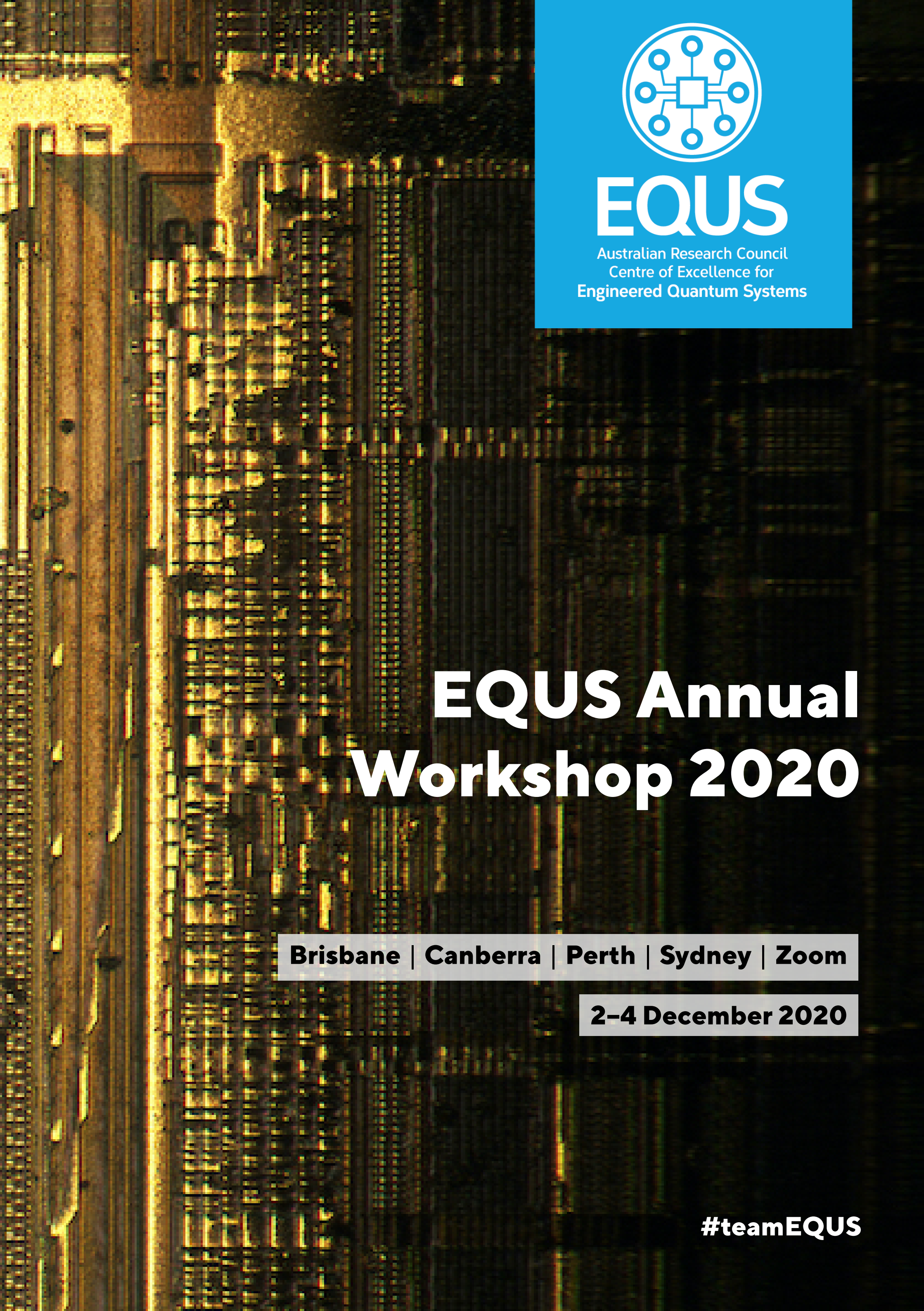

EQUS

Australian Research Council
Centre of Excellence for
Engineered Quantum Systems

EQUS Annual Workshop 2020

Brisbane | Canberra | Perth | Sydney | Zoom

2–4 December 2020

#teamEQUS

EQUS acknowledges the Traditional Owners of Country throughout Australia and their continuing connection to lands, waters and communities. We pay our respects to Aboriginal and Torres Strait Islander cultures and to Elders past and present.

Welcome

Welcome to the tenth EQUS Annual Workshop!

The unusual format of this year's workshop reflects the very unusual year we've had (to say the least). I thank you for your patience, perseverance, and ingenuity in the face of the many challenges 2020 has thrown at us.

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

Thank you to all our speakers, and especially to our two international speakers who have kindly agreed to talk to us — despite the antisocial hour — on areas that complement and extend our own research interests.

2021 will mark the midpoint for EQUS. I'm very excited by everything we've achieved so far, and look forward to continuing and building on our success next year as we move into the second half of our Centre. On that note, please consider completing our survey if you haven't done so already. The more people complete it, the more opportunity we'll have to improve EQUS for the benefit of everyone.

I hope to be able to see everyone in person next year in Noosa, if not well before.

Andrew White
EQUS Director

Overview

Perth
EZONE North
Business Incubator
Room 1.13, UWA

Sydney
Kirribilli Club
11 Harbourview Cres
Lavender Bay 2060

Brisbane
Stamford Plaza
39 Edward St
Brisbane City 4000

Canberra
Physics Studio
Ground Floor
Building 38a, ANU

	Registration/ Coffee	Start	End	Dinner
Perth				
Day 1	7:30 am	8:00 am	2:00 pm	
Day 2		8:00 am	2:00 pm	6:00 pm
Day 3		8:00 am	11:15 am	
Brisbane				
Day 1	9:30 am	10:00 am	4:00 pm	
Day 2	9:30 am	10:00 am	4:00 pm	6:00 pm
Day 3	9:30 am	10:00 am	1:15 pm	
Sydney & Canberra				
Day 1	10:30 am	11:00 am	5:00 pm	
Day 2		11:00 am	5:00 pm	6:00 pm
Day 3		11:00 am	2:15 pm	

Day 1

Wednesday 2 December

Master of Ceremonies: Tom Stace

AWST (WA)	AEST (QLD)	AEDT (ACT & NSW)	
7:30 am	9:30 am	10:30 am	Registration
			Workshop opens
8:00 am	10:00 am	11:00 am	Welcome to Country
8:15 am	10:15 am	11:15 am	Workshop welcome
			Session 1
8:30 am	10:30 am	11:30 am	Ramil Nigmatullin & Elisabeth Wagner
9:00 am	11:00 am	12:00 pm	Liam Bond
9:30 am	11:30 am	12:30 pm	Coffee (WA) Lunch (QLD, ACT, NSW)
			Session 2
10:15 am	12:15 pm	1:15 pm	Alex Terrasson
10:45 am	12:45 pm	1:45 pm	Lyle Roberts
11:15 am	1:15 pm	2:15 pm	Cindy Zhao
11:45 am	1:45 pm	2:45 pm	Lunch (WA) Coffee (QLD, ACT, NSW)
			Session 3
12:30 pm	2:30 pm	3:30 pm	Rohit Navarathna
1:00 pm	3:00 pm	4:00 pm	Dat Thanh Le
1:30 pm	3:30 pm	4:30 pm	Leo Assis
2:00 pm	4:00 pm	5:00 pm	**End Day 1**

Day 2

Thursday 3 December

Master of Ceremonies: Stephen Bartlett

AWST (WA)	AEST (QLD)	AEDT (ACT & NSW)	
	9:30 am		Coffee (QLD)
			Session 4
8:00 am	10:00 am	11:00 am	Invited talk: Naomi Nickerson
8:45 am	10:45 am	11:45 am	Juliette Soule
9:15 am	11:15 am	12:15 pm	Coffee (WA) Lunch (QLD, ACT, NSW)
			Session 5
10:00 am	12:00 pm	1:00 pm	Ting Rei Tang
10:30 am	12:30 pm	1:30 pm	Tyler Neely
11:00 am	1:00 pm	2:00 pm	Gerard Milburn
11:30 am	1:30 pm	2:30 pm	Lunch (WA) Coffee (QLD, ACT, NSW)
			Session 6
12:15 pm	2:15 pm	3:15 pm	Commercialisation: Sascha Schediwy
12:35 pm	2:35 pm	3:35 pm	Public good: Sally Shrapnel
12:55 pm	2:55 pm	3:55 pm	Open source: David Tuckett
1:15 pm	3:15 pm	4:15 pm	Invited talk: James Millen
2:00 pm	4:00 pm	5:00 pm	**End Day 2**
6:00 pm	6:00 pm	6:00 pm	Dinner

Naomi Nickerson

Dr Naomi Nickerson is the Director of Quantum Architecture at PsiQuantum, a quantum start-up that's building the first useful quantum computer. Her research focuses on how to make quantum error correction work in real devices. She completed her PhD at Imperial College London in 2015.

James Millen

Dr James Millen is a Lecturer in Advanced Photonics at King's College London and founder of the Levitated Nanophysics group. His research interests include opto- and electromechanics, nanothermodynamics and macroscopic quantum physics. In 2017, he was awarded the David Bates Prize for his contributions to experimental and theoretical quantum optomechanics. Dr Millen also has a keen interest in public outreach and engagement; he is currently Lecturer in Quantum Theory to the Public at the Royal Institution and runs The Quantum Workshop mobile experiment.

Dinner

Perth

Matilda Bay Restaurant
3 Hackett Dr, Crawley 6009

Sydney

Harborview Lounge
Kirribilli Club

Brisbane

Riverview Room
Stamford Plaza

Canberra

TBA
(check with ANU Node Professional)

Day 3

Friday 4 December

Master of Ceremonies: Thomas Volz

AWST (WA)	AEST (QLD)	AEDT (ACT & NSW)	
	9:30 am		Coffee (QLD)
			Session 7
8:00 am	10:00 am	11:00 am	Samuel Bartee
8:30 am	10:30 am	11:30 am	Lyra Cronin
9:00 am	11:00 am	12:00 pm	Michael Kewming
9:30 am	11:30 am	12:30 pm	Coffee (WA) Lunch (QLD, ACT, NSW)
			Session 8
10:15 am	12:15 pm	1:15 pm	Jacq Romero
10:45 am	12:45 pm	1:45 pm	**Awards and close**
11:15 am	1:15 pm	2:15 pm	**End Day 3**

Attendees at the EQUS Annual Workshop 2019

Coming up in 2021...

9–11 February

Coogee Workshop

Coogee, NSW

16–17 June

Midterm Review

Brisbane, QLD

1–3 December

EQUS Annual Workshop

Peppers, Noosa, QLD

Abstracts

Session 1

Ramil Nigmatullin & Elisabeth Wagner

Information flow and phase transitions in non-unitary quantum cellular automata

Macquarie University, CI: Gavin Brennan

Quantum simulations promise to simulate complex physics that is difficult to compute on classical machines. However, it is a challenge to make such simulations robust to error without demanding the full overhead of quantum error correction.

We investigate one route towards robust quantum simulations using quantum cellular automata (QCA) rules [1], with special focus on non-unitary QCA that simulate irreversible, open systems dynamics. Such rules can be used to prepare many-body entangled states in a manner that is tolerant to perturbations, and can be implemented using engineered dissipation via the dipole blockade mechanism in arrays of trapped Rydberg atoms [2]. We describe two novel features of such dynamics. First, the index [3], which measures information flow and defines an equivalence class for locally equivalent unitary QCA, is no longer rigid for non-unitary QCA. We show how an index derivative can be computed for Lindblad dynamics and identify the associated symmetries thereof as well as physical implications. Second, non-unitary QCA enables exploration of non-equilibrium dynamics of quantum many-body systems with dissipation and decoherence. We construct a non-unitary QCA that in the fully dissipative limit reduces to Domany-Kinzel cellular automaton (DKCA) [4] — a classic stochastic model of directed percolation in one dimension. We simulate the dynamics of the continuous and block-partitioned DKCA using infinite time-evolving block decimation for mixed states, showing that the system exhibits a phase transition in both cases. In the continuous case, the fixed point is associated with the ground state of a frustration-free stoquastic Hamiltonian. The model is used to study the

influence of quantum effects on the phase diagram of directed percolation.

[1] T. Farrelly. A review of quantum cellular automaton. arXiv:1904.13318 (2019).

[2] T. M. Wintermantel, Y. Wang, G. Lochead, S. Shevate, G. K. Brennen & S. Whitlock. Unitary and nonunitary quantum cellular automata with Rydberg arrays. *Phys. Rev. Lett.* 124:070503 (2020).

[3] D. Gross, V. Nesme, H. Vogts & R. F. Werner. Index theory of one-dimensional quantum walks and cellular automata. *Commun. Math. Phys.* 310:419–454 (2012).

[4] E. Domany & W. Kinzel. Equivalence of cellular automata to Ising models and directed percolation. *Phys. Rev. Lett.* 53:311–314 (1984).

Liam Bond

Robust preparation of entangled Dicke states in trapped ions

University of Queensland, CI: Matt Davis

Exploiting the properties of entanglement in quantum sensors can enable significant improvements in measurement precision scaling. The statistical error of a measurement scales as $1/\sqrt{N}$ using classical states, but can scale as $1/N$ through the use of N-particle entangled states. However, experimentally preparing large-N entangled states remains a challenge. Johnsson et al. [1] recently proposed a protocol that can robustly prepare N-particle entangled Dicke states without requiring fine-tuning or individual qubit addressability. We simulate this scheme, including realistic decoherence parameters, and find its performance is limited by decoherence in current ion trap architectures. However, we introduce modifications to the scheme that enable realistic, high-fidelity preparation of entangled Dicke states of up to 20 ions in current experiments. We also consider how the protocol can be used to engineer Schr odinger cat states, as well as codewords for quantum error correction.

[1] M. T. Johnsson, N. R. Mukty, D. Burgarth, T. Volz & G. K. Brennen. Geometric pathway to scalable quantum sensing. *Phys. Rev. Lett.* 125:190403 (2020).

Session 2

Alex Terrasson

Quantum correlations overcome the photodamage limits of microscopy

University of Queensland, CI: Warwick Bowen

State-of-the-art microscopy relies on intense lasers. Applied to biological systems, photodamage limits the imaging sensitivity and speed that is possible with classical illumination.

Quantum correlations are predicted to allow this limit to be overcome. We demonstrate this absolute quantum advantage for the first time, the imaging analogue of the 'quantum supremacy' demonstrated for computing by Google last year.

Our system is a Raman microscope that operates with quantum light at the same intensities as state-of-the-art microscopes.

We use it to image molecular bonds with quantum-enhanced contrast and unveil features that would not be resolved using classical light.

Raman microscopy is widely use in biomedicine for extremely high-specificity label-free imaging.

By showing that the sensitivity and imaging speed can be improved beyond what would otherwise be possible, our results lead the way to quantum-improved performance in imaging and diagnosis.

Lyle Roberts

Ultralow-optical-power phase tracking for space-based gravity measurements

Australian National University, CI: Kirk McKenzie

We present experimental details and results for tracking the phase of a sub-10 fW optical carrier using an optimised phasemeter and cavity-stabilised lasers for future space-based interferometers.

Cindy Zhao

Precision measurement of crystalline phase transitions and carrier density mobility in low-loss single crystals

University of Western Australia, CI: Michael Tobar

Microwave properties of novel crystals at cryogenic temperature are of special interest to construct hybrid quantum systems for applications for quantum technology and test for fundamental physics. In this talk, I will present the use of whispering gallery modes, which allow precise measurements of the crystal properties at cryogenic temperatures, with the aid of finite-element simulations. Some recent progress will be presented, which includes: (a) the measurement of temperature-dependent phase transition of a single crystal strontium titanate (STO) through precision measurement of permittivity and its transition from isotropic to uniaxial anisotropy then to biaxial anisotropy as the crystal structure changes; (b) study of a new low-temperature carrier freeze-out of isotopically pure silicon-28 below 1 K; and (c) cryogenic characterisation of GaAs single crystal for potential dark matter detection.

Session 3

Rohit Navarathna

Fast data acquisition and real-time analysis using a digitiser and a GPU

University of Queensland, CI: Arkady Fedorov

Certain experiments that probe the statistical nature of quantum mechanics demand data from a large number of single-shot measurements. Such experiments require fast data acquisition and fast analysis, the latter enabling storage of less data. The importance of these requirements are evident when considering time-sensitive resources like a dilution refrigerator, or limited hard-disk space. We present a faster, cheaper, and hard-disk-friendly package for data acquisition, using a digitiser and a GPU (graphics processing unit). This combination increases our measurement rate from 50 kHz to 3 MHz. The talk will cover this in the context of generating random numbers using a superconducting qutrit. Other advantages of the GPU platform are accessibility to program and flexible data processing. I will present the data processing pipeline and showcase the features of this platform.

Dat Thanh Le

Optimisation and quasiparticle poisoning in a passive on-chip superconducting circulator

University of Queensland, CI: Tom Stace

Microwave circulators are indispensable in experiments with superconducting circuits: they perform directional signal routing and noise isolation. Their conventional designs, which employ ferrite magnets, are bulky and involve large magnetic fields, thus rendering them unsuitable for integration on superconducting chips. One promising design for a ferrite-magnet-free superconducting circulator proposed in [1] is a Josephson-junction ring which is on-chip and operates in a passive manner. In this talk, I will present some studies on such device, including semi-analytical derivation of the scattering matrix elements, optimisation of operating parameters, and effect of quasiparticle poisoning. The presented results could assist to calibrate an actual implementation of the passive on-chip superconducting circulator.

[1] C. M uller, S. Guan, N. Vogt, J. H. Cole & T. M. Stace. Passive on-chip superconducting circulator using a ring of tunnel junctions. *Phys. Rev. Lett.* 120:213602 (2018).

Leo Assis

Precise determination of photon number in real time

University of Queensland, CI: Andrew White

Superconducting transition-edge sensors are photon-number-resolving detectors with high efficiency and virtually no dark counts. Here, we present a hardware processor capable of measuring transition-edge-sensor pulse characteristics on the fly, allowing real-time photon-number-resolving measurements. Our system is shown to achieve parts-per-billion precision in the low-photon-number limit, and it can discriminate up to 16 photons. Our work is an important step towards photonic fault-tolerant quantum computing, where photon-number-resolving measurements are an essential requirement.

Session 4

Naomi Nickerson

Invited talk: Architectures for photonic quantum computing

PsiQuantum

A linear optical approach to quantum computing offers highly coherent qubits, high-fidelity single qubit gates, and probabilistic entangling operations that can be implemented using well-known quantum optical methods. The key advantage of photonic quantum computing is the fact that the required photonic chips can be produced in conventional fabrication facilities used for commercial silicon photonics, allowing scaling to achieve large-scale error correction. As a hardware platform for quantum computation, linear optics offers unique flexibility in building up topological error-correcting schemes. Some interesting examples are the long-range connectivity which is straightforward in a photonic architecture, and the ability to move qubits in temporal as well as spatial dimensions. I will discuss linear optical quantum computing and how these physical features of the photonic approach can inspire novel schemes for fault-tolerant architectures.

Juliette Soule

Bosonic error correction in topological quantum systems

University of Sydney, CI: Stephen Bartlett

Bosonic codes are emerging as a highly effective way to increase fault tolerance in quantum computing systems. This talk will explore the concatenation of bosonic rotation codes with the Raussendorf model of fault-tolerant topological quantum computing, with the aim of achieving reduced error thresholds. The main focus will include designing a decoder for the two-dimensional case which is informed by the results of homodyne measurement on the bosonic qubits, and analytically probing the accuracy of an approximation applied to the system for the purposes of numerical simulation.

Session 5

Ting Rei Tang

Improving trapped-ion quantum computers with high-precision clocks

University of Sydney, CI: Michael Biercuk

The operational workflow of a quantum information processor can be essentially simplified to a three-step process: state preparation, computation, and measurement. Improving the individual fidelities of these operations, together with increasing the qubit coherence lifetime, is imperative to the overall performance of the quantum information processor. In this talk, I will describe the use of precision clocks in both the microwave and optical frequency domains to improve the performance of a trapped-ion-based quantum information processor. First, an ultralow-phase-noise microwave synthesis system based on a cryogenic sapphire oscillator is used to improve the qubit coherence time of an ytterbium (Yb) ion qubit by an order of magnitude to about 8 seconds. Enabled by quantum engineering techniques, this system also lends itself to cross characterisation and benchmarking of clocks in the classical and quantum domains, yielding a significant speedup over traditional testing and measurement methodology. Second, an optical atomic clock transition at 411 nm via an electric-dipole-forbidden coupling is used to improve measurement fidelity for an Yb qubit. We report a measurement fidelity of 0.999996.

Tyler Neely

The gas phase of vortex matter

University of Queensland, CI: Halina Rubinzstein-Dunlop

The point-vortex approximation for two-dimensional fluid flows describes 'vortex matter', where the constituent particles are the locally swirling elements of the fluid — point vortices. These systems exhibit complex dynamics, owing to long-range interactions and bounded phase spaces, leading to exotic high-energy equilibrium states that can be described by absolute negative Boltzmann temperatures.

Similar to normal matter, chiral vortex matter, consisting of point vortices all with the same sign of circulation, can exhibit solid, liquid, and gas 'phases'. While the solid and liquid phases describe a range of phenomena in quantum fluids, such as high-temperature superconductivity, the fractional quantum Hall effect, and rotational glitches in neutron stars, the gas phase has remained experimentally elusive, as it is strongly affected by energy loss.

I will describe our ongoing experiments on the gas phase of chiral vortex matter. By using a uniform disk-shaped Bose–Einstein condensate, we experimentally realise a system of point vortices isolated from the external environment, and we have precise experimental control of the initial energy and angular momentum of the vortices. By initialising the vortices in a highly non-equilibrium configuration, we demonstrate thermalisation on experimental timescales. The vortex distributions realised are in excellent agreement with the predictions of the microcanonical ensemble.

Gerard Milburn
The advantages of quantum neural networks for machine learning
University of Queensland

All neural network learning machines are necessarily dissipative — a direct result of the activation function model of neurons — and a fast learning rate implies a large dissipation rate. The fluctuation-dissipation theorem implies that learning is necessarily a stochastic process and classical thermal fluctuations drive transitions between data labels. These go to zero as the temperature goes to zero and classical neural networks fail. However quantum neural networks continue to function at zero temperature due to quantum noise arising from spontaneous emission, tunnelling or simply the need to make measurements to implement the feedback control required to train the network. In this talk I will give some simple examples from quantum optics to illustrate the principles of quantum neural networks.

Session 6

Sascha Schediwy
Commercialisation: Commercialising fundamental physics research
University of Western Australia

In this talk, I will describe my group's efforts in commercialising our fundamental physics research on phase-stabilised, atmospheric optical-frequency transfer, by translating our technology towards commercialisable free-space optical communications products.

Specifically, I will discuss two industry-supported research projects. The first is a SmartSat CRC research project to develop coherent free-space optical communications; the second is an EQUS Translational Research Laboratory grant to demonstrate an advanced optical communications ground station.

I will outline how these technology translation efforts have resulted in benefits to my group's fundamental physics research, by providing access to funding outside the scope of traditional funding routes. For example, the optical ground station grant will provide us with the necessary infrastructure to trial quantum key distribution to an aircraft, as a stepping stone to realising a quantum link to space.

Furthermore, I note that pursuing these commercialisation pathways has led to unexpected and unique opportunities that are of genuine personal interest to me, such as the possibility of helping provide communications to support NASA's Artemis Mission to land the first woman and next man on the Moon by 2024.

Sally Shrapnel
Public good: Safety in numbers
University of Queensland

The COVID-19 pandemic has undoubtedly made it hard to do good science — it has blocked the flow of international talent, frozen research funding and kept us from our labs. In this talk I will look at some of the clinical data science being undertaken to understand this new disease. In particular, I will ask where AI fits and whether the lack of AI-driven solutions is evidence that AI in medicine has been overhyped. Along the way I will share some personal experiences from my work in two large international observational clinical studies.

David Tuckett

Open source: Sharing research software: developing for reuse and extension

University of Sydney

What happens to the software that we develop during our research? Owing to immediate time constraints, it is often poorly documented and, after a surprisingly short time, it becomes too obscure to be reused or extended, even by the original author. Given my background as a software engineer, I developed software during my PhD with reuse and extension as core design goals. As I prepare to share this software with the research community, I discuss my motivation, experience and lessons learnt, covering such topics as development practices, design principles, packaging techniques and licensing.

James Millen

Invited talk: Levitated electromechanics

King's College London

Nanoparticles suspended and cooled in vacuum are seen as ideal candidates for testing the limits of quantum mechanics, beyond state-of-the-art sensing, and tabletop detection of gravitational waves and dark matter. The standard technology involves optical trapping and levitation, although this comes with issues of optical absorption and photon scattering.

Away from the optical regime, electromechanics concerns the control of mechanical motion via its coupling to an electrical circuit. Chip-based electromechanical systems are leading quantum technologies, allowing entanglement between different circuit signals, quantum squeezing, and the coherent conversion of signals between different frequency regimes.

I will present our preliminary results in the field of levitated electromechanics, where particles are levitated, detected and controlled all-electrically. I will introduce the concept of bath engineering in this system with a preliminary study of non-equilibrium dynamics, and our work towards miniaturisation. For more information see levi-nano.com.

In addition, I will present some tactics for tailoring academic job adverts to attract a more diverse range of candidates.

Session 7

Samuel Bartee

Fast detection of Aharonov–Bohm phase with gate reflectometry

University of Sydney, CI: David Reilly

Dispersive gate sensing is a scalable and high-fidelity means of reading out the state of a qubit by locally probing shifts in the quantum capacitance using a single gate electrode. Here, we apply dispersive gate sensing to a (trivial) topological regime, where we detect Aharonov–Bohm (AB) and Altshuler–Aronov–Spivak (AAS) oscillations in a gated ring structure created in a two-dimensional electron gas. Comparing dispersive gate sensing to transport measurements shows almost identical periodicity and phase for both AB and AAS oscillations. We achieve single-shot readout of the AB phase in 55 μs. These results reinforce the viability of measurement-based topological qubits as a platform for realising a scaled-up quantum computer.

Lyra Cronin

Towards a tunable room-temperature maser in diamond

Macquarie University, CI: Thomas Volz

Nitrogen–vacancy centres in diamond are a key quantum system for developing room-temperature quantum technologies. They show promise for quantum computing and quantum control applications, and have established themselves as a prime platform for room-temperature quantum sensing. Very recently, they have also found success as a gain medium for a solid-state room-temperature maser. First proposed in 2015 and then demonstrated experimentally in 2018, this technology is at the forefront of a renewed interest in masers realised with quantum emitter systems. While there are many uses for masers alone, there are also potential applications for this system in macroscopic high-sensitivity magnetometry, and low-noise microwave amplification. This talk will present the preliminary work that has gone towards realising a tunable nitrogen–vacancy diamond maser system, increasing the sophistication of our current equipment, and give an insight as to the areas we can explore once the system is up and running.

Michael Kewming

Quantum-enhanced agents

University of Queensland, CI: Sally Shrapnel

The concept of an embodied intelligent agent is a key concept in modern AI and robotics. Physically, an agent is an open system embedded in an environment which it interacts with through sensors and actuators. It contains a learning algorithm that correlates the sensor and actuator results by learning features about its environment. The sensor–actuator system is like a measurement-based control system. Quantum mechanics enables new measurement and control protocols capable of exceeding what can be achieved classically. We demonstrate how quantum optical sensors and actuators can dramatically improve an agent's ability to learn in a thermal environment. Furthermore, we use the Jarzynski equality to show that learning maximises the exchange in free energy between the agent's sensor and actuator.

Session 8

Jacq Romero
Robust and efficient high-dimensional quantum state tomography
University of Queensland

The exponential growth in Hilbert space with increasing size of a quantum system means that accurately characterising the system becomes significantly harder with system dimension d. We show that self-guided tomography is a practical, efficient, and robust technique of measuring higher-dimensional quantum states. The achieved fidelities are over 99.9% for qutrits ($d = 3$) and ququints ($d = 5$), and 99.1% for quvigints ($d = 20$), the highest values ever realised for pure-state qudits. We demonstrate robustness against experimental sources of noise, both statistical and environmental. The technique is applicable to any higher-dimensional system, from a collection of qubits through to individual qudits, and any physical realisation, be it photonic, superconducting, ionic, or spin.

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