an atomic ensemble quantum memory. In order to have high-fidelity gate operations, we make use of stimulated Raman transition and controlled Lamor precession jointly. We characterize the gate performances with quantum state tomography and quantum process tomography, both of which imply that high-fidelity operations have been achieved. Our work complements the experimental toolbox of atomic-ensemble quantum memories by adding the capability of single-qubit manipulation, thus may have important applications in future scalable quantum networks.

B41 - **Single-photon property characterization of 1.3 ?m emissions from InAs/GaAs quantum dots using silicon avalanche photodiodes**

Baoquan Sun
Institute of Semiconductors, CAS

We developed a new approach to test the single-photon emissions of semiconductor quantum dots (QDs) in the optical communication band. A diamond-anvil cell (DAC) pressure device was used for blue-shifting the 1.3 μm emissions of InAs/GaAs QDs to 0.9 μm for detection by silicon avalanche photodiodes (APDs). The obtained g(2)(0) values from the second-order autocorrelation function measurements of several QD emissions at 6.58 GPa were less than 0.3, indicating that this approach provides a convenient and efficient method of characterizing 1.3 μm single-photon source based on semiconductor materials.To further confirm the feasibility of the proposed approach, we traced the g(2)(τ) evolution of a single QD (with a emission line of $\sim$900 nm at 0 GPa) under pressure from 0 to 3 GPa, herein the g(2)(τ) was measured using silicon APDs. The results indicate that the single-photon emission mechanism of the QD remains well under different pressures. In addition, it was found that the tuned QD emission line is reversible as a function of pressure.

B42 - **Quantum theory of optical nuclear spin narrowing in diamond nitrogen-vacancy center**

Wen Yang
Beijing Computational Science Research Center

We develop a microscopic theory for the feedback control nuclear spin dynamics in diamond nitrogen-vacancy center. By adiabatically eliminating the fast motion of the NV center, we derive an analytical rate equation to describe the dynamics of the nitrogen and ^{13}C nuclei. The results provide a good explanation to the recently observed nitrogen and ^{13}C nuclear spin cooling in nitrogen-vacancy center by coherent population trapping [E. Togan *et al.*, Nature 478, 497 (2011)].

B43 - **Experimental observation of two-mode correlated emission lasing with a single superconducting artificial atom**

Zhihui Peng
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In contrast to conventional lasers, correlated emission lasers (CELs) have no incoherent population inversion process in any basis of three level atoms. Because of the atomic coherence, two spontaneous-emission events from two excited states are strongly correlated and it is possible to quench the phase-diffusion noise. We report on the demonstration of the two-mode correlated emission laser with a superconducting cascade three-level artificial atom capacitively coupled to a superconducting transmission line resonator (TLR). We observe the phase-diffusion noise of the two-mode CELs is reduced to 0.026% of the Schawlow-Townes limit and large number of photons emission in two different colours. The interference fringes of the two lasing fields when the phase delay in one mode is changed indicates that they are quantum correlated.

B44 - **Zero phonon-line spectra fine measurement of nitrogen vacancy centers in nanodiamonds using a Fabry-Perot interferometer**

Hong-Quan Zhao
Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences

Photoluminescence (PL) spectra of single nitrogen vacancy (NV) centers in 50-nm diamond nanocrystals at the zero-phonon line (ZPL) were directly observed using a Fabry-Perot interferometer at cryogenic temperatures. The narrowest linewidth of ZPL was 1.2 GHz (1.9$\pm$0.7 GHz on average), comparable to ZPL linewidths in PL spectra reported for NV centers in pure bulk diamond. This observation is important to the application of NV centers for use in quantum communication and computation devices, and in nano-sensing.

B45 - **Dynamic nuclear polarization of nitrogen-vacancy centers in diamond**

Wen-Hui Hu
Beijing Computational Science Research Center

Single nitrogen-vacancy (NV) centers in diamond triggered the research for wildly applications in quantum information processing and quantum metrology. One of the most important advantages of NV centers is the long coherence time (up to millisecond in room temperature) of the electron spins. Dynamical nuclear polarization (DNP) has been introduced as one efficient method to protect the coherence. The coherence time T2* should have been prolonged of two orders (102) theoretically, while is less than one order (<10) in experiments. In this work, we theoretically study the DNP progress by the NV center in a high-purity diamond, where the dipole-dipole hyperfine interaction between the center electron spin and the bath 13C nuclear spins is dominant. The simulations show that the saturated polarization depends on the period of the driving microwave pulse sequence and the efficiency of the initialization laser, accompanied with the magnitude of the external magnetic field. The polarization saturation comes from the capability of the polarization transfer and the equilibrium of probability distribution between the polarized and unpolarized states.

B46 - **Gallium Arsenide (GaAs) Quantum Photonic Waveguide Circuits**

Alberto Santamato
university of bristol

Integrated quantum photonics is a promising approach for future practical and large-scale quantum information processing technologies, with the prospect of on-chip generation, manipulation and measurement of complex quantum states of light. The gallium arsenide (GaAs) material system is a promising technology platform, and has already successfully demonstrated key components including waveguide integrated single-photon sources and integrated single-photon detectors. Here, we report GaAs photonic circuits for the manipulation of single-photon and two-photon states. Two-photon quantum interference with a visibility of 94.9 +/- 1.3% was observed in GaAs directional couplers. Classical and quantum interference fringes with visibilities of 98.6 +/- 1.3% and 84.4 +/- 1.5% respectively were demonstrated in Mach-Zehnder interferometers exploiting the electro-optic Pockels effect. This work paves the way for a fully integrated quantum technology platform based on the GaAs material system.

B47 - **Highly efficient entanglement swapping and teleportation at telecom wavelength**

Ruibo Jin
National Institute of Information and Communications Technology(NICT)

We demonstrate highly efficient entanglement swapping and teleportation with two ultra-bright entangled photon sources, and four highly efficient superconducting nanowire single photon detectors (SNSPDs) at telecom wavelength. A four-fold coincidence count rate of around 100 counts per second and a raw (net) visibility of 73% (85%) were achieved in a Hong-Ou-Mandel interference between independent sources. Our four-fold coincidence count rate is three orders higher than the previous experiments at telecom wavelengths. We also obtained high fidelities in the quantum teleportation and entanglement swapping tests. This experiment will be an important technological step toward building the practical quantum repeater network.

B48 - **Efficient generation of twin photons with 10 GHz repetition-rate-tunable comb laser**

Ruibo Jin
National Institute of Information and Communications Technology(NICT)

Efficient generation and detection of indistinguishable twin photons are at the core of quantum information and communications technology (Q-ICT). These photons are conventionally generated by spontaneous parametric down conversion (SPDC), which is a probabilistic process, and hence occurs at a limited rate, which restricts wider applications of Q-ICT. To increase the rate, one had to excite SPDC by higher pump power, while it inevitably produced more unwanted multi-photon components, harmfully degrading quantum interference visibility. Here we solve this problem by using recently developed 10 GHz repetition-rate-tunable comb laser, combined with a group-velocity matched PPKTP crystal, and superconducting nanowire single photon detectors. They operate at telecom wavelengths more efficiently with less noise than conventional schemes, those typically operate at visible and near infrared wavelengths generated by a 76 MHz Ti Sapphire laser and detected by Si detectors. We could show high interference visibilities, which are free from the pump-power induced degradation..

B49 - **Experimental implementation and validation of photonic Boson Sampling**

Marco Bentivegna
University La Sapienza of Rome

A boson sampling device is a specialized quantum computer that solves a problem that is strongly believed to be computationally hard for classical computers. Recently, a number of small-scale implementations have been reported, all based on multiphoton interference in multimode interferometers. Akin to several quantum simulation and computation tasks, an open problem in the hard-to-simulate regime is to what extent the correctness of the boson sampling outcomes can be certified. Here, we report new boson sampling experiments on larger photonic chips and analyse the data using a recently proposed scalable statistical test. We show that the test successfully validates small experimental data samples against the hypothesis that they are uniformly distributed. In addition, we show how to discriminate data arising from either indistinguishable or distinguishable photons. Our results pave the way towards larger boson sampling experiments whose functioning, despite being non-trivial to simulate, can be certified against alternative hypotheses.

B50 - **Experiment on error-insensitive**

approximate universal-NOT gates

Sang Min Lee
Pusan National University

We propose and experimentally demonstrate an approximate universal-NOT (UNOT) operation that is robust against operational errors. In our proposal, the UNOT operation is composed of stochastic unitary operations represented by the vertices of regular polyhedrons. The UNOT operation is designed to be insensitive to random operational errors by increasing the number of reference axes without increasing any resources or the total number of measurements. We used spontaneous parametric down-conversion (SPDC) and linear optics elements in the experimental realization and the stochastic map was characterized by quantum process tomography (QPT). From the results of the QPT, we calculated the sensitivities of the maps, which matched well with the simulations and analytic predictions. Our method can be applied to any antiunitary operation in a stochastic manner and stochastic maps.

B51 - **Phase Squeezing for Coherent Light by Post-Selection of Single Photon through Weak Cross Kerr Nonlinearity**

Fumiaki Matsuoka
Hokkaido University

A phase-squeezed light with large coherent amplitudes can be used to atomic entanglement generation with low error probability and to quantum repeaters with high fidelity and high success probability. However, the generation of such phase-squeezed light is not experimentally reported. In this presentation, we show that a scheme as follows can be taken as squeezer for phase fluctuations of a laser of 860nm band wavelength, which can interact with Cs atoms. When one arm of a Mach-Zehnder interferometer is interacted with a coherent light via weak cross-Kerr nonlinearity, a superposition of a phase-shifted coherent state and a non-phase-shifted coherent state is generated. The probability amplitudes of these states can be modified by the post-selection of the single photon, thus a quantum interference between the phase-shifted state and the non-phase shifted state can be controlled. The post-selection can be implemented by a variable beam splitter as an output of the Mach-Zehnder interferometer. When a transmissivity and a reflectivity of the variable beam splitter are slightly imbalanced, an effective squeezing effect can be obtained with a high fidelity to a phase-squeezed state.

B52 - **Continuous-Variable Quantum Computing in Optical Time-Frequency Modes using Quantum Memories**

Peter Humphreys
University of Oxford

We develop a scheme for time-frequency encoded continuous-variable cluster-state optical quantum computing using quantum memories. In particular, we propose a method to produce, manipulate and measure 2D cluster states in a single spatial mode by exploiting the intrinsic time-frequency selectivity of Raman quantum memories. Time-frequency encoding enables the scheme to be extremely compact, requiring a number of memories that is a linear function of only the number of different frequencies in which the computational state is encoded, independent of its temporal duration. We therefore show that quantum memories can be a powerful component for scalable photonic quantum information processing architectures.

B53 - **Programmable Optical Circuit for Implementing Two-Qubit Gates**

Xiaogang Qiang
Centre for Quantum Photonics, University of Bristol

Quantum computer has significant advantages for solving hard problems, which always attracts people's attention. One of the basic steps to build a quantum computer is to implement the quantum circuit which is able to realize given unitary operation. We built a programmable optical circuit for implementing two-qubit gates, based on Cartan's KAK decomposition. Any two-qubit gate that have decomposed form as linear sum of two tensor products of single qubit operations, can be implemented on the circuit, by configuring different parameters. The programmable optical circuit was implemented based on entangled photon pairs and displaced-sagnac structure, adopting an entanglement-based scheme. The circuit can implement not only unitary gates including control-U gates, but also non-unitary gates such as entanglement filter. We tested several different gates including CNOT, CH, CZ and entanglement filter, and estimated the performance of gates by measuring the classical fidelities for two complementary sets of input states. Besides these basic two-qubit gates, the circuit is also expected to implement various applications such as delayed-choice experiment and quantum chemistry simulation.

B54 - **Deterministic generation of qudit cluster states from optical coherent states and teleportation of qudits**

Jaewan Kim
Korea Institute for Advanced Study

Optical coherent state is interpreted as a qudit, d-dimensional quantum system with an arbitrary integer d, and how to deterministically generate a cluster state of qudits using weak cross phase modulation between qudits as a generalized Cont-Z. Such a qudit cluster state could be used for quantum information processing. Teleportation of a qudit (d-dimensional) is demonstrated as an example, and a scheme of qudit quantum repeater is proposed. Finally a simple proof of principle test of this scheme is presented. This scheme can be applied to spin coherent state with Ising interaction.

B55 - **Measurement of photonic quantum states over multiple spatial modes in a few-mode optical fiber**
Hee Su Park
Korea Research Institute of Standards and Science
Spatial modes of single photons are useful quantum information carriers that have intrinsically infinite dimension. Few-mode optical fibers can transport such multi-dimensional quantum states without suffering from space restriction. Unlike classical space-division-multiplexed optical communication using the spatial modes as independent channels, encoding quantum information over multiple spatial modes requires generation and measurement of coherent intermodal superposition states. This work describes experimental techniques to measure arbitrary superposition states of fiber spatial modes and spatial entanglement between photons in different fibers. Efficient spatial-mode analyzers based on in-line acousto-optic interaction is used for quantum state tomography, which is used to verify the entanglement of a Bell state composed of the two lowest-order spatial modes of an optical fiber. Resonant coupling of three spatial modes by two acoustic frequencies is also demonstrated. An analogy of the scheme with an externally driven three-level quantum state is shown by an EIT-like narrow-bandwidth transmission spectrum within an absorption band for the fundamental mode.

B56 - **Nonlocal quantum interference experiment with independent photon pairs**
Heonoh Kim
Pusan National University
Superposition principle and entanglement is at the heart of understanding foundations of quantum mechanics and exploring quantum information applications. Entanglement between multiparticle quantum systems is an important resource not only to study essential properties of quantum systems but also to implement photonic quantum information technologies including quantum teleportation and entanglement swapping. Here we report the experimental demonstrations of the nonlocal two-photon interference between pairs of photons which independently generated by spontaneous parametric down-conversion in the telecommunication wavelengths. Maximum visibility of the two-photon interference fringe is obtained when the two possible paths of two individual photons in different pairs are perfectly matched within the coherence length of single-photon wavepacket. Furthermore, it is pointed out that the most general form of two-photon interference effect can be explained by present experimental scheme.

B57 - **Driven quantum walks**
Linda Sansoni
Applied Physics, University of Paderborn
In the last few years the quantum walks (QW) have attracted much interest in the field of quantum simulation and computation [1]. Motivated by recent theoretical and experimental progress that combines QWs and parametric downconversion [2,3], we develop a different type of QW, which we call "driven quantum walk" [4]. Here, the walkers are created throughout the walk, leading to fundamentally different phenomena. We relate this to the traditional QW by showing that any driven QW can be decomposed into a traditional QW with an intricate input state. Furthermore, we are able to control the system with different pump shapes and frequencies that allows for in-situ control of the QW properties. This unique feature of driven QWs can be exploited for search algorithms: here we demonstrate that such an algorithm exhibits a quantum speed up over classical walker. [1] J. Kempe, Contemporary Physics 44, 307 (2003). [2] A. S. Solntsev et al., Phys. Rev. Lett. 108, 023601 (2012) [3] R. Kruse et al., New J. Phys. 15, 083046 (2013) [4] C. S. Hamilton et al. to be published in Phys. Rev. Lett. (2014)

B58 - **Theory of multi-photon pair effects in spontaneous parametric down conversion based quantum information processing**
Masahiro Takeoka
National Institute of Information and Communications Technology
In spontaneous parametric down conversion (SPDC) based quantum information processing (QIP) experiments, there is a tradeoff between the coincide count rates (i.e. the pumping power of the SPDC), which limits the rate of the protocol, and the visibility of the quantum interference, which limits the quality of the protocol. This tradeoff is mainly caused by the

multi-photon pair emissions from the SPDCs and one of the problem in theory is how to model the experiments without approximating such multi-photon emissions. In this paper, we establish a method to theoretically simulate the SPDC based QIPs which fully incorporates the effect of multi-photon emissions and various practical imperfections. Our method is based on the characteristic function formalism which has been used in continuous variable QIPs. We examine two basic examples, the Hong-Ou-Mandel interference and the Einstein-Podolsky-Rosen interference experiments, and derive the analytical expressions of the visibilities, which precisely agrees with the previous experimental results in the high pump power regime. We also show that the method is applicable to more advanced SPDC based QIP protocols in a systematic way.

B59 - **Quantum-enhanced classical secure delegated computations***

Stefanie Barz
University of Oxford

Cloud computing - the storage and processing of data on remote servers - has become highly relevant in the current information age. A long-standing question has been whether it is possible to delegate tasks securely - such that neither the computation nor the data is revealed to the server. Recently, two solutions to this problem were invented: one for classical computation providing computational security and one for quantum computation, which is unconditionally secure. Here, we study quantum-enhanced classical computation and show experimentally how a classical client with limited capacity can delegate a computation securely. The client needs only the power to implement single-qubit gates and have access to a random number generator. All other technology - lasers and the measurement devices - is operated at the server's side. *Authors: S. Barz, V. Dunjko, E. Kashefi, I. A. Walmsley

B60 - **Efficient quantum process tomography of linear optical devices**

Nicholas Russell
University of Bristol

The operation of any lossless quantum device can be described by a unitary operator, and once this unitary is known the device is fully understood. This makes the determination of the uni- tary for arbitrary devices crucial; not only from the perspective of fundamental science, but more practically in the design and verification of quantum technologies. Here, we present the first ex- perimental demonstration of an efficient process for determining the unitary description of a linear- optical device, on a quantum walk in evanescently coupled waveguides. Furthemore, we use our experimentally-determined description of the device, which relies on only single-photon and photon-pair measurements, to make predictions of 3, 4, and 5 photon statistics, which are then confirmed explicitly. Whilst we demonstrate our scheme in the setting of linear optics, our method is applicable to any system of non-interacting particles which produces single particle and two parti- cle correlations. These correlations can be measured using either quantum (Hong Ou Mandel) or semi-classical (Hanbury-Brown Twiss) interference.

B61 - **Efficient State Analysis and Entanglement Detection**

Christian Schwemmer
Max-Planck-Institute of Quantum Optics

Genuine multi-partite entangled quantum states promise fascinating applications like, e.g., quantum computing or quantum metrology. Hence, experimentally friendly tools to detect and characterize entanglement are needed. However, standard quantum state tomography suffers from an exponentially increasing measurement effort with the number of qubits. In contrast, low rank or permutationally invariant (PI) states, like GHZ, W, or Dicke states, enable tomographic analysis at highly reduced cost [1,2]. Here, we implement and compare PI tomography, compressed sensing tomography, and their combination against standard tomography for a six-photon symmetric Dicke state. For data processing, we developed a fitting algorithm based on convex optimization which is superior in terms of speed and accuracy. By means of this algorithm, we were also able to study whether the maximum likelihood principle itself leads to errors. We observed a systematic underestimation of the fidelity and an overestimation of entanglement. These problems can be avoided when the data is analyzed in a linear way. [1] Tòth et al., Phys. Rev. Lett. 105, 250403 (2010) [2] Gross et al., Phys. Rev. Lett. 105, 150401 (2010)

B62 - **Resource-efficient construction of a linear optical cluster state**

Mercedes Gimeno-Segovia
Imperial College London

Linear photonic systems are very promising basic building blocks of a quantum computer, as they have low-noise properties and high speed transmission. However, photons don't interact naturally, which makes implementing two qubits gates a difficult task, the implementations can only work probabilistically. One way of getting around this problem is using the MBQC model in which all the required entanglement is prepared offline, in the form of a multi-particle cluster state. Building such a cluster state is a challenging task, due to the non-deterministic nature of the entangling gates and the effect of loss. We present a scheme that uses linear optical elements, boosted fusion gates and GHZ states to efficiently construct a universal cluster state. In comparison with previous schemes, we significantly reduce the resources needed, while still maintaining a static procedure that avoids rerouting and the use of conditional dynamics. We analyse the percolation properties of the cluster, both in the absence of loss and in the presence of heralded loss, and show how using know renormalisation techniques we can obtain a cluster state that is universal for quantum computation.

B63 - **Decoherence-free Quantum Photonic Operations via Quantum Zeno Effect**

Yuping Huang
Northwestern University

Quantum Zeno effect is a counter-intuitive phenomenon occurring when a slow-evolving quantum system is frequently probed, with the result that the system is "frozen" in its initial state. Using this effect, it has been proposed that quantum information processing can be implemented in a decoherence-free subspace for atom-cavity systems. Here, we report our theoretical and experimental progress towards establishing a new platform for all-optical quantum information processing. Utilizing the quantum Zeno effect, we have theoretically discovered that exotic quantum operations, such as strong photon-photon interaction, deterministic generation of entanglement, and interaction-free Fredkin gates, can be realized without subject to background quantum noises that are otherwise inevitable. On the experimental side, we have demonstrated such Zeno-based all-optical effects in a prototype Fabry-Perot system and a Whispering-Gallery mode cavity with strong optical nonlinearity. For both systems, the experimental data fit well with theoretical predictions. Lastly, we will discuss new opportunities enabled by the Zeno effect for building practical quantum networks over long distances.

B64 - **Multiplexing continuous-variable quantum information in optics**

Seiji Armstrong
The Australian National University

Large entangled systems have recently been demonstrated in various optical platforms. In these experiments, quantised optical modes (qumodes) with continuous-variable encodings are made to propagate on the same optical channel. This leads to highly scalable architectures for quantum networks utilising entanglement. Qumodes have thus far been multiplexed in three domains: the spatial domain [1,2], the time domain [3], and the frequency domain [4,5]. Here, I present experiments performed in the first two domains. Spatial-mode multiplexing was performed in the Bachor Group [1]. By overlapping orthogonal spatial modes onto one optical beam, we define our qumodes to be linear combinations of different spatial regions of the beam. This highly efficient programmable quantum network was used in order to demonstrate the first observations of multipartite Einstein-Podolsky-Rosen steering [2]. To increase the scaling we followed a theoretical proposal by Menicucci, and in the Furusawa Group, we multiplexed qumodes in the time domain to create the largest entangled state reported to date [3]. The generated cluster state may be used for universal measurement-based quantum computing.

B65 - **High-speed quantum random number generator by measuring photon arrival time using external references**

Zhen Zhang
Tsinghua University

We present a practical high-speed quantum random number generator, where the timing of single-photon detection relative to an external time reference is measured as the raw data. The bias of the raw data can be substantially reduced compared with the previous realizations. The raw random bit rate of our generator can reach 109 Mbps. We develop a model for the generator and evaluate the minentropy of the raw data. Toeplitz matrix hashing is applied for randomness extraction, after which the final random bits are able to pass the standard randomness tests.

B66 - **Sorting orbital angular momentum of light based on polarization rotation**

Li-Xiang Chen
Xiamen University

The photons can carry both spin and orbital angular momentum (OAM). In contrast to photon spin with 2-dimensional thinking, twisted photons can realize a Hilbert space of much higher dimension, as the OAM numbe is theoretically unbounded. Here we presented a new experiment of mimicking Faraday rotation to induce angular momentum coupling from the orbital to spin form by a modified Mach-Zehnder interferometer. Our interferometer is able to impart the left- and right-handed circular components of incoming light with a different OAM-dependent phase retardation. As a result, we are able to rotate the polarization by an angle that is determined by the input OAM number. We have sorted successfully both a single OAM and a mixture of multiple OAM into individual even and odd subsets, and observed the characteristic single bright rings and the petal-like flowers. Moreover, we have succeeded in sorting fractional OAM for the first time. Because of this new orbital to spin angular momentum coupling effect, our scheme holds promise for simultaneous polarization and OAM multiplexing and demultiplexing in the high-capacity optical communications. [1] W. Zhang, Q. Qi, J. Zhou and L. Chen*, "Mimicking Faraday rotation to sort the orbital angular momentum of light," Physical Review Letters 112, 153601 (2014). [2] L. Chen*, J. Lei, and J. Romero, "Quantum digital spiral imaging," Light: Science & Applications 3, e153 (2014). [3] L. Chen*, W. Zhang, K. Cai, Y. Zhang, and Q. Qi, "Revisiting the which-way experiment with twisted light beams," Optics Letters 39, 5897 (2014). [4] M. Su and L. Chen*, "Remote state preparation of three-dimensional optical vortices," Optics Express 22, 10898 (2014).

B67 - **Strong coupling in coupled highly-dissipative cavity quantum electrodynamics**

Yong-Chun Liu
Peking University

The coherent light-matter interaction at the single-photon and electronic qubit level promises to be a remarkable potential for quantum information processing. Besides the efforts of improving the figure of merit of the cavities, here we demonstrate strong anharmonicity in the polariton dressed states via dark state resonances in a highly dissipative cavity. It is shown that the vacuum Rabi oscillation occurs for a single quantum emitter inside a cavity even with the bosonic decay-to-interaction rate ratio exceeding 100, when the photon field is coupled to an auxiliary high-Q cavity. Moreover, photon blockade is observable in such a highly dissipative cavity quantum electrodynamics system. This study provides a promising platform for overcoming decoherence and advancing the coherent manipulation of polariton qubits.

B68 - **Hybrid spin-optomechanics with nitrogen-vacancy centers built in diamond resonators and superconducting waveguide cavities**

Pengbo Li
Xian Jiaotong Univerisity

We study a spin-optomechanical interaction by integrating a microscale diamond beam with a single built-in nitrogen-vacancy (NV) center spin to a superconducting coplanar waveguide (CPW) cavity. Under an ac electric field and a gradient magnetic field, the mechanical motion of the beam can strongly couple both to the cavity field and to the single NV center spin at the single quantum level. This enables coherent information transfer between the NV spin and the CPW cavity via mechanically dark polaritons. This hybrid spin-optomechanics system, with tunable couplings by external fields, offers a realistic platform for implementing quantum information with single NV spins, mechanical resonators, and single microwave photons.

B69 - **Superradiance of Degenerate Atomic Fermi Gases in an Optical Cavity**

Zhenhua Yu
Institute for Advanced Study, Tsinghua University

The interaction between matter and electromagnetic field is the most fundmental and of widest applications at the energy scales relevant to human beings. Electromagnetic field in cavities has its own characteristics. We consider spinless Fermi gases placed inside a cavity. Due to the interaction between the Fermi gases and the cavity field, a superradiance transition occurs in the system when the pumping laser field applied on the fermions reaches a critical strength. We discover that Fermi surface nesting effect can strongly enhance the superradiance tendency in comparison to a Bose gas of same density. This feature leads to interesting reentrance behavior and topologically distinct structure in the phase diagram. Away from the Fermi surface nesting regime, the Pauli exclusion principle brings about the dominant effect for which the critical pumping strength is lowered in the low-density regime and increased in the high-density regime.

B70 - **Atomic mercury vapor inside a hollow-core photonic crystal fiber for nonlinear and quantum optics experiments**

Ulrich Vogl
Max Planck Institute for the Science of Light

Strong optical nonlinearities at ultra-low power levels have many potential applications in quantum optics and metrology. Here we introduce a system based on atomic mercury vapor at room temperature confined in a kagomé-style hollow-core photonic crystal fiber. Atomic mercury vapor offers strong optical nonlinearities in the ultraviolet region of the spectrum and hollow-core PCF filled with Hg vapor provide strong nonlinearities at the single photon level, permitting for example single photon all-optical switches and near-deterministic phase-gates with phase-shifts of order π [2]. Additionally, strong lateral confinement may allow the study of the dynamics of quasi one-dimensional photon-gas systems [3] and interactions of single photon wave packets [4]. We have demonstrated high mercury vapor pressure inside a HC-PCF with a core diameter of 18 μm. A maximum optical depth of 114(8) was reached at the transition of the 202Hg isotope. Doppler-free spectroscopy confirms that the transition shows no apparent transit-time broadening inside the fiber, making the system a promising platform for quantum optics at the single photon level. References: [1] P. St.J. Russell, J. Lightwave Tech. 24, 4729âĂŞ4749 (2006). [2] A. Furusawa and P. Van Loock, Quantum Teleportation and Entanglement: a Hybrid Approach to Optical Quantum Information Processing (John Wiley & Sons, 2011).[3] D. E. Chang, V. Gritsev, G. Morigi, V. Vuletic, M. D. Lukin, and E. A. Demler, Nature Physics 4, 884âĂŞ889 (2008).[4] O. Firstenberg, T. Peyronel, Q. Y. Liang, A. V. Gorshkov, M. D. Lukin, and V. Vuletic, Nature 502, 71 (2013).

B71 - **High-Fidelity quantum memory utilizing inhomogeneous nuclear polarization in a quantum dot**

Ding Wenkui
Wuhan University

We investigate numerically the encoding and retrieval processes for a quantum memory realized in a semiconductor quantum dot, focusing on the effect of inhomogeneously polarized nuclear spins whose polarization depends on the local hyperfine coupling strength. We find that the performance of the quantum memory is significantly improved by the inhomogeneous nuclear polarization, compared to the homogeneous one. Furthermore, the narrower the nuclear polarization distribution is, the better the performance of the quantum memory is. Our results shed new light on the implementation of a quantum memory in a quantum dot.

B72 - **Implementing a high-rate single-photon source using ultra-low-loss all-optical switching**

Timothy Rambo
Northwestern University, Center for Photonic Communication and Computing

A key limitation for using heralded single-photon sources as the basis for any quantum information processing or cryptography scheme is their probabilistic nature. One way to overcome this problem is to simultaneously trigger many sources, determine which source (if any) has generated a photon, and route that photon to the output mode of the system using an optical switching network. Assuming perfect devices this approach increases single-photon production probability in proportion to the number of sources without introducing additional noise. However switch insertion loss can quickly degrade performance, with 3 dB of loss negating any possible gains. We report the construction and characterization of a fiber-based all-optical switch network which operates at GHz repetition rates, induces a record-low 0.19 dB (4.3%) insertion loss on average per switch, and introduces 10-5 noise photons per switching operation. We will also report on experimental progress in integrating the switching network with four fiber-based heralded single-photon sources as well as with high efficiency superconducting nano-wire single-photon detectors.

B73 - **Random phasing in gain-switched laser diodes for random number generation**

Zhiliang Yuan
Toshiba Research Europe Limited

We investigate, both theoretically and experimentally, the phase randomness in a gain-switched semiconductor laser diode. The electromagnetic phase of the lasing is guaranteed to be random, provided that there is sufficient rest period (*geq*200 ps) for the laser cavity between gain-switching events. Gain-switching at extremely high clock rates (*geq*5 GHz) risks phase correlation and loss of phase randomness. Strong phase correlation is observed when the laser is driven at a clock rate of 10 GHz. In relation to the field of quantum key distribution, our results confirm the gain-switched laser diode as a suitable light source, capable of providing phase-randomized coherent pulses at a clock rate of up to 2.5 GHz. Exploiting the phase randomness, we demonstrate robust, high-speed random number generation using interference of the steady-state emission obtained through gain-switching a laser diode. Steady-state emission tolerates large temporal pulse misalignments and therefore significantly improves the interference quality. Using an 8-bit digitizer followed by a finite-impulse response unbiasing algorithm, we achieve random number generation rates of 8 and 20 Gb/s, for laser repetition rates of 1 and 2.5 GHz, respectively, with a $\pm 20\%$ tolerance in the interferometer differential delay. We also report a generation rate of 80 Gb/s using partially phase-correlated short pulses.

B74 - **Single-photon-level quantum memory for photonic states encoded in orbital angular momentum space**

Bao-Sen Shi
University of Science and Technology of China

Quantum memory is a key component of quantum networks. A successful development in enabling the distribution of quantum information requires storing single-photon light. Usually quantum information is encoded using a two-dimensional space, therefore each photon carries a quantum bit of information. If the photon could be encoded in a high-dimensional space instead, the channel capacity of the network and the transmission efficiency would then be greatly enlarged. Moreover, storing high-dimensional states in quantum memory can reduce its sensitivity to memory coherence time, leading to significant improvements in storage capacity. The degrees of freedom for orbital angular momentum (OAM) of a photon could consist of a high-dimensional space for encoding. Although some work in this regard has been reported for different physical systems, what is lacking is a way of storing and releasing sometime later a true single photon, including its shape and structure. Constructing this basic element of quantum memory has been a big challenge. Besides, constructing a quantum memory for a photonic entanglement is vital for realizing quantum communication and network, this derives from the fact that a quantum network needs the distribution of quantum entangled photons over channels between different nodes. A high-dimensional quantum internet needs to store OAM entangled states and perform entanglement swapping to efficiently extend the achievable communication distances. In this talk, I will introduce our experimental progresses along the construction of a quantum memory for OAM state. We report the first experimental realisation where a true single photon carrying OAM is stored via electromagnetically induced transparency in a cold atomic ensemble. Besides, we also report the first experimental realization of a quantum memory storing a photon encoded using a three-dimensional space spanned by OAM states. Furthermore, we report the first experimental realization of storin

B75 - **Direct generation of genuine single longitudinal mode narrowband photon pairs**

Kai-Hong Luo
Paderborn University

We report on an integrated single longitudinal mode narrowband photon pair source via non-degenerate type II parametric down-conversion in a resonant waveguide. The device is composed of a periodically poled Ti-indiffused LiNbO3 waveguide with high reflective dielectric mirror coatings deposited on the waveguide end-faces. Photon pairs with wavelengths around 890 nm and 1320 nm are generated. Clustering in the doubly resonant source leads to a tremendous narrowing of the spectral bandwidth. The whole conversion spectrum is only one single longitudinal mode with a narrow linewidth around 60 MHz, long correlation time around 5 ns and high spectral brightness 3×10^4 pairs/(s·mW·MHz). This source exhibits single longitudinal mode purity and remarkable temporal shaping capability. Especially, due to temporal broadening, two-photon autocorrelation with longer than 12 ns correlation time is resolved. The stable, miniaturized, fiber compatible and low-cost monolithic design is attractive to various quantum communication applications, for instance to address quantum memories with controllable waveform, narrow spectrum and excellent purity.

B76 - **InP-based Single Photon Detectors and Geiger-mode APD Arrays**

Xudong Jiang
Princeton Lightwave, Inc.

In this talk we will discuss the design, operation and performance of various InP-based single photon detectors, including discrete single photon avalanche diodes (SPADs), negative feedback avalanche diodes (NFADs) and Geiger-mode avalanche photodiode (GmAPD) arrays. The performance data from a large quantity of InP-based discrete SPAD devices will be presented, and these devices provide an excellent solution that is robust and scalable for quantum communications and other applications where single photon detection in the short wavelength infrared (SWIR) spectral band is critical. NFAD devices can work in the free running mode and provide an ideal choice for long distance, entanglement-based quantum key distributions (QKDs). We will also discuss the performance of GmAPD focal plane arrays(FPAs)under two different readout modes, i.e., framed readout mode and asynchronous readout mode. GmAPD FPAs with framed readout mode provide sensor engines for very high performance three-dimensional(3D)imaging laser radar(LADAR)systems, and GmAPD FPAs with asynchronous readout mode can enable high rate quantum key distributions and other quantum communications applications.

B77 - **Room-Temperature Single-photon level Memories: polarization qubit storage and cascadability.**

Figueroa Eden
Stony Brook University
An optical quantum memory is a stationary device that is capable of storing and recreating photonic qubits with a higher fidelity than any classical device. Thus far, these two requirements have been fulfilled in systems based on cold atoms and cryogenically cooled crystals. In this work we report a room-temperature memory capable of storing arbitrary polarization qubits with a signal-to-background ratio higher than 1 and an average fidelity surpassing the single-photon classical benchmark for weak laser pulses containing 1.6 photons on average. We also show results on the feasibility of cascading two of these systems using input signals at the few-photon level. Our results demonstrate that atomic vapor systems are close to reaching levels of quantum functionality akin to other quantum information processing architectures.

B78 - **Interfacing GHz-bandwidth heralded single photons with a room-temperature Raman quantum memory**
Theresa Champion
University of Oxford
For the first time a room-temperature, GHz-bandwidth memory with on-demand readout is interfaced directly with heralded single photons generated from spontaneous parametric downconversion (SPDC). Based on a far-off-resonant Raman transition, the memory protocol provides a time-bandwidth product of ?1000. This is sufficient for dramatically enhancing the scalability of photonic networks. The memory performance is tested by measuring the autocorrelation of the retrieved fields, benchmarked against autocorrelation measurements of coherent states with average input photon numbers comparable to the SPDC heralding efficiency. We observe a clear influence of the SPDC input photon statistics on the retrieved field which agrees well with our theoretical model of the memory interaction. Four-wave mixing (FWM) noise is identified as the sole significant noise source which currently prevents the preservation of sub-Poissonian statistics in the output signal. Our new insights, both experimental and theoretical, show that the one remaining challenge before implementing Raman memories in scalable photonic networks is the suppression of this FWM noise - a challenge we foresee as surmountable.

B79 - **Interfacing various atomic transitions and telecom wavelengths with a single tunable narrowband photon-pair source**
Gerhard Schunk
Max Planck Institute for the Science of Light
Today, sources of non-classical light do not offer the same performance as classical laser sources in terms of stability, compactness, efficiency, and wavelength tunability. We present a compact source of photon-pairs and squeezed light based on efficient parametric down conversion in a triply resonant whispering-gallery resonator (WGR) made out of lithium niobate [1,2,3,4]. The central wavelength of the emitted light can be tuned over hundreds of nanometer and allows for precise and accurate spectroscopy with single signal and single idler photons of tunable bandwidth. Based on our analysis of the various eigenmodes of the WGR, we employ different wavelength tuning mechanisms, which we combine for mode-hop free tuning. With this we demonstrate tuning to the D1 lines of rubidium (795 nm) and cesium (895 nm) and a scanning over the Doppler-broadened and Doppler-free absorption line of the Cs D1 F4'-F3 transition. The corresponding idler photons are emitted at 1317 nm for cesium and 1609 nm for rubidium. Providing this flexibility in connecting various alkali atoms with telecom wavelengths, this system opens up novel possibilities to realize proposed quantum repeater schemes.

B80 - **Supression of Noise in a Broadband Room-temperature Raman Quantum Memory**
Dylan Saunders
Oxford University
Warm, broadband, quantum memories are attractive candidates for scalable photonic networks. They provide a relatively simple experimental design and a large time-bandwidth. However, because of the nature of the Raman memory protocol, there is also an unwanted noise process - spontaneous four-wave-mixing. A process were the strong control beam induces both the desired Stokes Raman scattering for storage, but also unwanted anti-Stokes scattering. This anti-Stokes scattering produces noise in the output mode of the memory. In this work we investigate experimentally a technique to suppress this noise. Our memory is based on transient far off-resonance Raman absorption in a Cs vapour cell at 70C. Storage and subsequent readout is mediated by the presence of a strong control beam (bandwidth: 1.2Ghz). We insert our vapour cell in a ring cavity to suppress four-wave-mixing. This cavity has been designed to be resonant for the strong control field, the signal field, but anti-resonant for the anti-stokes frequency. We expect that our design will allow for our memory to operate in the quantum regime, preserving the photon statistics of any single-mode field we store in the memory.

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