Programme QIPCC 2016

	Monday 28 Nov	Tuesday 29 Nov	Wednesday 30 Nov
08:45 - 09:45	Attendee Arrivals	(School session) Roee Ozeri The trapped ion quantum toolbox	(Invited Speaker Talk) Mark Blumenthal High frequency single electron pumping
09:45 - 10:45		(School session) Mark Blumenthal A beginner's guide to low-dimensional electron gas systems	(Invited Speaker Talk) Roee Ozeri Weak dipolar interactions in trapped-ion chains
10:45 - 11:15		Tea	**Tea**
11:15 - 11:35		Yaseera Ismail Single photon source produced by a partially spatially coherent pump beam	Kevin Garapo Modern cryptography and quantum key distribution
11:35 - 11:55		Bienvenu Ndagano Quantum error correction with classical light	Thomas Unden Quantum Metrology enhanced by repetitive quantum error correction
11:55 – 12:15		Chemist Mabena Hong-Ou-Mandel interference in turbulence	Closing Meeting
12:30 – 14:00	**Lunch**	**Lunch**	**Lunch**
14:00 – 14:20	(Classroom session) Hermann Uys Ramsey interferometry and atomic clocks	Attie Hendriks Control of CO2 vibrational dynamics via shaped-pulse CARS	**Departures**
14:20 – 14:40		Isaac Nape Quantum eraser with vector modes	
14:40 – 15:00	(Classroom session) Francesco Petruccione A crash course in open quantum systems	Ilya Sinayskiy Open quantum Brownian motion	
15:00 - 15:20		**Tea**	
15:20 - 15:40	**Tea**	Philipp Uhrich Measuring dynamic correlation functions	
15:40 – 16:00	Hazmatally Goolam Hossen Non-reversal Open Quantum walks	Mark Fingerhuth Putting quantum machine learning algorithms to the test	
16:00 – 16:20	Filip Wudarski Who is afraid of the memory kernel master equation?	Charles Rigby Toward quantum feedback control with trapped ions	
19:30	**Dinner**	**Dinner**	

Abstracts

Monday, 28 November

14:00 – 15:20 Class room session

15:20 - 15:40 Tea

15:40 – 16:00 Non-reversal Open Quantum Walks – Hazmatally Goolam Hossen

A model of non-reversal quantum walk is introduced. In such a walk, the walker cannot go back to previously visited sites but it can stay on the same site or move to a new site. This is achieved with the help of a memory that records visited sites. The process is introduced on a line using the formalism of Open Quantum Walks (OQWs). Afterwards, non-reversal quantum trajectories are shown on a 2-D lattice. In this case, the ``quantum coin'' used consists of four Kraus operators, each representing one cardinal direction. Finally, examples of 3-D trajectories are illustrated.

16:00 – 16:20 Who is afraid of memory kernel master equations? – Filip Wudarski

The field of open quantum systems (OQS) is divided into local-in-time and nonlocal-in-time approach. The latter is based on memory master equation, that is under intensive study for almost 60 years and it is applied in the interdisciplinary fields (quantum biology, chemistry or quantum information theory). In this talk, after a brief introduction to OQS and its applications, we present necessary and sufficient conditions for memory kernel operator, that yield physically admissible dynamics.

Tuesday, 29 November

School Session

08:45 – 09:45 The trapped-ion quantum tool-box – Roee Ozeri

In this tutorial I will review the basic building blocks of Quantum Information Processing using cold trapped atomic ions. I will mainly focus on methods to implement single-qubit rotations and two-qubit entangling gates, which form a universal set of quantum gates. Different ion qubit choices and their respective gate implementations will be described.

09:45 – 10:45 - A Beginners Guide to Low-Dimensional Electron Gas Systems - Mark Blumenthal

The rapid expansion in technology based on solid state semiconductors has led to the development of materials with complicated bad structure. Such band structures have allowed for the formation of systems that exhibit low dimensional electron effects, whereby electrons are confined by limiting their degrees of freedom.

Via the use of modern day cleanroom processes and techniques, electrons can be confined into quantum dots systems where individual electrons can be isolated and manipulated.

In this school session the field of low dimensional electron gas systems will be Introduced. The formation of material systems known as Heterostructures grown via Molecular Beam Epitaxy will be presented, together with the cleanroom techniques used to fabricated nano-electronic devices.

Key experiments from literature in the field of quantum electronics will be explored, highlighting some of the fundamental quantum mechanical phenomena in this rapidly advancing subject.

10:45 – 11:15 Tea

Contributed Talks

11:15 – 11:35 Single photon source produced by a partially spatially coherent pump beam – Yaseera Ismail

The development of single photon sources is at the core of applications in the field of quantum information processing and communication. A single photon source may be produced through entanglement, achieved through a non-linear process known as Spontaneous Parametric Down Conversion (SPDC), experimentally created by making use of a non-linear crystal resulting in the generation of a single photon pair called a signal and idler photon. The emitted photons are entangled in position, momentum and polarization [1]. Of recent, there has been numerous studies based on the temporal and spatial coherence properties of the twin beam state [2].

It has been shown that the spatial-spectral and spatial-temporal properties of the entangled photons are affected by crystal and pump beam parameters. Recently, the spatial and spectral coherence of high intensity twin beam were studied by measuring the intensity auto- and cross-correlation function for the near-field and far-field configurations [2]. Preceding experiments considered the pump beam to be fully spatially coherent however it has been shown theoretically, that the spatial coherence properties of the pump field is entirely transferred to the spatial coherence properties of the down-converted two-photon field [3]. It has also shown that the entanglement of a spatial two-qubit state is affected by the spatial coherence properties of the two photon field [4].

Here, the spatial coherence properties of the entangled-photon pairs produced by SPDC are experimentally investigated taking into consideration the partial spatial coherence of the pump beam. For spatial correlation in SPDC, coincidence counts are recorded as a function of the detectors. It has been shown theoretically that the detection probability of the two-photon field is higher and less susceptible to atmospheric turbulence if the field is produced by a lower mode of partially coherent pump beam [5]. Therefore, entangled photon fields produced by a partially coherent pump is a significant means to prepare two-qubit states for quantum communication.

Reference

1. D. C. Burnham and D. L. Weinberg, “Observation of Simultaneity in Parametric Production of Optical Photon Pairs,” Phys. Rev. Lett. 25, 84-87 (1970).
2. A. Joobeur, B. E. A. Saleh and M. C. Teich, “Spatiotemporal coherence properties of entangled light beams generated by parametric down-conversion,” Phys. Rev. A 50(4), 3349-3363 (1994).
3. K. Jha and R.W. Boyd. “Spatial two-photon coherence of the entangled field produced by down-conversion using a partially spatially coherent pump beam,” Phys. Rev. A 81, 013828 (2012).
4. E. A. Saleh, A. F. Abouraddy, A.V. Sergienko, and M. C. Teich, “Duality between partial coherence and partial entanglement,” Phys. Rev. A 62, 043816 (2000).
5. Y. Qiu and W. She, "The influence of atmospheric turbulence on partially coherent two-photon entangled field," Appl. Opt.,108, 683-687 (2012).

11:35 - 11:55 Quantum error correction with classical light – Bienvenu Ndagano

One of the many disparities between quantum and classical mechanics is the nature of the particle correlations. Entanglement, widely recognized as a salient feature of quantum mechanics, allows for non-local correlations that have been exploited to achieve long range quantum communication. However, entanglement is fragile and entangled states are prone to decoherence when propagating though perturbing channels. To realize a robust quantum link, a tomography of the channel is essential, which naturally requires the link to work in the first place. Here, we show that this catch 22 can be resolved using classically entangled states. Using a turbulent atmosphere as an example, we show that the evolution of an entangled pair is equivalent to that of the entangled degrees of freedom of a classical beam. It is in light of this equivalence that we propose and demonstrate a scheme to perform the tomography of the quantum channel and quantum error correction, both using classical light.

11:55 – 12:15 Hong-Ou-Mandel interference in turbulence - Chemis Mabena

In this work, the effect of turbulence on the Hong-Ou-Mandel (HOM) effect is investigated, both experimentally and theoretically. For this purpose, we produce entangled photonic states generated by spontaneous parametric down-conversion. In our experiment, one of the photons propagates through turbulence, simulated with a spatial light modulator, while the other is left undisturbed. The atmospheric turbulence is simulated according to the Kolmogorov theory of turbulence and modelled as a single phase screen. Without any turbulence, one finds that symmetric states (anti-symmetric states) produce a dip (peak) in the coincidence counts after passing through the beam-splitter, thanks to the HOM effect. With the addition of turbulence in one of the photon paths, we found that (depending on whether the input state is symmetric or anti-symmetric) the dip or peak that is produced is smaller; its visibility is reduced. This phenomenon can be explained by the fact that the turbulence alters the probabilities of occurrence of the different HOM state combinations. As a consequence, the cancellations and enhancements of the coincidence counts for the different parts of the states after turbulence tend to cancel each other.

12:15 – 14:00 Lunch

14:00 – 14:20 Control of CO2 Vibrational Dynamics via Shaped-Pulse Coherent Anti-Stokes Raman Spectroscopy – Adriaan Hendriks

In this work we investigate the coherent control of carbon dioxide (CO_2) vibrational dynamics using Coherent anti-Stokes Raman Scattering (CARS). During CARS, vibrational modes are excited via Stimulated Raman Scattering (SRS). Subsequently a narrowband probe field de-excites the molecular ensemble providing not only information about the modes populated, but also on the evolution of the wave-packet created during excitation. By spectrally shaping one of the SRS pump fields the vibrational dynamics can be controlled. In this work it was assumed that the pump pulse structure which will lead to a desired dynamics is unknown. To find that structure, a learning algorithm was developed which utilizes a spatial light modulator in a 4f-optical configuration to spectrally shape the pump. Both a time-frequency representation of the shaped pulse (called the von Neumann basis) and a standard Fourier domain representation were benchmarked during optimization of a second harmonic generation (SHG) signal in a BBO crystal to ascertain which will suit the optimization problem best in terms of convergence rate and parameter space size. It was found that the von Neumann basis converged faster than the standard Fourier domain representation while still operating on a larger parameter space and therefore it was used in all subsequent work. In addition, we developed a quantum mechanical theoretical model of the CARS process to ensure proper understanding of our measurements. We demonstrated experimentally that mode excitation selectivity can be achieved using the pump fields extracted by the learning algorithm, and we explore the underlying selectivity mechanisms. Control of the relative phase of oscillation of different vibrational modes is also observed. Our work demonstrates coherent quantum control of all relevant aspects of the molecular vibrational dynamics of CO_2.

14:20 – 14:40 Quantum eraser with vector modes – Isaac Nape

Young's double slit experiment is one of the most celebrated achievement in quantum and classical optics; it provides experimental proof of the wave-particle duality of light. A photon incident on a double slit, exhibit wave-like behaviour and propagates through both slits, creating the fringes as a result of the path interference. However, when the paths are marked with orthogonal polarisation, the path information is revealed and the interference pattern is destroyed. The quantum eraser removes the path information with a projection on a complementary polarisation basis, and the interference pattern is recovered. Interestingly, the expression of the photon state after going through the marked shows an entanglement between the spatial degree of freedom (path) and the polarisation of the slits. The non-separability of these two degrees of freedom is known to exist in vector beam, where the spatial degree of freedom is coupled to the polarisation in a non-separable fashion. Using vector vortex modes carrying orbital angular momentum, we show that by manipulating the geometric phase of light, the marked double slit can be replaced with a birefringent phase plate that couples the polarisation and the angular momentum (OAM) of light in order to generate a vector mode. We show that, just as in Young's experiment, the paths (OAM) marked with polarisation do not lead to interference. However, when introducing the quantum eraser that projects the vector mode on a complementary polarisation basis, the paths are allowed to interfere, leading to the formation of azimuthal fringes whose frequency is proportional to the OAM content of the vector mode .

14:40 – 15:00 Open Quantum Brownian Motion – Ilya Sinyaskiy

Open quantum Brownian motion was introduced as a new type of quantum Brownian motion for Brownian particles with internal quantum degrees of freedom. Recently, an example of the microscopic derivation of open quantum Brownian motion has been presented. The microscopic derivation allows relating the dynamical properties of open Quantum Brownian motion and the thermodynamical properties of the environment. In the present work, we study the possibility of control of the external degrees of freedom of the "walker" (position) by manipulating the internal one, e.g. spin, polarization, occupation numbers. To this end we consider a free quantum Brownian walker with N-dimensional internal degree of freedom interacting with a decoherent environment. In this case, the connection between dynamics of the "walker" and thermodynamical parameters of the system is established.

15:00 – 15:20 Tea

15:20 – 15:40 Measuring Dynamic Correlation Functions – Philipp Uhrich

Dynamic (non-equal time) correlation functions of quantum systems are complex quantities, whose experimental accessibility is complicated by measurement backaction. However, we prove that the real part of dynamic correlation functions is not affected by backaction, and hence can be obtained by projective measurements. To our current understanding, the imaginary part is influenced by backaction and can therefore not be measured projectively. We thus introduce a non-invasive measurement protocol in which an ancilla is weakly coupled to the system under study, showing that an appropriate choice of the coupling Hamiltonian allows us to extract the imaginary part of the desired dynamic correlation function. Implementations in spin-1/2 lattice systems are discussed and we show that for such systems the weakness condition of the ancilla-system coupling is not necessary making the measurement of dynamic correlations in such systems simpler than expected.

15:40 – 16:00 Putting quantum machine learning algorithms to the test – Mark Fingerhuth

Quantum machine learning (QML), the intersection of quantum computation and classical machine learning, bears the potential to provide more efficient ways to deal with big data. So far, QML has been of almost entirely theoretical nature since the required computational resources are not in place yet. In this research, two k-nearest neighbour QML algorithms, one unpublished by Maria Schuld and the other described in Schuld et al. (2014), are simulated using IBM's 5-qubit quantum computer and Microsoft's quantum simulation toolsuite Liqui|>. In the talk it will be shown that small universal gate sets as provided by IBM strongly limit implementation of QML algorithms. Furthermore, for QML algorithms to be useful and implementable the problem of efficient quantum state preparation for arbitrary input data needs to be addressed.

Schuld, M., Sinayskiy, I., & Petruccione, F. (2014, December). Quantum computing for pattern classification. In Pacific Rim International Conference on Artificial Intelligence (pp. 208-220). Springer International Publishing.

16:00 – 16:20 Towards quantum feedback control of $^{171}Yb^{+}$ ions – Charles Rigby

Trapped laser cooled ions are ideal for the generation of quantum bits (qubits) required for development of quantum computing systems, quantum simulation and quantum metrology applications. To this end the reliable preparation, detection and manipulation of qubit states is of fundamental importance. We report on our recent successes at trapping and observation of single Yb ions in a linear Paul trap system. We present an outlook of experiments planned at our laboratory including: weak/unsharp measurements, feedback control, and observation of controllable multi-ion Young interference fringes.

Wednesday, 30 November

<u>Invited Speaker Talks</u>

08:45 – 09:45 High Frequency Single Electron Pumping – Mark Blumenthal

The ability to trap and manipulate single electrons presents the scientific community with the opportunity to not only probe some of the most fundamental theories of quantum mechanics but allows for the development of new technologies based on the intrinsic properties of electrons.

With the marked improvement in fabrication techniques used in the development of nano-sized devices, single electron transistors, electron pumps and charge detectors have all been realised. Such devices form the building blocks of future technologies such as quantum computing and cryptography.

The latest development in high frequency on demand single electron pumps will be shown. The inclusion of a high magnetic field as well as temperature effect studies will be shown.

The work will be presented in the context of utilising this high frequency on demand source of electrons to represent a new standard for electrical current.

The new dilution fridge system recently installed at the University of Cape Town will also be presented together with a basic introduction to dilution fridge technology.

09:45 – 10:45 Weak dipolar interactions in trapped-ion chains – Roee Ozeri

Trapped ions freeze into crystal arrays due to the long range Coulomb repulsion between their charges. However, because these ions have an internal atomic structure, they also poses electric and magnetic dipole moments. In this talk I will review two recent experiments in which the (extremely weak) magnetic and electric dipolar interactions were measured in between trapped ions in a linear crystal. In the first experiment, resonant electric dipole-dipole interactions were measured during photon scattering on an allowed optical dipole transition in chains of up to eight ions. The resonance frequency of the transition was shown to slightly (10's of kHz) shift whenever the separation between ions equaled an integer number of photon wavelength in what is known as collective Lamb shift [1]. This shift is due to emission and re-absorption of virtual photons between different ions in the chain, and is closely related to superradiance. In the second experiment, the magnetic spin-spin interaction between two trapped ions was observed to lead to the entanglement of their collective spin state. The measurement of this ultra-weak (mHz) interaction strength was made possible by restricting their spin evolution to a decoherence-free subspace. Since the magnetic moment of the ion is equal to that of a single electron, this measurement was used to bound the coupling of electron spin to hypothetical very-light force-mediators that extend the standard model of particle physics [2,3].

[1] Z. Meir, O. Schwartz, E. Shahmoon, D. Oron and R. Ozeri, Phys. Rev. Lett. 113, 193002 (2014)

[2] S. Kotler, N. Akerman, N. Navon, Y. Glickman and R. Ozeri, Nature 510, 376 (2014)

[3] S. Kotler, R. Ozeri, and D. J. Kimball, Phys. Rev. Lett. 115, 081801 (2015)

Contributed Talks

11:15 – 11:35 Modern Cryptography and Quantum Key Distribution – Kevin Garapo

Modern cryptography is the scientific information security approach that requires the formulation of accurate security definitions, the statement of the reasonable assumptions made in the formulation of the security definitions and the rigorous proof of security. Quantum key distribution is a modern cryptographic technique that can theoretically guarantee unconditional security in the distribution of long cryptographic secret-keys. The superior security of quantum key distribution is based on the fundamental laws of nature. Secret-keys generated using quantum key distribution techniques are viable for use in one-time pad encryption, which is the only known encryption scheme capable of achieving perfect secrecy, on condition that uniformly distributed random keys, which are as long as the messages to be encrypted, are used once. The main goal of the talk is to explicitly show the difference in level of security guaranteed by the best known classical cryptographic techniques as compared to cryptosystems based on the combination of quantum key distribution and one-time pad. In particular, we explore elliptic curve cryptography, which is used in classical secret-key agreement and compare its security to quantum key distribution.

11:35 – 11:55 Quantum metrology enhanced by repetitive quantum error correction – Thomas Unden

The accumulation of quantum phase in response to a signal is the central mechanism of quantum sensing, as such, loss of phase information presents a fundamental limitation. For this reason approaches to extend quantum coherence in the presence of noise are actively being explored. Here we experimentally protect a room-temperature hybrid spin register against environmental decoherence by performing repeated quantum error correction whilst maintaining sensitivity to signal fields. We use a long-lived nuclear spin to correct multiple phase errors on a sensitive electron spin in diamond and realize magnetic field sensing beyond the timescales set by natural decoherence. The universal extension of sensing time, robust to noise at any frequency, demonstrates the definitive advantage entangled multi-qubit systems provide for quantum sensing and offers an important complement to quantum control techniques. In particular, our work opens the door for detecting minute signals in the presence of high frequency noise, where standard protocols reach their limits.

11:55 – 12:15 Closing meeting

12:15 - 14:00 Lunch