Annual Workshop

December 9, 2015 - December 11, 2015

RACV Royal Pines, Benowa QLD

eQus

ARC CENTRE OF EXCELLENCE FOR ENGINEERED QUANTUM SYSTEMS

Program at a glance

	Wednesday	Thursday	Friday
6.30am		Yoga Breakfast	Yoga Breakfast
8.30am		Session one	Session five
10.30am	Registration	Morning tea Session two	Morning tea Session six
12.30pm	Lunch	Lunch	Lunch Session seven: Private meeting for CIs
2.30pm	Workshop opens	Session three Afternoon tea	Afternoon tea Session eight
4.30pm	SAC & AB meeting	Session four *Posters*	
6.30pm	Welcome dinner	Pizza and Pool	
8.30pm			

Welcome

Professor Gerard Milburn, Centre Director, EQuS

Welcome to the fifth EQuS Annual Workshop. I would particularly like to welcome our overseas guests who have kindly agreed to talk to us on areas that complement and extend our own research interests. Also, welcome back to the members of our Scientific Advisory Committee (SAC), Rainer Blatt and John Clarke, and welcome, for the first time, to our new SAC member, Alain Aspect. Your commitment to ensuring the quality of our science has served us well and has helped put us into a competitive position as we seek funding for another seven years.

A Centre of Excellence is a collaborative project and depends on the exchange of ideas. Our Annual Workshop is the primary forum for this, from PhD students to CIs. The winning idea for your first postdoc application, next DP or Centre application, may start here. So look beyond your current interests and do not miss an opportunity to learn something new.

Prof. Gerard Milburn

Invited Speakers

Professor Alain Aspect

Professor Aspect is currently an Augustin Fresnel Professor at the Institut d'Optique Graduate School and a Professor at Ecole Polytechnique. He is also a CNRS distinguished scientist at Laboratoire Charles Fabry, Institut d'Optique.

Professor Aspect was the first to exclude subluminal communication between the measurement stations in experimental demonstrations that quantum mechanics invalidates separable hidden-variable theories and the first to demonstrate experimentally the wave-particle duality of single photons. He co-invented the technique of velocity-selective coherent population trapping, was the first to compare the Hanbury Brown-Twiss correlations of fermions and bosons under the same conditions, and the first to demonstrate Anderson localization in an ultra-cold atom system.

DAY ONE: Speaking on the Atomic Hong-Ou-Mandel effect

Professor Bill Munro

Professor Munro graduated in 1989 with a BSc in Chemistry and Physics (Waikato, New Zealand), followed by an MSc in Physics (Waikato) in 1991 and a DPhil in Quantum Optics (Waikato) in 1994.

In 2000, he became a senior researcher in the Australian Special Centre for Quantum Information Processing. In November 2000, Professor Munro joined HP Labs as a research scientist and was instrumental in HP's development of quantum enabled technologies. In early 2010, he moved to Japan and joined NTT BRL as a research specialist. This was followed in 2014 by being promoted to senior research scientist and became BRL's first foreign group leader. He currently runs the theoretical quantum physics research group.

DAY TWO: Speaking on Hybridization

Professor Jörg Schmiedmayer

Professor Schmiedmayer is Professor of Physics at the TU-Wien (Vienna University of Technology). He received his doctoral degree in nuclear physics from the TU-Wien (1987). After a postdoc in Vienna and Oak Ridge, he changed to quantum physics and went as a research scientist to Harvard and MIT.

In 1995, he joined A. Zeilinger in Innsbruck where he developed integrated matter-wave optics and the atom chip. Before coming back to the TU-Wien in 2007, he held a chair in experimental physics in Heidelberg. His research interests cover a wide range, from many-body quantum physics with ultracold atoms to interconnecting quantum systems from photons, atoms and spins, and superconducting quantum circuits.

DAY TWO: Speaking on Correlation functions and how they factorize

Professor Jack Harris

Professor Harris studies the quantum aspects of motion in mechanical, optical and electronic systems.

His experiments use ultrasensitive force detectors to measure the ground state properties of electrical circuits, the quantum back-action of displacement measurements, and eventually the quantum properties of the mechanical force sensors themselves.

DAY TWO: Speaking on Observing quantum effects and topological effects in the motion of a millimeter-scale object

Professor Ian Walmsley

Professor Walmsley FRS is Pro-Vice-Chancellor for Research and Hooke Professor of Experimental Physics at the University of Oxford. He is a Professorial Fellow at St Hugh's College, Oxford.

Prior to being appointed Pro-Vice-Chancellor (Research) in February 2009, he was Head of Atomic and Laser Physics at Oxford, and served as Director of the Institute of Optics at the University of Rochester in the US. In 2011, he also took on responsibility for Academic Services and University Collections. His research is in the areas of ultrafast optics and quantum optics. In April 2012, he was elected to the Fellowship of the Royal Society.

DAY THREE: Speaking on Networked Quantum Information Technologies

Workshop Program

DAY ONE
Wednesday, December 9

11:30am	Registration opens
12:30pm	Lunch, Prince foyer
1:45pm	Prince Room opens
2:15pm	Welcome *Prof. Gerard Milburn*
	Overview and progress of EQuS to date *Prof. Gerard Milburn*
2:45pm	Atomic Hong-Ou-Mandel effect: a landmark in quantum atom optics *Prof. Alain Aspect*
3:15pm	Afternoon Tea, Prince foyer Hotel check-in
3:45pm	Overview of Quantum Measurement & Control *Assoc. Prof. Michael Biercuk*
4:00pm	Overview of Quantum-Enabled Sensors & Metrology *Assoc. Prof. Warwick Bowen*
4:15pm	Overview of Synthetic Quantum Systems & Quantum Simulation *Prof. Stephen Bartlett*
4:30pm	Workshop concludes for the day
5.00pm -6.00pm	Meeting of SAC and AB, Boardroom
6:30pm - 9:00pm	Workshop Opening Dinner, Poolside

Prof. Alain Aspect

Atomic Hong-Ou-Mandel effect: a landmark in quantum atom optics

In 1986, the original Hong-Ou-Mandel effect was a milestone in quantum optics. Due to a quantum interference between two-photon amplitudes, it cannot be described by any classical concept, wave or particle, and may be considered the simplest illustration of the second quantum revolution, based on the phenomenon of entanglement.

We have observed this intriguing effect with pairs of He* atoms. This opens the way towards studying a yet more intriguing quantum situation involving entanglement, leading to a test of Bell's inequalities with massive particles.

DAY TWO
Thursday, December 10

6.15am - 7.00am	Yoga, Concert Lawns (grassed area near Playground)
6.30am - 8.30am	Breakfast, Kalinda Restaurant
Session 1	Chair: Dr. Thomas Volz
9.00am	Nanodiamond for MRI (with 5min Q&A) *David Waddington, PhD student*
9.20am	Precision and Quantum Low-Noise Measurement Techniques for Axion-Like Dark Matter Particle Searches (with 5min Q&A) *Dr. Stephen Parker, Postdoc*
9.40am	Hybridization, a nice tool for quantum engineering *Prof. Bill Munro*
10.10am	Q & A
10.30am - 11:15am	Morning Tea, Prince foyer
Session 2	Chair: Prof. Halina Rubinsztein-Dunlop
11.15am	Dynamics of 87Rb BECs in configurable microscopic potentials (with 5min Q&A) *Dr. Tyler Neely, Postdoc*
11.35am	A bulk/boundary correspondence from the MERA (with 5min Q&A) *Dr. Sukhi Singh, Postdoc*
11.55am	Correlation functions and how they factorize *Prof. Jörg Schmiedmayer*
12.25pm	Q & A
12.45pm - 2.00pm	Lunch, Prince foyer
Session 3	Chair: Assoc. Prof. Warwick Bowen
2:00pm	Testing quantum contextuality with superconducting circuits (with 5 min Q&A) *Dr. Markus Jerger, Postdoc*
2:20pm	Ribbon operators for detecting topological order in generic systems (with 5 min Q&A) *Jacob Bridgeman, PhD student*
2:40pm	Observing quantum effects and topological effects (although not quantum topological effects) in the motion of a millimeter-scale object *Prof. Jack Harris*
3:10pm	Q&A
3:30pm - 4:10pm	Afternoon Tea, Prince foyer
Session 4	
4:10pm	Three Minute EQuS Poster Presentations
5:00pm - 7:00pm	Poster Judging & General Discussion Refreshments Served, Convention Lobby
7:00pm - late	Announcement of Poster Prize winners Pizza and Pool Competition, Hydrate Bar

Day Two, Session One

David Waddington
The development of new nanoparticle imaging modalities: Nanodiamonds for MRI

Nontoxic nanodiamonds have proven useful as a vector for therapeutic drug delivery to cancers and as optical bioprobes of subcellular processes. Despite their potential clinical relevance, a means of noninvasively imaging NDs in vivo is still lacking. Standard MRI modalities are impractical for imaging nanodiamond in vivo due to the low abundance and gyromagnetic ratio of the spinful 13C isotope.

In this talk, I will outline new MRI modalities for imaging nanodiamond:

- Direct detection of hyperpolarized 13C in nanodiamonds: We have developed a technique that uses intrinsic paramagnetic impurities to hyperpolarize 13C in the nanodiamond core, resulting in long lived nuclear spin polarization ~10 000 times larger than is normally available at room temperature. I will present preliminary data from an MRI system we have installed at the University of Sydney to image these hyperpolarized nanodiamonds.
- Imaging of nanodiamonds via the Overhauser effect: Paramagnetic impurities on the surface of nanodiamonds couple strongly to their environment. This coupling can be leveraged to hyperpolarize 1H when nanodiamonds are suspended in water. This discovery has enabled us to take high resolution, high contrast images of synthetic nanodiamonds in water with an Overhauser-enhanced MRI (OMRI) imaging technique, originally developed for free radical imaging.

Our results will drive further research into the use of MRI methodologies as a means of tracking ND and other nanoparticles in vivo.

Dr. Stephen Parker
Precision and Quantum Low-Noise Measurement Techniques for Axion-Like Dark Matter Particle Searches

Axions and axion-like particles are proposed weakly interacting sub-eV particles that make compelling dark matter candidates. The most promising searches involve lab-based low-energy experiments that exploit axion-to-photon coupling mechanisms, which provide a sensitive portal to detection with minimal model dependency. These experiments require extremely low noise precision measurement technology in the RF and microwave spectrums. Here we present an overview of these concepts, with a focus on current and future work at UWA.

Prof. Bill Munro
Hybridization, a nice tool for quantum engineering

The hybridization of distinct quantum systems has opened new avenues that allow us to engineer devices with the properties we require. We show a number of examples including long-lived dark states and the generation of spin squeezed states. Further we show a counter-intuitive use of a hybrid system where the coherence time of a quantum system can be significantly improved by coupling it with a much shorter lived system.

Day Two, Session Two

Dr. Tyler Neely
Dynamics of 87Rb BECs in configurable microscopic potentials

We present our ongoing development of a two-component Bose-Einstein condensate (BEC), consisting of 87Rb and sympathetically cooled 41K, loaded into configurable optical potentials. By utilising a digital micromirror device (DMD) and high-resolution imaging system, a wide range of precise 2D potentials can be created. In particular, we will describe the aspects of our new setup for producing high-resolution patterns (maximum resolution of 650 nm FWHM @532 nm), through direct imaging of the DMD to the atom plane. By applying this to our high-atom number 87Rb condensates, we have demonstrated the ability of our system to create configurable BECs. Ongoing investigations of atom transport between direct and tunnel-coupled reservoirs will be described.

Dr. Sukhiwinder Singh
A new bulk/boundary correspondence for quantum many-body systems

A bulk/boundary correspondence relates a (d+1)-dimensional quantum system to another quantum system that lives on the (d)-dimensional boundary of the bulk space such that the physical properties of one system can be derived from the other.

A celebrated example of a bulk/boundary correspondence is the anti-deSitter spacetime/conformal field theory (AdS/CFT) correspondence [1], according to which a (d+1)-dimensional (quantum) gravity theory is equivalent to a (d)-dimensional CFT that lives on the boundary and which does not contain gravity. (The AdS/CFT correspondence provides a concrete implementation of the holographic principle, believed by many to be a feature of quantum gravity). Another example is that certain topological field theories that describe topological phases of matter (e.g., fractional quantum hall systems) in two dimensions correspond to one dimensional CFTs at the boundary, which describe the gapless edge modes exhibited at the boundary of topological materials. Though these correspondences originated in string theory and quantum field theory, they have recently been applied in condensed matter physics to study certain quantum phases of matter and the phase transitions between them.

In this talk I introduce a new bulk/boundary correspondence for quantum many-body systems from an entanglement perspective. The correspondence applies to ground states of quantum many-body systems described by local Hamiltonians, and is based on encoding the ground state as a multi-scale entanglement renormalization ansatz (MERA) [2]---a tensor network decomposition of the ground state wavefunction, which has been used as a successful ansatz for several quantum lattice models. Our correspondence relates, for example, the ground state of a one dimensional lattice system undergoing a continuous phase transition (thus described by a CFT in the continuum) to a quantum state of a two dimensional system whose degrees of freedom live on a two dimensional AdS lattice. I will summarize some non-trivial features of our bulk/boundary correspondence and possible connections to the AdS/CFT correspondence.

[1] J. Maldacena, Adv. Theory. Math. Phys. 2, 231 (1998).
[2] G. Vidal, PRL 99, 220405 (2007).

Prof. Jörg Schmiedmayer
High order correlations and what we can learn about the solution for many-body problems from experiment

The knowledge of all correlation functions of a system is equivalent to solving the corresponding quantum many-body problem. If one can identify the relevant degrees of freedom, the knowledge of a finite set of correlation functions is in many cases sufficient to determine a sufficiently accurate solution of the corresponding field theory. Complete factorization is equivalent to identifying the relevant degrees of freedom where the Hamiltonian becomes diagonal. I will give examples how one can apply this powerful theoretical concept in experiment.

A detailed study of non-translation invariant correlation functions reveals that the pre-thermalized state a system of two 1-dimensional quantum gas relaxes to after a splitting quench [1], is described by a generalized Gibbs ensemble [2]. This is verified through phase correlations up to 10th order.

Interference in a pair of tunnel-coupled one-dimensional atomic super-fluids, which realize the quantum Sine-Gordon / massive Thirring models, allows us to study if, and under which conditions the higher correlation functions factorize [3]. This allowed us to characterize the essential features of the model solely from our experimental measurements: detecting the relevant quasi-particles, their interactions and the different topologically distinct vacuum-states the quasi-particles live in. The experiment thus provides a comprehensive insights into the components needed to solve a non-trivial quantum field theory.

Our examples establish a general method to analyse quantum systems through experiments. It thus represents a crucial ingredient towards the implementation and verification of quantum simulators.

Work performed in collaboration with E.Demler (Harvard), Th. Gasenzer und J. Berges (Heidelberg). Supported by the Wittgenstein Prize, the Austrian Science Foundation (FWF): SFB FoQuS: F40-P10 and the EU: ERC-AdG QuantumRelax

[1] M. Gring et al., Science, 337, 1318 (2012);
[2] T. Langen et al., Science 348 207-211 (2015).
[3] T. Schweigler et al., arXiv:1505.03126

Day Two, Session Three

Dr. Markus Jerger

Testing quantum contextuality with superconducting circuits

Contextuality is one of the most fundamental properties which distinguish quantum mechanics from classical theories. It has also been suggested to be the 'magical' resource responsible for an exponential speedup of a quantum computer. We will provide the first experimental evidence of this resource for a three-level quantum system built upon superconducting circuits - one of the leading architectures for quantum computation. By engineering the dispersive shifts of a superconducting qutrit coupled to a microwave cavity, we realize strong projective binary-outcome measurements. In conjunction with the high contrast readout permitted by a parametric amplifier, this allows us to close both the measurement and compatibility loopholes which were present in previous experimental tests.

Jacob Bridgeman

Ribbon operators for detecting topological order in generic systems

In this talk I will discuss unusual phases of matter expected to be realised in low temperature spin systems. These topologically ordered models possess degenerate ground spaces which can be utilised for quantum information processing.

Usually detection of ordering requires knowledge of the ground states, however this is incredibly challenging. In this work, we present a new approach in analogy with the Heisenberg picture of quantum mechanics. Rather than attempting to understand the ground state ordering directly, we investigate the operators which act on it.

We present numerical results demonstrating unusual quasiparticle behaviour which implies topological order is present in several models.

Prof. Jack Harris

Observing quantum effects and topological effects (although not quantum topological effects) in the motion of a millimeter-scale object

In 1909, Albert Einstein showed that the form of the Planck blackbody spectrum implies that the radiation pressure exerted on a macroscopic solid object is comprised of small (but not infinitesimal) kicks. Since then, the notion of radiation pressure exerted by individual photons has played an important role in developing our understanding of quantum measurements. Recently, advances in optical and mechanical instrumentation have highlighted the possibility of using the quantum aspects of radiation pressure to detect quantum features in the motion of macroscopic objects. In this talk, I will describe our group's work in this area, and will focus on recent measurements of the quantum motion of a 40 nanogram oscillator that has been laser cooled nearly to its ground state. I will also describe how this same system can be used (in the classical regime) to study topological effects that arise in the dynamics of an apparently simple system: a pair of coupled harmonic oscillators under parametric control.

Poster presentations

Group one

PhD Students

James Bennett, University of Queensland
A quantum optomechanical interface beyond the resolved sideband limit

Thomas Boele, University of Sydney
Brute force hyperpolization of nanodiamonds

Keith Motes, Macquarie University
Linear optical quantum metrology with single photons –– Exploiting spontaneously generated entanglement to beat the shotnoise limit

Sebastian Pauka, University of Sydney
Improving fidelity for fast readout of spin qubits

Claire Edmunds, University of Sydney
Eliminating residual qubit-oscillator entanglement in trapped ion systems

Nathan McMahon, University of Queensland
Exploration of a bulk/boundary correspondence from the Multiscale Entanglement Renormalisation Anzats (MERA)

Postdoctoral research fellows

Dr. Beibei Li University of Queensland
Cavity optomechanical magnetometry

Group two

PhD Students

Alice Mahoney, University of Queensland
On-chip microwave quantum Hall circulator

Benjamin McAllister, University of Western Australia
The UWA Scion Dark Matter detection experiment

Ewa Rej, University of Sydney
13C spin dynamics in hyperpolarized nanodiamond

Yauhen Sachkou, University of Queensland
Real-time measurement of superfluid motion

Postdoctoral research fellows

Dr. Fabio Costa, University of Queensland
Process matrices as quantum causal models

Dr. Sandeep Mavadia, University of Sydney
Optimised feedback for frequency metrology experiments

Poster night

PhD Students

#	Full name	Poster Title	Poster authors
1	Ewa Rej	13C spin dynamics in hyperpolarized nanodiamond	E. Rej, T. Gaebel, T. Boele, D.E.J. Waddington and D. J. Reilly
2	Christopher T. Chubb	Polynomial-time degenerate ground state approximation of gapped 1D Hamiltonians	C. T. Chubb and S. T. Flammia
3	Yauhen Sachkou	Superfluid optomechanics: light-based control of superfluid motion	Y.Sachkou, G. I. Harris, D. L. McAuslan, E. Sheridan, C. Baker and W. P. Bowen
4	Henry Stoke	Tensor Networks in Quantum Error Correction	H. Stoke
5	Thomas Boele	Brute Force Hyperpolarization of Nanodiamonds	T. Boele, E. Rej, T. Gaebel and D. Reilly
6	Hakop Pashayan	Simulating Quantum Systems with Negativity	H. Pashayan, J. Wallman and S. Bartlett
7	Rafael Alexander	One-way quantum computing with arbitrarily large time-frequency continuous-variable cluster states	R.I N. Alexander, P. Wang, N. Sridhar, M. Chen, O. Pfister and N. C. Menicucci
8	Benjamin Timothy McAllister	The UWA Scion Dark Matter Detection Experiment	B. T. McAllister, S. R. Parker, E. M. Ivanov and M. E. Tobar
9	Christina Giarmatzi	Witnessing causal nonseparability	C. Giarmatzi, M. Araújo, C. Branciard, F. Costa, A. Feix and Č. Brukner
10	Ignazio Zachary Cristina	Storing and Retrieving Spin Order in Arrays of SPin-1/2 Particles	I. Z. Cristina and S. D. Bartlett
11	Markus Rambach	Generating Narrow-Band Single Photon Pairs Suitable for Quantum Memories	M. Rambach, A. Nikolova, T.J. Weinhold and A.G. White
12	Marie Claire Jarratt	New Approaches for Readout of Quantum Systems	M.C. Jarratt, J. Colless, J. Hornibrook, S. Pauka and D. Reilly
13	Sam Roberts	Symmetry protected topological order in the 3-dimensional cluster model	S. Roberts and S. Bartlett
14	Sebastian Pauka	Enhanced readout methods for Spin Qubits	S. Pauka and D. Reilly
15	Seyed Nariman Saadatmand	Properties of the topological phases of the spin-1/2 J1-J2 triangular Heisenberg model	S. Saadatmand and I. McCulloch
16	Alexander Buese	Quantum interference of engineered states of light through the interaction with plasmonic nano-structures	A. Buese, M. Juan and G. Molina-Terriza
17	Xin He	Enhanced Optical Forces From Superfluid Flow	X. He, D. L. McAuslan, G. I. Harris, Y. Sachkou, C. Baker and W. P. Bowen
18	Guillaume Gauthier	87Rb and 41K Bose-Einstein condensates in configurable optical potentials	T. W. Neely, G. Gauthier, C. Yang, M. Baker, N. McKay-Parry, I. Lenton and H. Rubinsztein-Dunlop

#	Full name	Poster Title	Poster authors
19	Clara Javaherian	Platonic quantum switches	C. Javaherian and J. Twamley
20	James Bennett	A Quantum Optomechanical Interface Beyond the Resolved Sideband Limit	J. S. Bennett, K. Khosla, L. S. Madsen, M. R. Vanner, H. Rubinsztein-Dunlop and W. P. Bowen
21	Alice Mahoney	On-Chip Quantum Hall Circulator	A. C. Mahoney, J. I. Colless, S. J. Pauka, J. M. Hornibrook, A. C. Doherty, J. D. Watson, M. J. Manfra and D. J. Reilly
22	Claire Edmunds	Control of Spin-Motional Entanglement via Phase-Modulated Composite Pulses	C.L. Edmunds, S. Mavadia, A.R. Milne, T.J. Green and M.J.Biercuk
23	Natasha Brianne Taylor	Multi-Site Electron Transfer	N. Taylor and I. Kassal
24	Nikita Kostylev	Superstrong Coupling of a Microwave Cavity to YIG Magnons	N. Kostylev, M. Goryachev and M. E. Tobar
25	Samantha Hood	Entropy and disorder enable charge separation in organic solar cells	S. Hood and I. Kassal
26	Ian Conway Lamb, Steven Waddy, Kushal Das, Yuanyuan Yang	Cryogenic classical electronics for quantum control	I. Conway Lamb, S. Waddy, K. Das and Y. Yang
27	Thomas A. Bell	Crafting Time Averaged Optical Potentials	T. Bell, J. Glidden, M. Baker, T. Neely and H. Rubinsztein-Dunlop
28	Reece Roberts	Optomechanics with Levitated Nanodiamonds	R. P. Roberts, M. L. Juan, T. Volz and G. Molina-Terriza
29	Keith Motes	Linear Optical Quantum Metrology with Single Photons: Exploiting Passively Generated Entanglement to Beat the Shot-Noise Limit	K. R. Motes, J. P. Olson, E. J. Rabeaux, J. P. Dowling, S. J. Olson and P. P. Rohde
30	David Waddington	Imaging Nanodiamonds with the Overhauser Effect	D. E. J. Waddington, M. Sarracanie, H. Zhang, T. Gaebel, D. R. Glenn, E. Rej, N. Salameh, R. L. Walsworth, D. J. Reilly and M. S. Rosen
31	Matthew van Breugel	Silicon-Vacancy Centres in CVD Grown Nanodiamond for Near-Resonant Optical Trapping	M. van Breugel, C. Bradac, M. Juan, G. Molina-Terriza and T. Volz
32	Erick Rafael Romero Sanchez	Quantum magneto-mechanics through inductive coupling.	E. Romero, J. Twamley, M. Vanner and W. Bowen
33	Jake A P Glidden	Time-averaged optical potentials for Sagnac protocols with 87Rb Bose-Einstein condensates	J. A. P. Glidden, T. A. Bell, M. Baker, T. Neely and H. Rubinsztein-Dunlop
34	Parth Girdhar	All Two Qubit States Demonstrably Steerable Via Dichotomic Measurements are Bell Nonlocal	P. Girdhar
35	Jacob C Bridgeman	Ribbon Operators in Topologically Ordered 2D Spin Systems	J. C. Bridgeman, S. T. Flammia and D. Poulin
36	Nathan McMahon	Exploration of a bulk/boundary correspondence from the Multiscale Entanglement Renormalisation Anzats(MERA)	N. McMahon, S. Singh and G. Brennen
37	Harrison Ball	The effect of noise correlations on randomized benchmarking	H. Ball,T. M. Stace, S. T. Flammia and M. J. Biercuk
38	Xanthe Croot	Coupling Spin Qubits in GaAs via an Intermediate Quantum State	X. G. Croot, S. J. Pauka and D. J. Reilly
39	Alan Robertson	Quantum Error Correction using a Biased Noise Model	A. Robertson

Postdoctoral research fellows

#	Full name	Poster Title	Poster authors
1	Maxim Goryachev	Cryogenic Quartz BAW Resonator Technology for Test of Fundamental Physics	M. Goryachev and M.E. Tobar
2	Lars Skovgaard Madsen	Cold atoms around a tapered optical fibre	L. S. Madsen, J. Bennett, V. V. Jimenez, M. Baker, H. Rubinsztein-Dunlop and W. Bowen
3	Fabio Costa	Causal models for quantum systems	F. Costa
4	Sandeep Mavadia & Stephen Dona	Optimised feedback for frequency metrology experiments	S. Mavadia, A. Milne, C. Edmunds and M. Biercuk
5	Leandro Aparecido Nogueira de Paula	Creating Microwave Media from a Lattice of Tuneable Re-entrant Posts	L. de Paula, M. Goryachev and M. Tobar
6	Sahar Basiri-Esfahani	Integrated quantum photonic sensor based on Hong–Ou–Mandel interference	C. R. Myers, A. Armin, J. Combes and G. J. Milburn
7	Christopher Baker	A silica microtoroid based cavity opto-electromechanical system	C. Baker, C. Baker, D. McAuslan and W. Bowen
8	Clemens Müller	Interacting two-level defects as sources of fluctuating high-frequency noise in superconducting circuits	C. Müller, J. Lisenfeld, A. Shnirman, and S. Poletto
9	Pavel Bushev	Hybrid quantum systems with rare-earth doped crystals	S. Probst, N. Kukharchyk, H. Rotzinger, S. Wünsch, M. Siegel, A. Wieck, A. V. Ustinov and P. Bushev
10	David McAuslan	Whispering Gallery Mode Biosensing Using Back-Scattered Light	J. Knittel, J.D. Swaim, D. L. McAuslan, G. A. Brawley and W. P. Bowen
11	Magdalena Zych	Bell inequalities for temporal order of events	M. Zych, F. Costa, I. Pikovski and C. Brukner
12	Matt Woolley	Quartz-superconductor quantum electromechanical system	M. J. Woolley, M. F. Emzir, G. J. Milburn, M. Jerger, M. Goryachev, M. E. Tobar and A. Fedorov
13	Beibei Li	Ultrasensitive and broadband magnetometry using cavity optomechanics	B. Li, E. Sheridan, H. Rubinsztein-Dunlop and W. Bowen
14	Carlo Bradac	Diamond Colour Centres	C. Bradac, M. van Breugel and T. Volz
15	Victor Manuel Valenzuela Jimenez	Non Destructive Measurement of Atom Number in a Tapered Fiber Trap	V. Valenzuela, L. Madsen, H. Rubinsztein-Dunlop and W. Bowen.
16	Stuart Szigeti	Finite-temperature hydrodynamics for one-dimensional Bose gases: breathing mode oscillations as a case study	I. Bouchoule, S. S. Szigeti, M. J. Davis, and K. V. Kheruntsyan
17	Ivan Kassal	Coherent transport enhancements in incoherent light harvesting	I. Kassal
18	Mathieu Juan	Nano-diamonds for levitated optomechanics	M. L. Juan, R. Roberts, C. Bradac, B. Besga, J. Bertelot, R. Quidant, O. Romero-Isart, G. Brennen, T. Volz and G. Molina-Terriza

DAY THREE
Friday, December 11

6.15am - 7.00am	Yoga, Concert Lawns (grassed area near Playground)
6:30am - 8:30am	Breakfast, Kalinda Restaurant
Session 5 9:00am	Chair: Prof. Michael Tobar Microwave Reentrant cavities for quantum devices (with 5min Q&A) *Natalia Carvalho, PhD Student*
9:20am	Probing nanoholes with two-photon quantum states of light (with 5min Q&A) *Alexander Buese, PhD Student*
9:40am	Networked Quantum Information Technologies *Prof. Ian Walmsley*
10:10am	Q&A
10:30am - 11:00am	Morning Tea, Prince foyer Check-out of hotel. Stow bags in secure luggage room.
Session 6 11:00am	Chair: Dr. Arkady Fedorov Josephson-junction arrays: introduction and parity effect (with 5min Q&A) *Prof. Tim Duty, Chief Investigator (on behalf of Dr. Sergey Kafanov)*
11:20am	Experiments on Josephson-junction chains in the charge regime: are they quantum-coherent insulators? (with 5min Q&A) *Dr. Karin Cedergren, Postdoc*
11:40am - 12:30pm	EQuS XPrize Competition
11:40am - 12.30pm	SAC Meeting, Boardroom
12:30 - 1:30pm	Lunch, Prince foyer
Session 7 2:00 - 3:00pm	Private Meeting CI meeting, Prince Room
3:00 - 3:30pm	All workshop delegates reconvene for Afternoon Tea, Prince foyer
Session 8 3:30pm	What can EQuS do better in 2016? *Group discussion*
3:45pm	Summary and next steps *Prof. Gerard Milburn*
4:00pm	Workshop concludes
4:15pm	Buses depart for University of Queensland, St Lucia and Gold Coast airport

Day Three, Session Five

Natalia Carvalho

Microwave Reentrant cavities for quantum devices

Currently, a tuneable microwave cavity is being developed to accommodate a transmon qubit, a type of superconducting circuit that acts as a quantum two-level system – effectively, an artificial atom [1]. The goal is couple microwave radiation to these transmon devices, hence the tunability provided by the cavity would enable us to manipulate and control such a system. We have designed a cavity able to tune its resonant frequency over a range larger than 100 MHz at cryogenic temperatures [2], and are now optimizing this system to operate the tuning cavity in the superconducting regime. Once this is achieved, the cavity will be ready to receive the transmon chip.

We are also working on the investigation of bulk acoustic wave (BAW) resonators in microwave reentrant cavities. BAW resonators offer a promising way to process quantum information through the coupling between microwaves and acoustic phonons [3]. In this sense, we are developing a device able to excite phonons through non-linearities and the piezoelectricity of the plano-convex quartz crystal. Such a resonator must have resonant mode frequencies of a few to several hundred megahertz, which makes it a good candidate to cool down phonons to the quantum ground state.

[1] J. Koch et al., Phys. Rev. A 76, 042319 (2007).
[2] N. C. Carvalho et al., Rev. Sci. Instrum. 85, 104705 (2014).
[3] M. Goryachev et al., Appl. Phys. Lett. 100, 243504 (2012).

Alexander Buese

Probing nanoholes with two-photon quantum states of light

Quantum interference of two photons is a fundamental building block for all photonic quantum information technologies. It is based on the indistinguishability of two or more outcomes of the transformation of the modes of each photon. This indistinguishability allows their amplitudes to add coherently and interfere. Two identical photons impinging on a beamsplitter, as in the famous Hong-Ou-Mandel experiment, is not the only realisation of such interference. We experimentally demonstrate the successful transfer of this concept to a novel system. A specifically engineered two-photon state passing through a nano-structure, which instead of opening two spatial pathways, can change the polarization and spatial mode of each photon. Quantum interference is then possible between the two channels of changed and un-changed polarizations for each photon. By manipulating a phase inside the input state, we can switch the quantum interference on and off. Essential for this experiment is an excellent control over all degrees of freedom of both photons. We employ a collinear, type II, spontaneous parametric down-conversion source for the pair creation and then achieve indistinguishability by controlling the phase-matching conditions, compensating the time-delay and bringing the pair into the desired state of polarization and orbital angular momentum. The nano-structure in our experiment is a sub-wavelength aperture in a gold film. We believe that this work will allow us to effectively use quantum metrology schemes in plasmonic nanostructures.

Prof. Ian Walmsley

Networked Quantum Information Technologies

Hybrid light-matter networks offer the promise for delivering robust quantum information processing technologies, from sensor arrays to secure communications to quantum simulators and eventually to a quantum computer. I will describe the UK Quantum Technology Programme, the Oxford-led Hub and some of the science and engineering progress to build a resilient quantum network.

Day Three, Session Six

Prof. Tim Duty

Josephson-junction arrays: introduction and parity effect

Josephson-junction arrays are potentially the simplest circuit technology for implementation of artificially engineered quantum materials. This arises since flux and charge, canonically conjugate quantum variables like position and momentum, are readily accessible in superconducting devices. Due to the macroscopic quantum nature of superconductivity, they can be manipulated and measured using voltages and currents. Long-range interactions occur naturally due to the screened Coulomb potential between localised charges, opening up many possibilities for strongly interacting quantum many-body systems, novel quantum phases and topologically protected quantum bits.

While there have been a huge number of theoretical ideas and proposals suggesting Josephson-junction arrays as possible experimental implementations, actual experimental progress using such arrays has been relatively modest. This has been due to a number of challenges related to fabrication, disorder, and the understanding of microscopic aspects of quantum transport in these systems. Here we review the basics of Josephson-junction chains, SQUID arrays and ladders, and 2D arrays. In addition, we point out some of the experimental complexities such as the parity effect and non-equilibrium aspects of transport.

[1] K. Cedergren, S. Kafanov, J-L. Smirr, J. H. Cole, and T. Duty, "Parity effect and single-electron injection for Josephson-junction chains deep in the insulating state", Physical Review B 92, 104513 (2015).

Dr. Karin Cedergren

Experiments on Josephson-junction chains in the charge regime: are they quantum-coherent insulators?

One-dimensional arrays of Josephson junctions are interesting due to their intricate interplay between superconducting phase coherence and Coulomb blockade. While arrays in the phase coherent regime (characterised by a large Josephson energy) exhibit a supercurrent, arrays where the charging energy dominates show insulating behaviour and only conduct above a certain threshold voltage. The destruction of superconducting phase coherence and localisation of Cooper pairs takes place at a superconductor- insulator quantum phase transition of the system. So far there has been little experimental work to illuminate the detailed mechanisms governing this transition in one-dimensional arrays, although there are a number of theoretical models. One very rudimentary approach regards the Coulomb blockade as arising from coherent tunnelling of flux quanta across the junctions. Such tunnelling of flux quanta can be regarded as coherent quantum phase slips of the superconducting phase across the array, and would lead to a zero current state up to a certain voltage threshold [1,2]. Such a picture is envisioned as an electromagnetic "dual" to the standard Josephson effect. A complementary theory, which attempts to include spatial dependence as well as disorder, suggests that lifting of the Coulomb blockade occurs by depinning of quasi-charge across the junctions [2]. This idea is related to similar models for charge-density wave and flux lattice depinning due to Larkin [4], Imry and Ma [5], Fukuyama and Lee [6].

We have experimentally studied the insulating region approaching the transition point, by fabricating and measuring a large number of arrays where the ratio between the Josephson energy (EJ) and the Cooper pair charging energy (ECP) has been carefully tuned. We observe that the threshold voltage is a robust feature of this transition and that it depends on the plasma frequency of the device. We conclusively show that when scaled with the plasma frequency, the threshold voltage as a function of EJ/ECP follows the same behaviour in all devices. Such a dependence on the plasma frequency would be expected for theories that consider the lowest Bloch band energy as the origin of the pinning potential. In addition, a robust dependence of the threshold voltage on EJ/ECP is experimentally shown for devices with significantly different junction barriers and hence different IV characteristics above the threshold. The presented data makes it possible to quantitatively compare experimental results with theoretical predictions.

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[3] N. Vogt, R. Schäfer, H. Rotzinger, W. Cui, A. Fiebig, A. Shnirman, and A.V. Ustinov, "One-dimensional Josephson junction arrays: Lifting the Coulomb blockade by depinning", Phys. Rev. B 92, 045435 (2015)
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[5] Y. Imry and S.-k Ma, Phys. Rev. Lett. 35, 1399 (1975)
[6] H. Fukuyama and P. A. Lee, Phys. Rev. B 17, 535 (1978)

Feedback

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