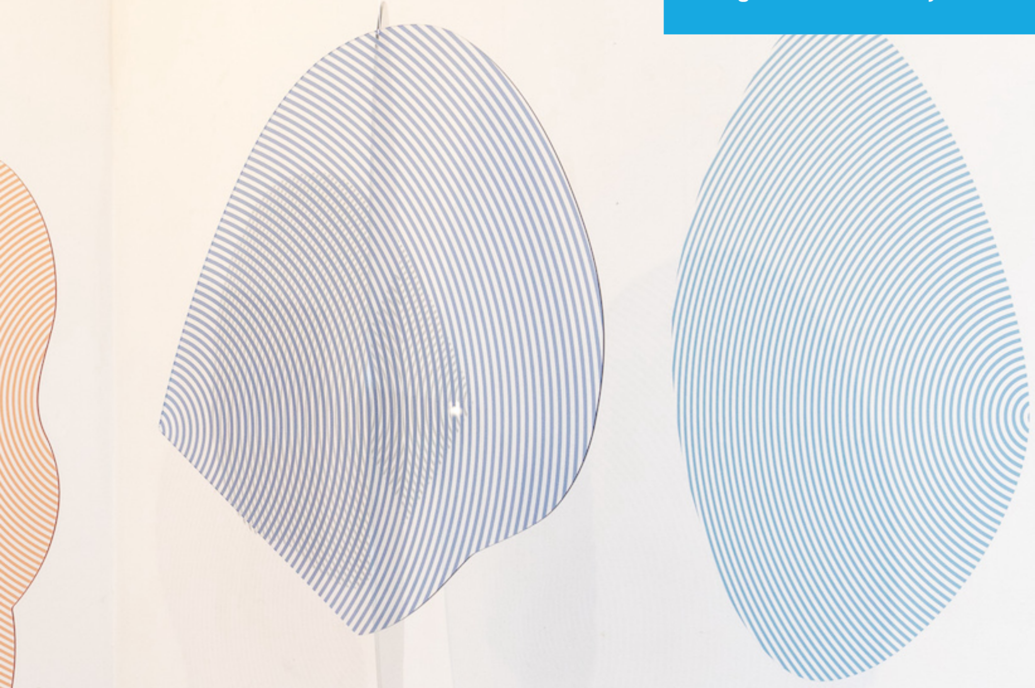
EQUS
Australian Research Council
Centre of Excellence for
Engineered Quantum Systems



EQUS Annual Workshop 2023

Fremantle/Walyalup

20–23 November 2023

#teamEQUS | #EQUSworkshop23

EQUS acknowledges the Traditional Custodians and Cultures of the lands and seas on which we live and work. We pay our respects to all First Nations Peoples, Elders and Ancestors. We acknowledge that sovereignty was never ceded and stand in solidarity towards a shared future.

When we acknowledge Country, one of things we're doing is honouring and respecting the long tradition of knowledge-making in First Nations cultures, including in the STEM disciplines of science, technology, engineering and maths.

In particular, we acknowledge the Whadjuk People as the Traditional Owners of the greater Fremantle/Walyalup area, and that the cultural and heritage beliefs of the Whadjuk People are still important to the Nyoongar People today.

It always was and always will be Aboriginal land.

Timetable overview

(All times are AWST)	Registration/ tea/coffee	Start	End	Dinner/social
Day 0: Monday 20 November	6:00 pm			6:00 pm
Day 1: Tuesday 21 November				
Stream A	8:00 am	8:30 am	4:00 pm	7:00 pm
Stream B	8:00 am	8:30 am	7:00 pm	7:00 pm
Day 2: Wednesday 22 November	8:00 am	9:00 am	5:00 pm	7:00 pm
Day 3: Thursday 23 November	8:00 am	9:00 am	3:05 pm	
AC meeting		3:00 pm	3:45 pm	
SAC meeting		3:45 pm	5:00 pm	

Venue details

Esplanade Hotel
46–54 Marine Terrace
Fremantle/Walyalup WA 6160

Monday welcome function
Pool area

Conference sessions
Sirus room

Wednesday dinner & awards
Sirus room

AC & SAC meetings
Australia II meeting room

Welcome to Country
Esplanade Park

Tuesday social dinner
The Palace Arcade
96 High Street
Fremantle/Walyalup WA 6160

Translation & industry showcase
EZONE
The University of Western Australia
Crawley WA 6009

Group photo
Esplanade Park

Bus departure times

Monday 20 November

Bus 1: 1:00 pm, Virgin terminal
(For Virgin flights arriving 11:20 am, 12:15 pm & 12:30 pm)
To Esplanade Hotel via Qantas terminal

Bus 1: 1:05 pm, Qantas terminal
(For Qantas flights arriving 12:15 pm, 12:20 pm & 12:30 pm)
To Esplanade Hotel

Bus 2: 2:45 pm, Qantas terminal
(For Qantas flights arriving 1:20 pm & 2:05 pm)
To Esplanade Hotel

Tuesday 21 November

Bus 1: 1:30 pm, Esplanade hotel
To EZONE, UWA

Bus 2: 6:30 pm, EZONE, UWA
To Esplanade Hotel

Thursday 23 November

Bus 1: 6:15 pm, Esplanade Hotel
To Qantas and then Virgin terminals

Bus 2: 8:30 pm, Esplanade Hotel
To Qantas and then Virgin terminals

Day 1

Tuesday 21 November

8:00 am–8:30 am	Tea & coffee
8:30 am–8:45 am	**Welcome to Country: Betty Jane Garlett**
9:00 am–9:15 am	**Director's welcome: Andrew White**
9:15 am–10:15 am	**Keynote presentation: Arghavan Safavi-Naini**
10:15 am–10:45 am	Morning tea
	Session 1
10:45 am–11:05 am	Daniel Dahl
11:05 am–11:25 am	Salini Karuvade
11:25 am–11:45 am	Simeon Simjanovski
11:45 am–12:30 pm	Lunch
	Session 2
12:30 pm–12:50 pm	Yun-Chih Liao
12:50 pm–1:10 pm	Sebastian Malewicz
1:10 pm–1:30 pm	Emma Paterson
	Stream A
1:30 pm–4:00 pm	**Poster session & afternoon tea** (afternoon tea from 3:00 pm)
4:00 pm–7:00 pm	Free time
	Stream B
1:30 pm–2:00 pm	Travel (bus)
2:00 pm–6:00 pm	**Translation & industry showcase**
6:30 pm–7:00 pm	Travel (bus)
7:00 pm–9:00 pm	**Social dinner**

Arghavan Safavi-Naini

Assistant professor, Institute of Physics, University of Amsterdam

Trapped-ion quantum computing with tweezers and electric fields

Day 1: Tuesday 21 November, 9:15 am–10:15 am

Trapped ions are one of the most mature platforms for quantum computation and quantum simulation. In trapped-ion quantum simulators the spin–spin interactions mediated by the collective motion of the ions in the crystal (phonons) are of the form r^{-a}, where $0 < a < 3$. In this talk, I will show that additional optical tweezer potentials may be used to engineer the phonon spectrum and thus tune the interactions and connectivity of the ion qubits beyond the power-law interactions accessible in current set-ups [1,2]. Next, I will show that the combination of optical tweezers that deliver qubit-state-dependent local potentials and an oscillating electric field allows us to create a scalable architecture for trapped-ion quantum computing [2,4]. Because the electric field allows for long-range qubit-qubit interactions mediated by the centre-of-mass motion of the ion crystal, it is inherently scalable to large ion crystals. Furthermore, this scheme does not rely on either ground-state cooling or the Lamb–Dicke approximation.

[1] Arias Espinoza, J. D. et al. Engineering spin–spin interactions with optical tweezers in trapped ions. *Phys. Rev. A* 104:013302 (2021).
[2] Bond, L. et al. Effect of micromotion and local stress in quantum simulations with trapped ions in optical tweezers. *Phys. Rev. A* 106:042612 (2022).
[3] Mazzanti, M. et al. Trapped ion quantum computing using optical tweezers and electric fields. *Phys. Rev. Lett.* 127:260502 (2021).
[4] Mazzanti, M. et al. Trapped ions quantum logic gate with optical tweezers and the Magnus effect. *Phys. Rev. Res.* 5:033036 (2023).

Dr Arghavan Safavi-Naini is an assistant professor at the University of Amsterdam in the Institute of Physics. She is a former EQUS Research Fellow, having worked with Chief Investigator Matt Davis at The University of Queensland, where her research focused on quantum simulation of quantum many-body systems. She completed her PhD in physics at MIT in 2014. She is a member of the Quantum Software Consortium and recently received a Quantum Delta NL grant for her project 'trapped ions make excellent quantum bits'. This project was one of 16 projects granted within the National Growth Fund program Quantum Technology.

Day 2

Wednesday 22 November

8:00 am–9:00 am	Tea & coffee
	Session 3
9:00 am–9:20 am	Chris Baker
9:20 am–9:40 am	Xanthe Croot
9:40 am–10:00 am	Graeme Flower
10:00 am–10:15 am	**Portfolio update: Public engagement**
10:15 am–10:30 am	**Portfolio update: EQUIP (equity in quantum physics)**
10:30 am–11:00 am	Morning tea
11:00 am–12:00 pm	**Keynote presentation: Kae Nemoto**
12:00 pm–12:10 pm	**Group photo** (Esplanade Reserve Park)
12:10 pm–1:00 pm	Lunch/networking lunch for women & gender-diverse EQUS members
	Session 4
1:00 pm–1:20 pm	Sam Bartree
1:20 pm–1:40 pm	Laura Henderson
1:40 pm–2:00 pm	Jue Zhang
2:00 pm–2:20 pm	Christophe Valahu
2:20 pm–3:05 pm	**Three-minute thesis competition**
3:05 pm–5:00 pm	**Poster session & afternoon tea**
5:00 pm–7:00 pm	Free time
7:00 pm–10:00 pm	**Dinner & awards**

Kae Nemoto

Professor, Okinawa Institute of Science & Technology, National Institute of Informatics

Science and technology of quantum complex dynamics

Day 2: Wednesday 22 November, 11:00 am–12:00 pm

There has been a huge world-wide effort to find problems that small-scale quantum processors (noisy, intermediate-scale quantum (NISQ) processors) can easily solve. However, it turns out to be rather difficult to find problems NISQ processors are good at. In this talk, we address this issue by asking ourselves questions: what have we created though developing NISQ technology; and what are these noisy quantum systems capable of? To do this, we first introduce the quantum extreme reservoir computation with small and simple engineered quantum systems, which can solve various classification problems with high accuracy. We then discuss the complexity behind the quantum dynamics the quantum extreme reservoir computation model creates and explore the origin of the computational power in this model.

Professor Kae Nemoto is a professor at Okinawa Institute of Science and Technology (OIST) and the Center Director for the OIST Center for Quantum Technologies. She is also a professor at the National Institute of Informatics in Tokyo, where she serves as the director of the Global Research Center for Quantum Information Science and the co-director of the Japanese–French Laboratory for Informatics. Her research focuses on applications for quantum computers, quantum machine learning, quantum computer architectures, quantum middleware, quantum networks, quantum internet and complex systems. She also leads an academic education consortium, the Quantum Academy for Science and Technology, to provide high-quality lectures and education materials for undergraduate and graduate levels in this field. She is a Fellow of the American Physical Society and of the Institute of Physics (UK).

Day 3

Thursday 23 November

8:00 am–9:00 am	Tea & coffee
9:00 am–10:00 am	**Keynote presentation: Tom Stace & Russell Manfield**
10:00 am–10:15 am	**Portfolio update: Mentoring & career development**
10:15 am–10:30 pm	**Portfolio update: Quantum for educators**
10:30 am–11:00 am	Morning tea
	Session 5
11:00 am–11:20 am	Carolyn Wood
11:20 am–11:40 am	Tyler Jones
11:40 am–12:00 pm	Omprakesh Chandra
12:00 pm–13:00 pm	Lunch
	Session 6
1:00 pm–1:20 pm	Tim Newman
1:20 pm–1:40 pm	Lewis Williamson
1:40 pm–2:00 pm	Jemy Geordy
2:00 pm–2:20 pm	Xanda Kolesnikow
2:20 pm–2:35 pm	**Director’s farewell: Andrew White**
2:35 pm–3:05 pm	Afternoon tea
3:00 pm–3:45 pm	Advisory Committee meeting
3:45 pm–5:00 pm	Scientific Advisory Committee meeting

Tom Stace & Russell Manfield

EQUS Chief Investigator, CEO & co-founder, Analog Quantum Circuits;
Lecturer & Entrepreneur-in-Residence, UQ School of Business

Analog Quantum Circuits—the physics and the company

Day 3: Thursday 23 November, 9:00 am–10:00 am

How do signals get to and from quantum computers? This is a technology problem, which Analog Quantum Circuits is trying to solve. In this talk, I'll explain what we are attempting to do and why we think it's important, and give some hints at our progress so far.

Professor Tom Stace completed his PhD at the Cavendish Lab at The University of Cambridge in the UK on quantum computing, followed by postdoctoral research at the Department of Applied Mathematics and Theoretical Physics, also at Cambridge, and Queens' College, Cambridge. He has held various ARC research fellowships, most recently a Future Fellowship (2015–2019), and was Deputy Director of EQUS from 2018 to 2021. He is the CEO and co-founder of Analog Quantum Circuits, which is Queensland's first quantum start-up, and the first superconducting quantum technology startup in Australia.

Dr Russell Manfield has an engineering background, beginning his career in the mining and telecommunication sectors, before starting new ventures in training, technology and agri-tech domains. He uses this background in his teaching for courses covering entrepreneurship, innovation and strategy. He has built online courses for scale and geographic dispersion, covering corporate innovation, service innovation culture, innovation strategy for quantum technology and navigating the demands of twenty-first-century work skills. He has a particular interest in impact strategies for new ventures to craft sustainable value frameworks, so welcome entrepreneurial research opportunities that target emerging economies, fast-evolving technology domains and design thinking pedagogy for new generations of innovators.

Abstracts

Session 1

Day 1: Tuesday 21 November, 10:45 am–11:45 am

Daniel Dahl

High-dimensional quantum gates

The University of Queensland, obo Chief Investigator Jacq Romero

In quantum information science, using multidimensional states known as qudits enhances the security and capacity of quantum systems beyond what is achievable with conventional qubits. Gate operations on qudits are largely unexplored, but will be pivotal for advancing quantum information processing. A practical and popular method for physically representing qudits is through azimuthal Laguerre-Gaussian transverse spatial modes of light, which theoretically have unlimited dimensionality. Manipulating these spatial modes facilitates the execution of arbitrary unitary transformations, which are the building blocks of complex quantum computation. A practical approach for achieving these transformations is multiplane light conversion, which involves sequential spatial phase adjustments. Our research demonstrates the application of multiplane light conversion in implementing quantum gates—the discrete Fourier transform gate, X gate and Z gate—on a qudit with a dimensionality of 17, defined by the first 17 azimuthal Laguerre-Gaussian modes. This is the highest dimensionality achieved in an experimental demonstration of quantum gates for qudits based on transverse spatial modes of light.

Salini Karuvade

Operationalising inner-product change for quantum computation

The University of Sydney, obo Chief Investigator Andrew Doherty

The uniqueness of the inner product associated with a quantum system has come under scrutiny following the advent of quasi-Hermitian Hamiltonians, which are non-Hermitian operators with real eigenvalues. A changing inner product is valuable for quantum information processing applications; however, perfunctory use of this change can lead to counterfactual conclusions. In this talk, I introduce an operational framework for changing the inner product of a quantum system, which is fully consistent with quantum mechanics and does not lead to counterfactual conclusions. Next, I present a quantum algorithm for changing the inner product of a quantum system and explain its utility in computing functions of non-Hermitian matrices.

Simeon Simjanovski

Decaying turbulence and shear flow instability in Bose–Einstein condensates

The University of Queensland, obo Chief Investigator Halina Rubinsztein-Dunlop

Two-dimensional Bose–Einstein condensate superfluids underly several quantum technologies, including compact atom–wave interferometers [1], superfluid Helmholtz oscillators [2] and superfluid Josephson junctions [3]. Recent proposals have considered fluxon qubits for computation, similarly relying on superfluid flow around an enclosed ring [4]. A key limitation in implementing this technology is the fundamental problem of quantum turbulence, which results from flow exceeding a critical velocity. In this talk, we approach the turbulence problem from the bottom up, considering the creation of turbulence from the breakdown of an ordered shear layer in a Bose–Einstein condensate. We observe behaviour analogous to classical Kelvin–Helmholtz instability, which leads to shear-layer breakdown and subsequent decaying turbulence. We measure characteristic features of the Kelvin–Helmholtz instability, including the emergence of periodic structure under the breakdown and subsequent growth of vortex structures and clusters. Notably, our system exhibits a power-law in the decay of the cluster number, consistent with observations in classical turbulence [5,6]. We also observe delayed equilibration of the clusters, in contrast to maximum fluid entropy models [7].

[1] Woffinden, C. W. et al. Viability of rotation sensing using phonon interferometry in Bose–Einstein condensates. *SciPost Phys.* 15:128 (2023).
[2] Gauthier, G. et al. Quantitative acoustic models for superfluid circuits. *Phys. Rev. Lett.* 123:260402 (2019).
[3] Ryu, C., Samson, E. C. & Boshier, M. G. Quantum interference of currents in an atomtronic SQUID. *Nat. Commun.* 11:3338 (2020).
[4] Oliinyk, A., Malomed, B. & Yakimenko, A. Nonlinear dynamics of Josephson vortices in merging superfluid rings. *Comm. Nonlin. Sci. Num. Sim.* 83:105113 (2020).
[5] Mcwilliams, J. C. The vortices of two-dimensional turbulence. *J. Fluid Mech.* 219:361–385 (1990).
[6] Schecter, D. A. et al. Vortex crystals from 2D Euler flow: experiment and simulation. *Phys. Fluids* 11:905–914 (1999).
[7] Reeves, M. T. et al. Turbulent relaxation to equilibrium in a two-dimensional quantum vortex gas. *Phys. Rev. X* 12:011031 (2022).

Session 2

Day 1: Tuesday 21 November, 12:30 pm–1:30 pm

Yun-Chih Liao

Microscopic studies on superconducting devices

The University of Queensland, obo Chief Investigator Tom Stace

A Josephson junction is an essential element for quantum computing in superconducting implementations. The conventional analysis of this device starts from the Lagrangian of the electric circuit and quantises the Hamiltonian in the canonical way. Differing from this semi-classical approach, we build up a fully quantum picture from the wavefunction of the electrons transmitting inside the superconductors without passing through the 'classical' Lagrangian. We establish the connection between BCS (Bardeen–Cooper–Schrieffer) theory and the well known Cooper-pair-box formalism and provide evidence that the required basis size is much smaller than the total particle number.

Sebastian Malewicz

Engineering classes of two-photon states using linear interactions and nonclassical interference

The University of Queensland, obo Chief Investigator Andrew White

The term two-photon interference typically refers to destructive interference observed in coincidence measurements between two identical single photons entering a 50/50 beam splitter coincidentally. This phenomenon, first experimentally tested by Hong, Ou and Mandel [1] is at the core of a series of quantum optical technologies. In this work, we discuss how a deeper analysis of two-photon interference reveals various behaviours associated with single photons under linear scattering processes. We experimentally demonstrate a type of quantum interference that reveals an equivalence between class two-photon states under liner optical transformation [2]. This quantum interference is manifested in a reduction of two-photon count events while maintaining the total two-photon coincidences. We observe this effect by producing an unbalanced source of two-photon states using photons produced by spontaneous parametric down-conversion and a series of linear optical components, followed by photon-number-resolving measurements. Using a beam splitter with variable reflectivity, we implement linear transformations that engineer a series of two-mode two-photon states. Finally, we study the effect of optical losses that occur in a non-ideal experimental environment. We show that, in contrast to the usual Hong–Ou–Mandel effect, photon losses have a substantial role in observing this phenomenon.

[1] Hong, C. K., Ou, Z. Y. & Mandel, L. Measurement of subpicosecond time intervals between two photons by interference. *Phys. Rev. Lett.* 59:2044–2046 (1987).
[2] Lund, A. P. Classes of two-photon states defined by linear interactions and destructive two-photon quantum interference in a single mode. *Phys. Rev. A* 92:053844 (2015).

Emma Paterson

The twisted anyon cavity resonator as a potential dark matter detector and sensing device

The University of Western Australia, obo Chief Investigator Mike Tobar

The minimum axion mass detectable by existing photonic dark matter searches is set by the frequency and hence size of the detector, which places the lower limit at around 10^{-7} eV [1], leaving the ultralight dark matter parameter space relatively unexplored. In this work, we describe a new class of electromagnetic resonator: the anyon cavity resonator, which has the potential to couple to ultralight dark matter axions. This is possible because of the existence of a single electromagnetic mode with nonzero helicity, which is generated in vacuo through a pure photonic magneto-electric coupling of a transverse electric and transverse magnetic mode [2]. This coupling arises from the introduction of mirror asymmetry via the twisting of the hollow structure of the resonator and is optimised with a triangular cross-section. The origin of these high-helicity modes is demonstrated using finite-element simulation and validated with experimental measurements. A sensitive ultralight-axion laboratory dark matter experiment through photon coupling may be realised by implementing such a resonator in an ultrastable oscillator configuration and searching for signals in the Fourier spectrum of amplitude fluctuations. It is predicted that this experiment could search for dark matter down to 10^{-24} eV, with a minimum coupling strength of $10^{-15.8}$ GeV^{-1} [2], covering a completely unexplored region of parameter space. This removes the typical requirement for an external magnetic field and, therefore, permits the use of high-Q superconducting materials to reduce surface losses and enhance sensitivity to axions.

[1] Thomson, C. A. et al. Upconversion loop oscillator axion detection experiment: a precision frequency interferometric axion dark matter search with a cylindrical microwave cavity. *Phys. Rev. Lett.* 126:081803 (2021).
[2] Bourhill, J. F. et al. Searching for ultralight axions with twisted cavity resonators of anyon rotational symmetry with bulk modes of nonzero helicity. *Phys. Rev. D* 108:052014 (2023).

Session 3

Day 2: Wednesday 22 November, 9:00 am–10:00 am

Chris Baker

Cavity optomechanics with superfluid helium: nonlinear waves and solitons

The University of Queensland, obo Chief Investigator Warwick Bowen

Cavity optomechanics focuses on the interaction between confined light and a mechanical degree of freedom. This field has a broad range of applications, including high-precision acceleration, force and magnetic sensing, and the Nobel-prize-winning observation of gravitational waves. In this talk, I will present research interfacing cavity optomechanics and superfluid physics [1–5]. I will present experimental results where we cover nanofabricated silicon photonic crystal structures with a thin superfluid helium-4 film. This creates an optically addressable quasi-one-dimensional wave tank that contains a few femtolitres of superfluid helium, upon which waves can be generated, propagate and be readout. Because of the absence of viscosity of superfluid helium, the depth of the film h can be made as small as a few nanometres without wave attenuation, something that is impossible with classical fluids. Our platform thus enables us to generate waves with an aspect ratio (defined as the wavelength over depth λ/h) exceeding 10,000:1, two orders of magnitude larger than that achievable in the largest wave tanks and exceeding that of the most extreme terrestrial phenomena such as tsunamis. This, combined with our recently developed ability to engineer strong fountain-pressure forces [6] enables us to drive large-amplitude waves and experimentally generate rich regimes of nonlinear hydrodynamics. Using these characteristics, I will show how our superfluid wave tank enables us to generate and measure (within a submillimetre-sized device in a laboratory setting) a rich variety of nonlinear phenomena, including soliton fission, dispersive shock waves, optomechanical dissipative solitons [7] and rogue waves.

[1] He, X. et al. Strong optical coupling through superfluid Brillouin lasing. *Nat. Phys.* 16, 417–421 (2020).
[2] Sachkou, Y. P. et al. Coherent vortex dynamics in a strongly interacting superfluid on a silicon chip. *Science* 366, 1480 (2019).
[3] Harris, G. et al. Laser cooling and control of excitations in superfluid helium. *Nat. Phys.* 12, 788–793 (2016).
[4] Wasserman, W. W. et al. Cryogenic and hermetically sealed packaging of photonic chips for optomechanics. *Opt. Express* 30, 30822–30831 (2022).
[5] Baker, C. G. et al. Theoretical framework for thin film superfluid optomechanics: towards the quantum regime. *New J. Phys.* 18, 123025 (2016).
[6] Sawadsky, A. et al. Engineered entropic forces allow ultrastrong dynamical backaction. *Sci. Adv.* 9:eade3591 (2023).
[7] Zhang, J. et al. Optomechanical dissipative solitons. *Nature* 600:75–80 (2021).

Xanthe Croot
Hybrid semi-superconducting quantum circuits
The University of Sydney

Superconducting circuits at microwave frequencies have the extraordinary ability to facilitate coherent light-matter interactions. This phenomenon, circuit quantum electrodynamics, is a powerful tool in superconductor-based quantum computing, where on-chip microwave photons can entangle separated qubits, can act as quantum memories and are routinely used for quantum non-demolition measurement. The emergence of hybrid quantum systems—those that merge traditionally incompatible technologies—has created the possibility of extending circuit quantum electrodynamics to other qubit platforms. An example of this is spins in semiconductors, which are extremely compact and long-lived, but have substantial limitations due to their short-range interactions. In this talk, I will discuss an experiment where two individual electron spins, separated by over 4 mm, were coherently coupled via a microwave-cavity photon. I will detail the development of low-power qubit control techniques that emerged from this experiment, before discussing my current work and research directions.

Graeme Flower
Development of quantum technologies for axion detection
The University of Western Australia, obo Chief Investigator Maxim Goryachev

In this talk, we will discuss the current status of the ORGAN experiment to detect dark matter axions and progress made towards improving the readout chain of the detector. This will first cover some basics of axion detection, how the ORGAN experiment works and results so far. Next, we will discuss the progress of the next iteration: ORGAN Q, expected to begin data-taking (hopefully) soon after the workshop. This stage implements a Josephson parametric amplifier in the readout chain to greatly reduce system noise and tests improved readout calibration. Linear amplifiers are limited by the standard quantum limit, so finally we will discuss theory progress towards single-photon counting with current-biased Josephson junctions.

Session 4

Day 2: Wednesday 22 November, 1:00 pm–2:20 pm

Sam Bartree

Spin qubits with integrated millikelvin CMOS control

The University of Sydney, obo Chief Investigator David Reilly

A key virtue of spin qubits is their tiny, submicrometre footprint, which enables billions of qubits to fit on a single silicon wafer. However, with each qubit requiring a handful of gate electrodes for control, management of this extreme interconnect density is challenging. Monolithic integration of qubits with CMOS-based control circuits might address this challenge, although the effect of heat and crosstalk on the qubits is likely to pose a substantial risk to this approach. An alternative architecture [1] uses heterogeneous 'chiplet'-style packaging in which the control circuits and qubits are proximal, but positioned on separate dies and wired-up using dense, lithographically defined interconnects at millikelvin temperatures. Here, we report the realisation of a cryo-CMOS control architecture (based on 28-nm fully depleted silicon-on-insulator) and benchmark its performance using silicon MOS-style electron spin qubits [2]. The fidelity of single- and two-qubit gate operations acts to probe the effect of heat and noise arising from the cryo-CMOS control circuits. These results suggest that heterogeneous integration is a viable means of scaling-up the control interface of spin-based quantum processors.

[1] Pauka, S. J. et al. A cryogenic CMOS chip for generating control signals for multiple qubits. *Nat. Electron.* 4:64–70 (2021).

[2] Veldhorst, M. et al. A two-qubit logic gate in silicon. *Nature* 526:410–414 (2015).

Laura Henderson

Machine learning with continuous-variable quantum kernels: a toolkit

The University of Queensland, obo Chief Investigator Sally Shrapnel

The popular qubit framework has dominated recent work on quantum kernels, with results characterising expressability, learnability and generalisation. As yet, there is no comparative framework to understand these concepts for continuous-variable quantum computing platforms. We develop a framework for understanding continuous-variable quantum kernels that uses ideas from holomorphic-function quantum computing. Holomorphic functions characterise degrees of 'quantumness' via the notion of stellar rank, which is used to provide a taxonomy for quantum advantage. Within this taxonomy, we provide a closed-form expression for a general holomorphic encoding kernel and provide a specific example: a single-mode displacement-encoding kernel. We prove the first is universal—and hence highly expressive—for any given compact dataset. We discuss the effects of noise and bandwidth on our kernels. In doing so, we extend the potential for quantum-kernel machine learning to continuous-variable bosonic sampling platforms.

Jue Zhang
Laser stabilisation and progress at ANU
The Australian National University, obo Chief Investigator Kirk McKenzie

Active laser stabilisation ties a frequency of a laser to an ultrastable reference, such as an optical resonator, by comparing the laser frequency to the reference and using feedback control to regulate the laser. Coating Brownian thermal noise, which arises from the random Brownian motion of the mirror-coating materials, is the primary limitation of precision measurements at frequencies below 10 Hz. We propose a multicavity transverse mode readout scheme that achieves an equivalent thermal noise level to that of a mesa flat-top beam. The mesa flat-top beam is well known for its efficiency in reducing thermal noise compared to a conventional Gaussian beam, by effectively increasing the sampling area, although it presents technical challenges in its generation. With optimal weighting of different spatial modes, this approach allows us to improve the coating thermal noise by a factor of 2.46 with 25 modes and of 1.61 with 3 modes in short cavities, equivalent to cooling the system from 300 K to 120 K. In this talk, we will present the progress of laser stabilisation for the reference cavity and the design of the test cavity.

Christophe Valahu
Quantum simulation of molecular dynamics with a trapped ion
The University of Sydney, obo Chief Investigator Mike Biercuk

Photochemical reactions that occur in molecular processes such as our vision often involve rapid and efficient reactions that occur on femtosecond timescales. However, simulating their dynamics can be challenging with conventional computers, particularly in strong vibronic (vibrational and electronic) coupling regimes where common approximations break down. We show that vibronic-coupling Hamiltonians representing ultrafast molecular dynamics can be efficiently simulated on an analogue quantum simulator with coupled internal and bosonic states. We experimentally demonstrate our simulator by engineering a Jahn–Teller conical intersection in the internal and external degrees of freedom of a trapped ion. We reconstruct the probability density of the motional wavepacket as it encircles the conical intersection and observe clear interference due to geometric phase. Our experimental results validate the feasibility of using analogue quantum simulators with trapped ions to study ultrafast molecular dynamics.

Session 5

Day 3: Thursday 23 November, 11:00 am–12:00 pm

Carolyn Wood

Quantum machine learning via Kerr nonlinearity

The University of Queensland, obo Chief Investigator Gerard Milburn

Kernel methods are of current interest in quantum machine learning because of similarities with quantum computing in how they process information in high-dimensional feature (Hilbert) spaces. Kernels are believed to offer particular advantages when they cannot be computed classically [1], so a kernel with indisputably nonclassical elements is desirable. Kerr nonlinearities, known to be a route to universal continuous-variable quantum computation [2], may be able to play this part for quantum machine learning. In this work, we introduce a two-mode bosonic kernel with a cross-Kerr nonlinearity, and show its use as the basis for a support vector machine classifier where classical data is encoded in quantum states. This scheme is a continuous-variable generalisation of the binary support vector machine classifier of IBM [3]. We explore the unique structure of the kernel and encoded data. We then discuss possible experimental platforms such as superconducting quantum circuits.

[1] Schuld, M. & Petruccione, F. Quantum models as kernel methods. In *Machine Learning with Quantum Computers* 217–245 (Springer, 2021).
[2] Lloyd, S. & Braunstein S. L. Quantum computation over continuous variables. *Phys. Rev. Lett.* 82:1784–1787 (1999).
[3] Havlíček, V. et al. Supervised learning with quantum-enhanced feature spaces. *Nature* 567:209–212 (2019).

Tyler Jones

Multitime quantum process tomography of a superconducting qubit

The University of Queensland, obo Chief Investigator Arkady Fedorov

The maturation of quantum technologies in the past decade has been enabled by the on-going advancement of noise characterisation techniques. For Markovian noise sources, quantum process tomography (a natural extension of quantum state tomography) is one such technique which has become ubiquitous in the experimental toolbox. However, techniques like quantum process tomography have no capacity to characterise sources of non-Markovian noise (such as memory effects, system drifts and crosstalk), which we know exist nontrivially in the vast majority of experimental hardware. In this talk, we introduce a methodology to perform multitime quantum process tomography, which uses a process matrix formalism to enable full characterisation of non-Markovian dynamics. We discuss the experimental procedure required to perform multitime process tomography on a superconducting quantum device, and present results where we successfully detect quantum memory effects on an in-house superconducting device and a publicly available IBM processor.

Omprakash Chandra

Nonlocal gates for quantum error correction

Macquarie University, obo Chief Investigator Gavin Brennen

Recently, high-fidelity nonlocal many-body gates were achieved via coupling qubits to a common bosonic mode. These gates may be used to encode nonlocal cat states or for multicontrolled phase gates. In this talk, I will demonstrate how to integrate this mechanism into primitives for quantum error correction. I will talk about how this protocol is fault-tolerant for Steane's code and look at higher-weight stabiliser codes such as hypergraph product codes. Biased erasures are the dominant form of noise in this architecture. I will also talk about a recently developed 'fast erasure decoder for hypergraph product codes' and present some numerical simulations. I will conclude with challenges and future aspects we want to look at.

Session 6

Day 3: Thursday 23 November, 1:00 pm–2:20 pm

Tim Newman

Site engineering for erbium quantum technologies

The University of Sydney, obo Chief Investigator John Bartholomew

Single erbium ions in crystals are compelling candidates for high-performance quantum light-matter interfaces [1]. A critical part of each demonstration is enhancing the emission rate of single ions by manipulating the local photonic density of states using optical resonators with high quality factors and low mode volume [2–4]. A complementary strategy to achieve high Purcell enhancement is engineering the crystal-field interaction to increase the optical dipole moment. Towards this goal, we have modified the nanoscale crystalline environment of erbium in calcium fluoride, modelled its crystal-field Hamiltonian, and performed an initial experimental characterisation. I will report on the properties of erbium-oxygen complexes, including lifetime, line widths and dipole moment, from these ensemble measurements, and our progress on coupling these sites to high-quality-factor whispering-gallery-mode resonators.

[1] Ourari, S. et al. Indistinguishable telecom band photons from a single Er ion in the solid state. *Nature* 620:977–981 (2023).

[2] McAuslan, D. L., Longdell, J. J. & Sellars, M. J. Strong-coupling cavity QED using rare-earth-metal-ion dopants in monolithic resonators: what you can do with a weak oscillator. *Phys. Rev. A* 80:062307 (2009).

[3] Dibos, A. M., Raha, M., Phenicie, C. M. & Thompson, J. D. Atomic source of single photons in the telecom band. *Phys. Rev. Lett.* 120:243601 (2018).

[4] Gritsch, A., Ulanowski, A. & Reiserer, A. Purcell enhancement of single-photon emitters in silicon. *Optica* 10:783 (2023).

Lewis Williamson

Extracting quantum work from coherence in many-body bosonic systems

The University of Queensland, obo Chief Investigator Matt Davis

One of the defining features of a quantum system is coherence: the ability of a system to exist in superpositions of eigenstates of some observable. Recent work has explored the utility of coherence in engine operation, either to increase power output or to extract work that is not accessible classically. We present a protocol to extract work from coherence in a twomode interacting bosonic system. For a given particle number, the work is predominantly nonclassical within a narrow range of temperatures. This range may be broadened substantially by incorporating squeezing into the protocol. The work output may be utilised or measured via linear coupling to an external bosonic mode.

Jemy Geordy

Coherent quantum control of nano-diamond nitrogen-vacancy spin ensembles in a noisy spin bath

Macquarie University, obo Chief Investigator Thomas Volz

A fully controllable spin ensemble within a nanoparticle with reduced coupling to its immediate intrinsic surroundings can be a powerful tool for quantum sensing applications. Negatively charged nitrogen–vacancy (NV) centre spins in nanodiamonds are a prime example with a strong use-case in high-sensitivity magnetometry in ambient conditions, offering high spatial resolution and miniaturised quantum memories for enhanced functionality. To make full use of the potential of nitrogen–vacancy diamond sensors based on spin ensembles, two challenges need to be addressed. The first one is the fast decay of the intrinsic quantum coherence due to the coupling of the ensemble of nitrogen–vacancy spins to its intrinsic surrounding spin bath (generally consisting of nuclear and electronic spins). The second one is the random orientation of the nanodiamond relative to the external control fields. I will present the latest results from on-going experiments on the application of various dynamical decoupling methods to nitrogen–vacancy ensembles in nanodiamonds with controlled spin–bath driving. We are also exploring optimisation algorithms to mitigate problems due to the random orientations of nanodiamond nitrogen–vacancy ensembles for coherent control. Furthermore, we introduce periodic driving in the system in combination with the conventional dynamical decoupling. We observe an unusual, sharp change in the coherence decay timescales, in comparison with the conventional dynamical decoupling.

Xanda Kolesnikow

GKP state preparation using periodic driving

The University of Sydney, obo Chief Investigator Stephen Bartlett

The Gottesman–Kitaev–Preskill (GKP) code may be used to overcome noise in continuous-variable quantum systems. However, preparing GKP states remains experimentally challenging. We propose a method for preparing GKP states by engineering a time-periodic Hamiltonian whose Floquet states are GKP states. This Hamiltonian may be realised in a superconducting circuit comprising a SQUID shunted by a superinductor and a capacitor, with a characteristic impedance twice the resistance quantum. The GKP Floquet states may be prepared by adiabatically tuning the external magnetic flux drive. We predict that highly squeezed GKP magic states can be prepared on a microsecond timescale, even in the presence of photon loss and flux noise at typical rates.

Portfolio updates & competitions

Translation & industry showcase

Day 1: Tuesday 21 November, stream B

1:30 pm–2:00 pm	Travel (bus) Arrivals & refreshments
2:00 pm–3:00 pm	Introduction to quantum technology Quantum technology for Australia & industry applications
3:00 pm–3:30 pm	Break and discussion
3:30 pm–4:30 pm	Real-world case studies Advice on how to engage Strategic considerations
4:30 pm–6:30 pm	Networking & refreshments EQUS translation & quantum technology showcase Interactive science activities
6:30 pm–7:00 pm	Travel (bus)

Public engagement

Day 2: Wednesday 22 November, 10:00 am–10:15 am

Ben McAllister

EQUIP (equity in quantum physics)

Day 2: Wednesday 22 November, 10:15 am–10:30 am

Tim Newman

Mentoring & career development

Day 3: Thursday 23 November, 10:00 am–10:15 am

Katrina Tune

Quantum for educators

Day 3: Thursday 23 November, 10:15 am–10:30 am

Lachlan Rogers

Poster competition

Day 1: Tuesday 21 November, 1:30 pm–4:00 pm, stream A
Day 2: Wednesday 22 November, 3:05 pm–5:00 pm

Aaron Quiskamp (UWA)
Abhijeet Alase (USYD)
Abhinash Roy (MQ)
Airin Antony (UQ)
Alex Hahn (MQ)
Ali Fawaz (MQ)
Andrew Groszek &
Charles Woffinden (UQ)
Andrew Wade (ANU)
Angela White (UQ)
Anindya Sundar Paul† (MQ)
Ben Carey (UQ)
Ben Dix-Matthews (UWA)
Ben Field (USYD)
Brendan Harlech-Jones (USYD)
Chris Baker* (UQ)
Cindy Zhao (UWA)
Cyril Laplane (MQ)
Daniel Dahl*† (UQ)
Daniel Peace (UQ)
David Sommers (UQ)
Divita Gautam (UQ)
Dominic Williamson (USYD)
Elizabeth Marcellina (USYD)
Elrina Hartman (UWA)
Emily Rose Rees (ANU)
Emma Paterson* (UWA)
Evan Hockings (USYD)
Fatemeh Mohit (UQ)
Felix Thomsen (USYD)
Gargi Tyagi (USYD)
Glen Harris (UQ)
Hyma Harish Vallabhapurapu (MQ)
Jake Wilson (UQ)
Jasleen Kaur (MQ)
Jeremy Bourhill (UWA)
Jesse Slim (UQ)
Joseph Pham (USYD)
Julian Jee (USYD)
Juliette Soule (USYD)
Kun Zuo (USYD)
Lauren McQueen (UQ)
Lawrence Cohen (USYD)
Lewis Williamson* (UQ)
Maarten Christenhusz (UQ)
Maiyuren Srikumar(USYD)
Nathaniel Bawden (UQ)
Nicholas Fazio (USYD)
Nikhil Pramod Narkhede (MQ)
Nishta Arora† (UQ)
Parth Girdhar (UNSW)
Raji Bhaskaran Nair (MQ)
Rakesh Saini (MQ)
Robert Wolf (USYD)
Robin Harper (USYD)
Salini Karuvade* (USYD)
Samuel Smith (USYD)
Sarath Raman Nair (MQ)
Seok-Hyung Lee (USYD)
Sonali Parashar (UWA)
Sophie Muusse (ANU)
Stefan Zeppetzauer (UQ)
Stefanus Tanuarta (USYD)
Steven Samuels (UWA)
Steven Waddy (USYD)
Tavshabad Kaur (UQ)
Thomas Smith (USYD)
Tim Hirsch (UQ)
Tim Newman* (USYD)
Tina Jin (UQ)
Torsten Gaebel (USYD)
Vassili Matsos (USYD)
Victor Manuel Valenzuela Jimenez (UQ)
Will Campbell (UWA)
Xanda Kolesnikow* (USYD)
Yangming Wang (USYD)
Yun-Chih Liao (UQ)
Zachary Kerr (UQ)
Zsolt Szabo (MQ)

Three-minute thesis competition

Day 2: Wednesday 22 November, 2:20 pm–3:05 pm

David Gozzard (UWA)
Maverick Millican (USYD)
Sayantan Das (UQ)
Leo Sementilli (UQ)
Robert Crew (UWA)
Anindya Sundar Paul‡ (MQ)
Daniel Dahl*‡ (UQ)
Nishta Arora‡ (UQ)
Varun Srivastava (MQ)
Yuktee Gupta (USYD)

* Also presenting. † Also doing 3MT. ‡ Also doing a poster.

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