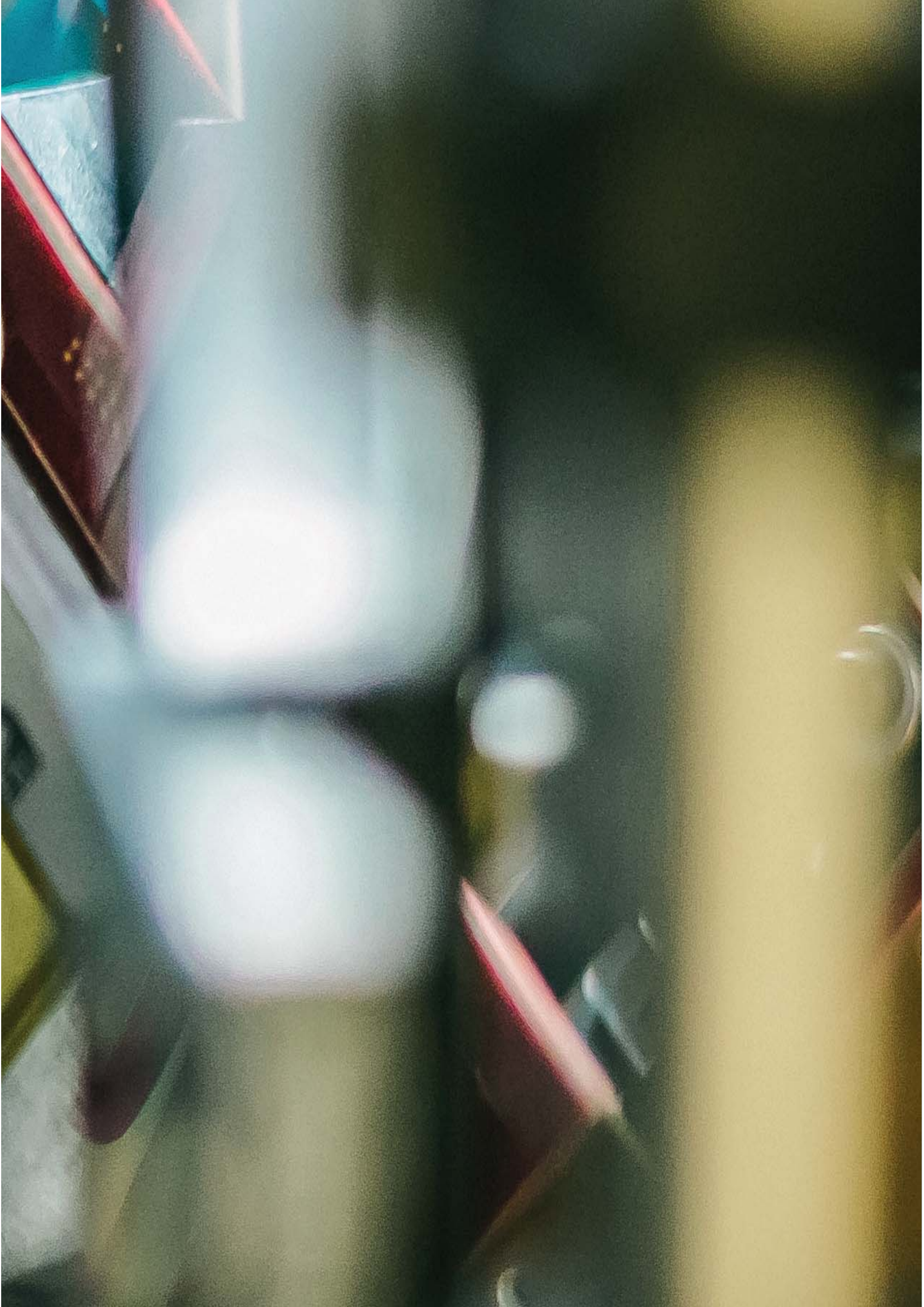
EQUS ANNUAL WORKSHOP 2018

December 6-8

Rendezvous Hotel

Scarborough Beach

EQUS
Australian Research Council
Centre of Excellence for
Engineered Quantum Systems



Welcome

Welcome one and all to the first 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, and welcome back to the members of our Scientific Advisory Committee.

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.

I encourage you to look beyond your current interests and do not miss an opportunity to learn something new.

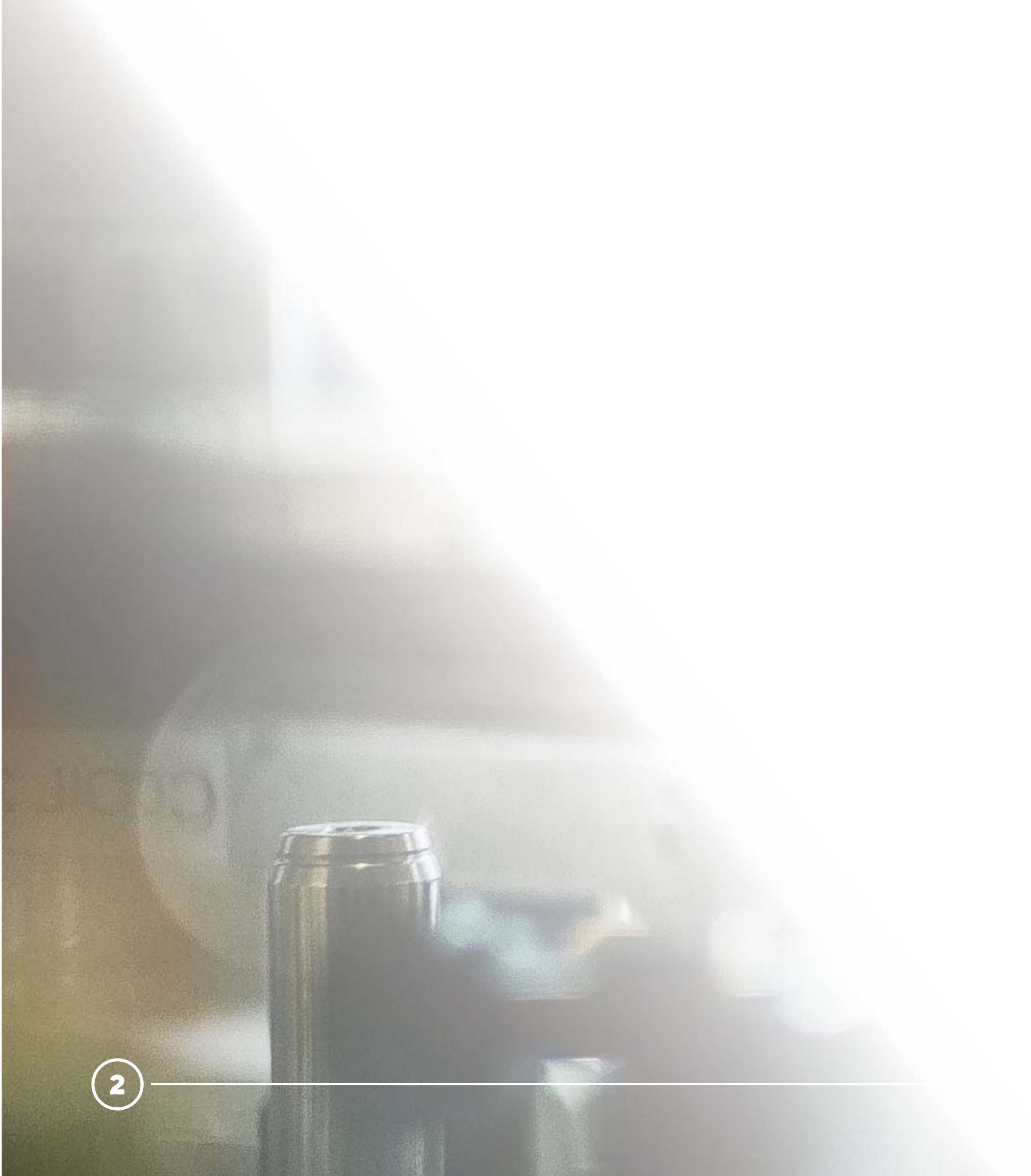
Andrew White

Centre Director

Pre-Workshop

WEDNESDAY 5TH DECEMBER

9.00 am	Scientific Advisory Committee meeting
7.00 pm–8.00 pm	Welcome with canapes and drinks—*Mentelle Deck*



Invited Speakers

Alexia Auffèves is a CNRS senior scientist working at the Néel Institute of Grenoble, France. She is a partner investigator with EQUS. After an experimental PhD in atomic physics and a post-doc in semiconductors, she is now working as a theorist. Her fields of expertise are quantum optics, solid state physics, quantum thermodynamics and quantum foundations.

Joseph Emerson is a Faculty member at the Institute of Quantum Computing and the Department of Applied Mathematics at the University of Waterloo, a Fellow in the Quantum Information Science program at the Canadian Institute for Advanced Research, and CEO and Founder of the start-up Quantum Benchmark. His interests are in quantum information science and the foundations of quantum theory and he is regarded as a world-leading authority on the characterization of quantum systems. He is currently developing methods to assess and improve the performance of quantum computers in the presence of noise, a key step toward making large-scale quantum information processors viable.

Yiwen Chu is a Postdoctoral Associate in the Schoelkopf Lab at Yale University. For her PhD she studied defect centers in diamond and their uses in quantum optics in the group of Mihkail Lukin at Harvard. The experiments she worked on included entangling the spin of a nitrogen-vacancy center to an emitted photon and developing diamond-based nanophotonic structures. At Yale, she worked on exploring new materials, designs, and geometries for making the next generation of superconducting qubits and resonators. Her current research involves using electromechanics and optomechanics to create and control quantum states of sound.

Peter Wolf has held a CNRS research position at the Paris Observatory since 2007. He received a BSc in Physics and Philosophy from the university of York in 1992, his PhD from the University of London in 1997 and his "Habilitation à diriger des recherches" from Université Pierre et Marie Curie in Paris in 2005. He has worked as a physicist at the Bureau International des Poids et Mesures (BIPM). His research activity is both theoretical and experimental and centred on tests of fundamental physics. It focuses in particular on ground and space tests of general relativity and related studies in alternative theories of gravitation, dark matter, atomic clocks, atom interferometers and time/frequency transfer techniques.

Cathy Foley is CSIRO Chief Scientist. She is also the Chair of the Australian National Fabrication Facility Victorian Node Collaboration Committee and chairs and participates in many University and government Committees. She has made distinguished contributions to the understanding of superconducting electronics and to the development of devices using superconductors for a number of applications including to detect magnetic fields and locate valuable deposits of minerals. As CSIRO's Chief Scientist, she is working to support CSIRO's research to enable Australia's preparedness for the future, assisting to build strong partnerships with other research organisations and to enable effective research translation national prosperity in a global context based on science and engineering excellence.

Day One

THURSDAY 6TH DECEMBER

6.00 am	Yoga—*Scarborough Beach Reserve* (free, with yoga mats supplied)
6.00 am–onwards	Breakfast—*Straits Café*

• Please hang up your posters •

8.00 am	Registration—*Preston Room*
8.30 am	**Welcome**
	Welcome to Country
	Professor Andrew White
	Python Workshop Introduction
9.00 am	**Research theme overview**
	Professor Stephen Bartlett (Design quantum materials)
	Professor Warwick Bowen (Quantum-enabled diagnostics and imaging)
	Professor Michael Tobar (Quantum engines and instruments)
10.00 am	**Portfolio leader reports**
	Professor Halina Rubinsztein-Dunlop (Translational Research Laboratory)
	Professor Matthew Davis (Mentoring)
	Professor Tom Stace (Outreach)
	Professor Andrew White (Equity and Diversity)
10.45 am	**Morning tea**

11.15 am

Session one Chair: Assoc. Professor Thomas Volz *Preston Room BC*

- Quantum thermodynamics, motivations and prospects
  Alexia Auffeves (30 mins)
- The ORGAN experiment)
  Ben McAllister (20 mins)
- Composite particles for testing quantum and gravity interface
  Magdalena Zych (20 mins)
- Quantum rifling: how to protect a qubit from unwanted collapsing
  Daniel Szombati (20 mins)

12.45 pm

Lunch

2.30 pm

Session two Chair: Assoc. Professor Arkady Fedorov *Preston Room BC*

- How to extend the reach of quantum computing beyond the classical horizon
  Joseph Emerson (30 mins)
- Quantum topology identification with quantum walks and deep neural network
  Wei-Wei Zhang (20 mins)
- Squeezing and shaking inversion-symmetric defects in diamond
  Lachlan Rogers (20 mins)
- Scientific networking
  Murray Kane (30 mins)

4.00 pm

Afternoon tea and poster session—*Preston Room*

6.00 pm–7.30 pm

Dinner (food truck and giant games)—*Scarborough Beach Reserve, foreshore*

• Scarborough Sunset Markets around the corner •
5.00 pm–9.00 pm

SESSION ONE

Alexia Auffèves
Quantum thermodynamics, motivations and prospects

Quantum thermodynamics is an emerging field aiming to extend the laws of thermodynamics to quantum systems. Typical motivations are e.g. understand and quantify irreversibility in the quantum regime, or evidence quantum supremacy on the performances of coherent heat engines. In this talk I will review recent achievements around the thermodynamics of quantum measurement, which appears at the ultimate source of randomness and entropy in the quantum regime. I will present a proposal for a new generation of quantum engines, that run on quantum measurement only. I will conclude on the interest of quantum thermodynamics for quantum information technologies.

Ben McAllister
The ORGAN experiment

The nature of the dark matter in the galactic halo is one of the greatest open questions in physics. Axions are hypothetical weakly interacting particles, and are among the most compelling candidates to comprise the dark matter. The mass and coupling strength of the axion are only weakly bounded by cosmology, creating a large parameter space that experiments must search. The most mature laboratory-based axion detection technique is called the haloscope, a type of detector which uses resonant cavities and precision microwave detection to search for dark matter axions via their weak coupling to photons. The ORGAN Experiment is a haloscope, designed to search the promising high mass range for axion dark matter. We discuss the experiment, first results and future plans, as well as the applications of quantum technologies to axion detection.

Magdalena Zych
Composite particles for testing quantum and gravity interface

A major goal of modern physics is to understand and test the regime where quantum mechanics and general relativity both play a role. However, its new effects are thought to be relevant only at high energies or in strong gravitational fields, beyond the reach of present-day experiments. I will discuss a novel approach to this challenge, focused on low-energy but composite quantum systems. I will discuss new physical effects in this regime which are promising for near future experiments. I will particularly focus on new insights into the Einstein Equivalence Principle (EEP) resulting from this approach, and sketch some ideas for tests of genuine quantum aspects of the EEP.

Daniel Szombati
Quantum rifling: how to protect a qubit from unwanted collapsing

The Stern Gerlach experiment exemplifies properties of quantum measurement: a spin with random orientation is shot through a magnetic field, which acts as a classical detector of the spin state, by selectively deflecting the spin towards one of only two possible trajectories (up or down) depending on the spin orientation. But what happens to the spin flying through the field if it is also spinning fast, like a bullet fired from a rifled gun barrel? We implement such a scenario in a Circuit QED system, where a superconducting qubit acts as the spin and a coupled coplanar waveguide resonator as the classic measurement apparatus. When our spin is rifled fast enough, the spin is not deflected but flies in a straight line, with no backaction of the detector on the spin. We demonstrate our protocol's usefulness on a system of two qubits coupled to the same cavity: by rifling one qubit, it can be protected from decoherence caused by the measurement photons in the cavity while we read out the other qubit. Although the presented experiments were performed in a circuit QED system, such a protocol can be performed for any qubit coupled to a classical detector.

SESSION TWO

Joseph Emerson

How to extend the reach of quantum computing beyond the classical horizon

In the very near future, we will see prototype quantum processors which aim to compute beyond the horizon of what can be computed via classical computing. Achieving this goal depends not just on the number of qubits, but depends critically on improving the quality of the gate operations. I will give an overview of the current landscape in terms of capabilities across of different hardware platforms for quantum computing, and present our recent results with the University of Innsbruck demonstrating high quality gate operations on up to 10 entangled ions using a method called cycle benchmarking. I will then give an overview of the landscape of real-world applications of quantum computing and what it will take to get us there.

Wei-Wei Zhang

Quantum topology identification with quantum walks and deep neural network

Topological quantum materials are a promising platform for topological quantum computation and the design of novel components for quantum computers. A priority and necessary condition for both the discovery of novel topological quantum systems and the analysis of novel topologically protected edge modes is the identification of topological invariants for quantum matters. In this talk, I will present a universal automatic method for topology identification which first combines quantum walks and Deep Neural Network. Consider the well developed experimental technologies for quantum walks and the great learning ability of deep neural network. Our work enables the efficient discovery and analysis of novel topological materials and therefore the design of a practical quantum computer.

Lachlan Rogers

Squeezing and shaking inversion-symmetric defects in diamond

Silicon-vacancy and germanium-vacancy colour centres share an inversion-symmetric geometry in the diamond lattice. Many of the attractive properties of this family of quantum emitters are due to the symmetry, making "shape" an important element in engineering and leveraging these colour centres for technical applications. Squeezing the colour centres with static crystal strain is one approach, and I will present progress towards characterising strain parameters. Phonons may be understood as time-varying strain, and offer a different domain for colour-centre tuning. I will report emerging applications in thermometry.

Day Two

FRIDAY 7TH DECEMBER

6.00 am — Yoga—*Scarborough Beach Reserve* (free, with yoga mats supplied)

6.00 am–onwards — Breakfast—*Straits Café*

7.30 am — EQUIP breakfast—*Pool Deck* (ticketed)

9.00 am — **Session three** **Chair: Professor Jason Twamley** ***Preston Room BC***

- Connecting quantum systems using acoustic resonators
  Yiwen Chu (30 mins)
- Observation of vortex dynamics and evaporative heating in strongly interacting 2D superfluid
  Eugene Sachkou (20 mins)
- CSS holographic quantum error correcting codes
  Rob Harris (20 mins)

10.30 am — **Morning tea**

11.00 am — **Session four** **Chair: Dr John McFerran** ***Preston Room BC***

- Searching for ultra-light dark matter using atomic clocks at Paris Observatory
  Peter Wolf (30 mins)
- Entanglement dynamics in a trapped-ion quantum simulator
  Arghavan Safavi-Naini (20 mins)
- Custom instrumentation for control and readout of intermediate scale quantum systems
  Steven Waddy (20 mins)
- Superfluid dynamics of two-component BEC in a toroidal trap
  Mark Baker (20 mins)

12.30 pm **Lunch**

2.30 pm **Session five** Chair: Assoc. Professor Gavin Brennan *Preston Room BC*

- EU/UK Landscape
  Peter Knight (20 mins)
- Large ion crystals in a Penning trap
  Robert Wolf (20 mins)
- Cavity-based readout and control of Majorana qubits
  Thomas Smith (20 mins)
- Fabrication @ CSIRO: CSIRO fabrication capabilities
  Fabio Isa (20 mins)

4.00 pm **Afternoon tea**

• Freetime! •

6.30 pm **Workshop dinner**—*Mentelle Room*

Yiwen Chu

Connecting quantum systems using acoustic resonators

The ability to engineer different types of quantum mechanical objects allows us to take advantage of their unique properties and create useful hybrid technologies. A central goal of the emerging field of quantum acoustics is the ability to create complex quantum states of macroscopic mechanical objects, which can have applications as quantum memories or transducers. In particular, coupling motion to nonlinear quantum systems opens up the possibility of creating, storing, and manipulating non-Gaussian mechanical states. I will describe our recent experiments involving a high frequency bulk acoustic wave resonator strongly coupled to a superconducting qubit using piezoelectricity. We use this device to demonstrate quantum operations on the coupled qubit-phonon system, including the creation and measurement of quantum mechanical states such as phonon Fock states. I will also describe some prospects for building even more complex hybrid quantum systems, such as incorporating Brillouin optomechanical devices for microwave to optical transduction.

Eugene Sachkou

Observation of vortex dynamics and evaporative heating in strongly interacting 2D superfluid

Two-dimensional liquid helium is a strongly interacting quantum fluid which exhibits rich quantum behaviour such as topological quantum phase transitions. The key role in these phase transitions is played by quantized vortices that determine microscopic dynamics of superfluid helium films. However, none of the experimental techniques available so far have been capable of probing the microscopic dynamics of strongly interacting 2D superfluids in real-time and resolving single quantized vortices.

In this talk I will introduce a novel approach to probe the microscopic physics of 2D quantum fluids based on the optomechanical interaction between a nanometer-thick superfluid helium film and an optical whispering-gallery-mode microcavity. By monitoring concurrent dynamics of multiple sound waves within the superfluid film, we are able to track both the number of vortices and their spatial distribution in real-time. Moreover, we observe an evaporative heating of a vortex cluster in a strongly interacting quantum fluid for the first time.

Rob Harris

CSS holographic quantum error correcting codes

Holographic quantum error correcting codes have been proposed as a model for the AdS/CFT correspondence. They are formed by tessellation of smaller error correcting codes on a negatively curved surface, creating a finite rate code with potential for practical uses. While the original proposal for such codes required seed codes that satisfy a very restrictive constraint, we show that a much less strict constraint is sufficient, admitting a wider class of holographic codes. This allow us to create our heptagon code, a CSS holographic code based on the Steane code, and another variant based on the surface code. We demonstrate, using an optimal decoding algorithm, that the heptagon code has promising thresholds against erasure, and will present progress on the performance against Pauli errors.

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SESSION FOUR

Peter Wolf

Searching for ultra-light dark matter using atomic clocks at Paris Observatory

In the current cosmological paradigm, some galactic and cosmological observations are explained by the introduction of cold dark matter (DM) and of dark energy. Little is currently known about these two components that constitute the major part of our Universe, and they have so far escaped direct detection. We present theoretical and experimental results on searches for ultra light (<< MeV) dark matter using quantum devices like atomic clocks and magnetometers. We will focus more particularly on recent experimental searches using atomic clocks and time/frequency techniques at the Paris Observatory, with an overview of ongoing and planned experiments.

Arghavan Safavi-Naini

Entanglement dynamics in a trapped-ion quantum simulator

When quantum information "scrambles", information initially stored in the local degrees of freedom of a quantum many-body system spreads over its many-body degrees of freedom, becoming inaccessible to local probes and thus apparently lost. Scrambling and entanglement are considered key concepts that reconcile seemingly antithetical behaviors including thermalization of isolated quantum systems and information loss in black holes. Moreover, these two concepts have revolutionized our understanding of non-equilibrium phenomena. I will show that a specific family of fidelity out-of-time-order correlators (FOTOCs), recently measured in a trapped-ion quantum simulator via time reversal of the many-body dynamics followed by a fidelity measurement, can serve as a unifying diagnostic tool that elucidates the intrinsic connection between fast scrambling, volume law entanglement, ergodicity, quantum chaos, and the associated butterfly effect in the semiclassical dynamics of the system. I will demonstrate the utility of the FOTOCs using the Dicke model which has been recently benchmarked in a 2d trapped-ion quantum simulator.

Steven Waddy

Custom instrumentation for control and readout of intermediate scale quantum systems

On the path of turning a small number of qubits into a useful quantum computer, a method for controlling solid-state quantum devices with a large number of gates (or a large number of devices with few gates) is required. We have created custom instrumentation to control and readout larger systems of quantum devices. A high channel count precision low-noise DAC/AWG and an FPGA based multi-channel RF readout system.

Mark Baker

Superfluid dynamics of two-component BEC in a toroidal trap

Superfluidity is a striking example of the strange properties of quantum systems manifesting at the macroscopic scale. In addition to the familiar superfluid behaviour of liquid helium at low temperatures, Bose-Einstein condensates (BEC) of ultra-cold dilute gases also have superfluid phases, and have been an area of recent study. A natural extension is to study multi-component superfluids by utilising the magnetic hyperfine states of the Rb BEC. To this end, using RF transitions, we prepare multi-component BECs in the F=1 hyperfine state, confined in a ring shaped optical trap. The relative scattering properties result in an immiscible system, with an azimuthal phase separation of the components around the ring. We present our preliminary work studying the dynamics of superfluid mixtures in our ring, including the observation of classical solid-body rotation of the phase separated superfluids, with arbitrary circulation and angular momentum, in the presence of a rotating magnetic driving field.

SESSION FIVE

Robert Wolf

Large ion crystals in a Penning trap

Laser-cooled ions in a Penning trap are a promising candidate for near-term quantum simulation of exotic forms of quantum magnetism. In this talk we describe the first demonstrations of laser-cooled crystals of Beryllium ions in our Penning trap and associated supporting capabilities. We introduce a novel injection locked laser system permitting efficient photoionization of Beryllium using low-cost solid-state sources. Trapping and manipulation of ion crystals using both static electric and magnetic fields, together with a rotating-wall potential, permits stroboscopic site-resolved imaging of individual atoms in a triangular lattice showing stability over tens of seconds. Finally, we demonstrate coherent manipulation of ion spins using a custom, high-power, low-phase-noise microwave source and delivery system near 55 GHz.

Thomas Smith

Cavity-based readout and control of Majorana qubits

I will present readout and control protocols based on coupling Majorana bound states to cavities. In particular, I consider hybrid superconductor–semiconductor nanowires where the Majorana–cavity coupling is mediated by a quantum dot. The resulting qubit–cavity interaction can be operated in the dispersive regime, familiar from circuit QED. Alternatively, a longitudinal interaction can be activated by parametric modulation of the qubit–cavity coupling strength. I explore how these interactions can be used for readout of Majorana qubits, as well as their use for cavity-mediated entangling gates.

Day Three

SATURDAY 8TH DECEMBER

• Take down your posters by 11.00 am •

6.00 am — Yoga—*Scarborough Beach Reserve* (free, with yoga mats supplied)

6.30 am–onwards — Breakfast—*Straits Café*

9.00 am — **Session six** Chair: Professor Tom Stace *Preston Room BC*

- Making magnetometers—challenges to take it from the bench to application
  Cathy Foley (30 mins)
- Hectometer revivals of quantum interference
  W. Y. **Sarah Lau** (20 mins)
- Digital interferometry for sensors and control
  David Gozzard (20 mins)
- Road trippin'
  #TEAMEQUS (20 mins)

10.30 am — **Morning tea**

11.00 am — **Session seven** Chair: Professor Michael Biercuk *Preston Room BC*

- The case for diversity and how do you achieve it?
  Cathy Foley (30mins)
- Winning poster talk
- Centre prizes
- Wrap up

12.30 pm — **Lunch**

• Conference ends •

SESSION SIX

Cathy Foley

Making magnetometers—challenges to take it from the bench to application

Making a device and showing that it works and is better than other reported devices is "easy". But getting a device into the application and to be commercialised is complex and rarely achieved in Australia (or anywhere). This talk will use magnetometers as a case study to explore what it takes to get it out of the lab.

W. Y. Sarah Lau

Hectometer revivals of quantum interference

The Hong-Ou-Mandel (HOM) interference is the most significant photonic effect, one with no counterpart in classical optics. The interference is fragile–it is sensitive to distinguishability in all degrees of freedom–and normally occurs on the order of very short path length differences–micrometers to millimeter. Despite these limitations, HOM interference has proven application in quantum computing, metrology and quantum foundations. We report HOM interference observed after more than 100m path length difference between photons from a cavity-enhanced spontaneous parametric down-conversion source, equating to the 84th HOM revival. In addition to producing HOM revivals, the source can alternatively generate two-photon NOON states. These two features result from the unique half waveplate 'flip trick' of our source effectively producing two distinct frequency combs, each of which can be temporally accessed. This combination makes our source a novel metrological tool to allow enhanced precision on a sub-wavelength scale in a quantum-secure way.

David Gozzard

Digital interferometry for sensors and control

The research undertaken at the Australian National University node of EQUS focuses on the development of digitally enhanced heterodyne interferometry techniques and the application of these techniques to construct high-precision optomechanical systems and sensors. The current focus of the group's work is the development of robust optical-phased arrays for applications in laser communications, interferometry and sensing. This talk will provide an introduction to the concepts and advantages of digitally enhanced heterodyne interferometry, give an overview of the group's work in optical-phased arrays, and provide examples of the wider applications of digitally enhanced heterodyne interferometry such as cavity locking.

SESSION SEVEN

Cathy Foley

The case for diversity and how do you achieve it?

Diversity and Inclusion has been touted as a critical evaluation criteria by the ARC when choosing which CoE to support. But why is this important to achieve science excellence? This talk will provide the case for diversity and inclusion as a critical issue to achieve excellence and provide some ideas on how to achieve it.

2019 events

Python Workshop	January 29–February 1, 2019
Coogee'19—Sydney Quantum Information Theory Workshop	February 5-8, 2019 Coogee Bay Hotel, Coogee, Sydney
Idea Factory	May/June, 2019
EQUS Summer School	December, 2019
Annual Workshop	December, 2019

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