ANNUAL REPORT 2019

EQUS

Australian Research Council
Centre of Excellence for
Engineered Quantum Systems

EQUS acknowledges the support of the Australian Research Council

Australian Government
Australian Research Council

We also acknowledge the financial and in-kind support provided by our collaborating organisations

The University Of Queensland Australia

The University of Sydney

Macquarie University Sydney · Australia

The University of Western Australia

Australian National University

Cover image
A quiet day in the lab facilitates the creation of snowflakes from liquid nitrogen
Photo by Rohit Navarathna

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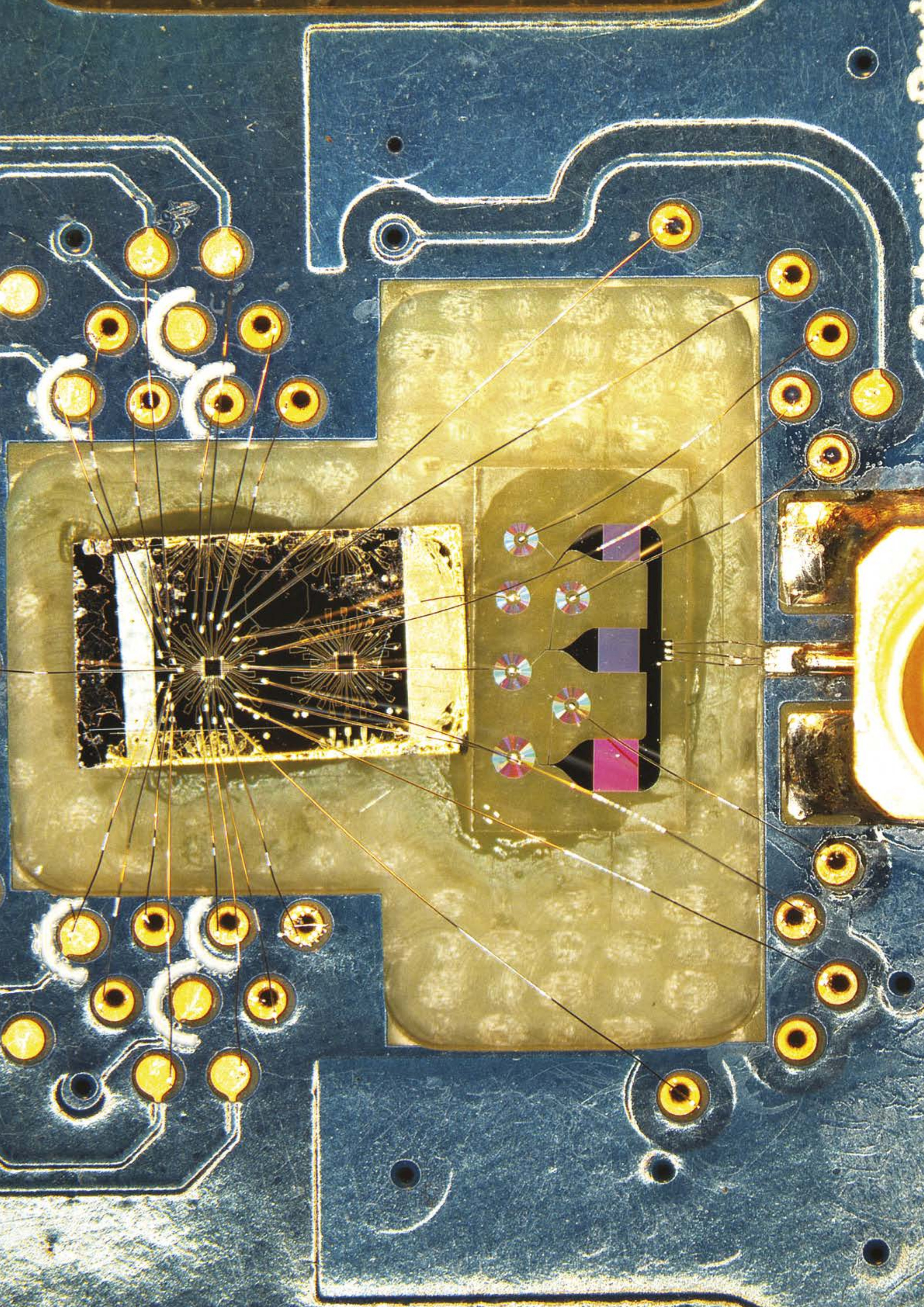
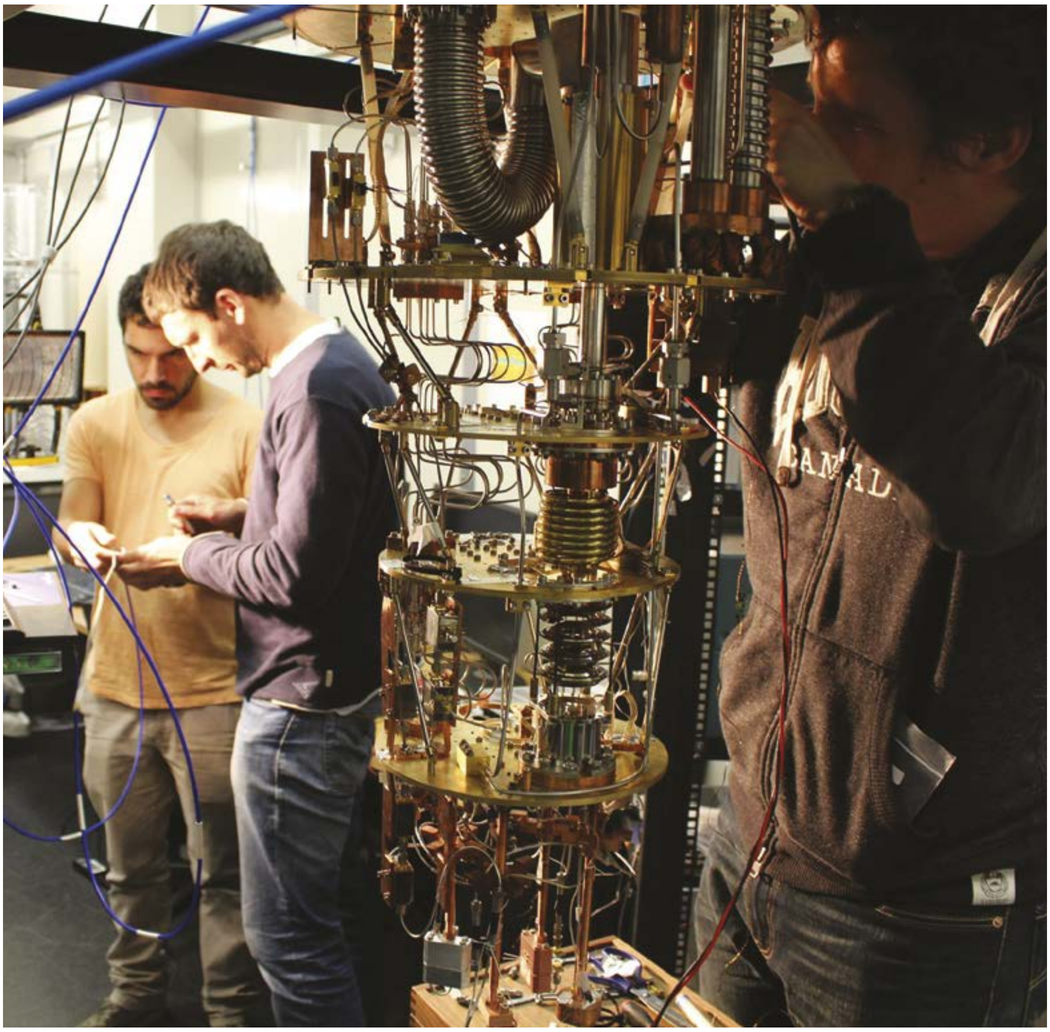


Executive summary

Quantum technologies use the properties of quantum mechanics for practical applications. Quantum technologies can be found in our everyday lives, from smart phones and cars to industrial applications in manufacturing, engineering and imaging.

Today's technology only captures a small fraction of the potential of quantum physics. New developments in research and engineering mean a new generation of technologies are being created. These technologies have potential uses in a range of fields – including health, telecommunications, and finance – and will impact across business and society as a whole.

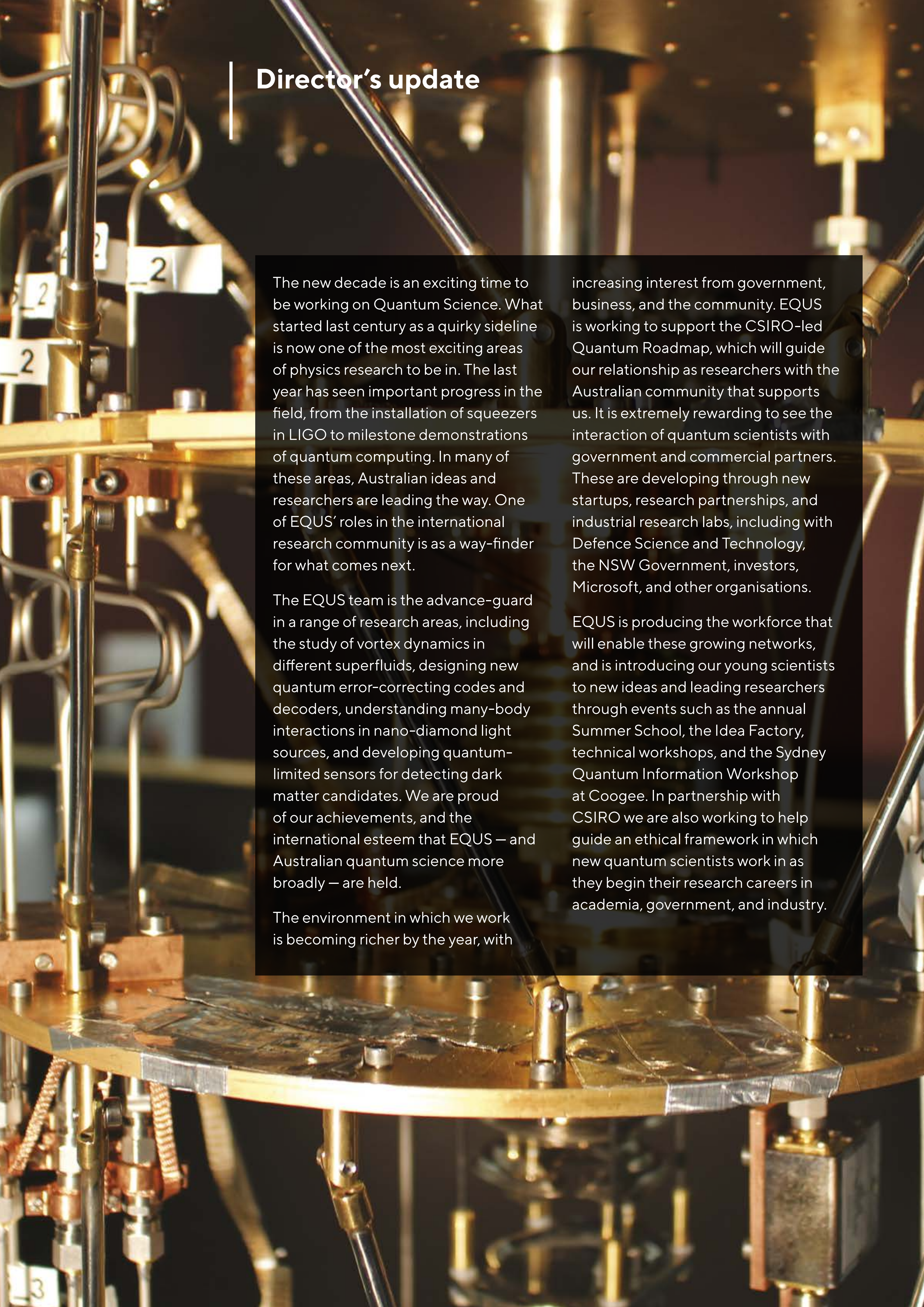
The Australian Research Council Centre of Excellence for Engineered Quantum Systems (EQUS) is a seven-year investment of over $40 million by the Australian government in quantum technologies. EQUS researchers are conducting world-leading research into building quantum machines, with programs to develop the Designer Quantum Materials, Quantum-enabled Diagnostics & Imaging, and Quantum Engines & Instruments at the heart of these machines.



Far left
CMOS bonded chip from the Quantum Nanoscience Lab

Left
Inside the Superconducting Quantum Devices Lab

Director's update



The new decade is an exciting time to be working on Quantum Science. What started last century as a quirky sideline is now one of the most exciting areas of physics research to be in. The last year has seen important progress in the field, from the installation of squeezers in LIGO to milestone demonstrations of quantum computing. In many of these areas, Australian ideas and researchers are leading the way. One of EQUS' roles in the international research community is as a way-finder for what comes next.

The EQUS team is the advance-guard in a range of research areas, including the study of vortex dynamics in different superfluids, designing new quantum error-correcting codes and decoders, understanding many-body interactions in nano-diamond light sources, and developing quantum-limited sensors for detecting dark matter candidates. We are proud of our achievements, and the international esteem that EQUS — and Australian quantum science more broadly — are held.

The environment in which we work is becoming richer by the year, with increasing interest from government, business, and the community. EQUS is working to support the CSIRO-led Quantum Roadmap, which will guide our relationship as researchers with the Australian community that supports us. It is extremely rewarding to see the interaction of quantum scientists with government and commercial partners. These are developing through new startups, research partnerships, and industrial research labs, including with Defence Science and Technology, the NSW Government, investors, Microsoft, and other organisations.

EQUS is producing the workforce that will enable these growing networks, and is introducing our young scientists to new ideas and leading researchers through events such as the annual Summer School, the Idea Factory, technical workshops, and the Sydney Quantum Information Workshop at Coogee. In partnership with CSIRO we are also working to help guide an ethical framework in which new quantum scientists work in as they begin their research careers in academia, government, and industry.

Director's update

Over the last year, the EQUS team has enjoyed a multitude of successes and new opportunities. Among the highlights are:

- The launch of the Deborah Jin Fellowship program, with our first two Fellows starting at UQ and at UWA. Welcome aboard Dr Elizabeth Bridge and Dr Cindy Zhao!
- Prestigious prizes: Prof Halina Rubinsztein-Dunlop was awarded the Officer of the Order of Australia and gave the 2019 Lise Meitner Lectures in Europe; Prof Steven Flammia won the Pawsey Medal of the Australian Academy of Science; Dr Jacquiline Romero was named as one of 15 L'Oréal-UNESCO International Rising Talents in a ceremony in Paris, and was one of two recipients of the 2019 Westpac Research Fellowship; Dr Maxim Goryachev was awarded the 2019 National Measurement Institute Prize; and last, but certainly not least, PhD researcher Riddhi Gupta won the inaugural EQUS' Director's Medal.
- The program from the EQUS Translation Research Laboratory (TRL), directed by Prof Halina Rubinsztein-Dunlop. Highlights from 2019 include the inaugural EQUS Industry Showcase, which ran in Brisbane in July, and the launch of the EQUS Equipment Register, made possible by Dr Matthew van Breugel who spent months travelling between EQUS nodes registering the 100+ pieces of kit—thank you again Matthew! TRL is now supporting an increasing number of EQUS projects, including two that participated in the ON Program run by CSIRO, and is working on a number of exciting programs over the coming year.

It is also worth taking a moment to reflect on effects of anthropogenic climate change, in the form of the unprecedented fires in Australia late in 2019, particularly in the southeast corner of the country. These were devastating, both for the people directly affected, and as a visceral shock to the wider nation. Leading up to the new year, EQUS had been working closely with the Australian Science Teachers Association to develop and deliver quantum teaching material for high-school science teachers across the nation. Unfortunately, this — and other summer science-residential programs in Canberra — were cancelled as a consequence of the smoke afflicting the area. We are grateful to ASTA for their efforts before and during the crisis, and look forward to running the program under better conditions in the future.

All the best for the year ahead...

Professor Tom Stace, Deputy-Director
Professor Andrew White, Director

Left
A close up from the Superconducting Quantum Devices Lab

Governance

SCIENTIFIC ADVISORY COMMITTEE

The Scientific Advisory Committee advises the Centre Director on the strategic direction of current and future scientific research. The Scientific Advisory Committee met at the EQUS Annual Workshop in December 2019.

Below
Professor Sir Peter Knight

The Scientific Advisory Committee consists of:

- Professor Sir Peter Knight FRS, Principal of the Kavli Royal Society International Centre, and Past-President of both the Institute of Physics and the Optical Society of America (Chair)
- Professor Alain Aspect, at the Laboratoire Charles Fabry, Institut d'Optique
- Professor Rainer Blatt, at the Institute of Experimental Physics, University of Innsbruck
- Professor John Clarke, at the Department of Physics, University of California, Berkeley
- Professor Birgitta Whaley at Whaley Research Group, University of California, Berkeley.

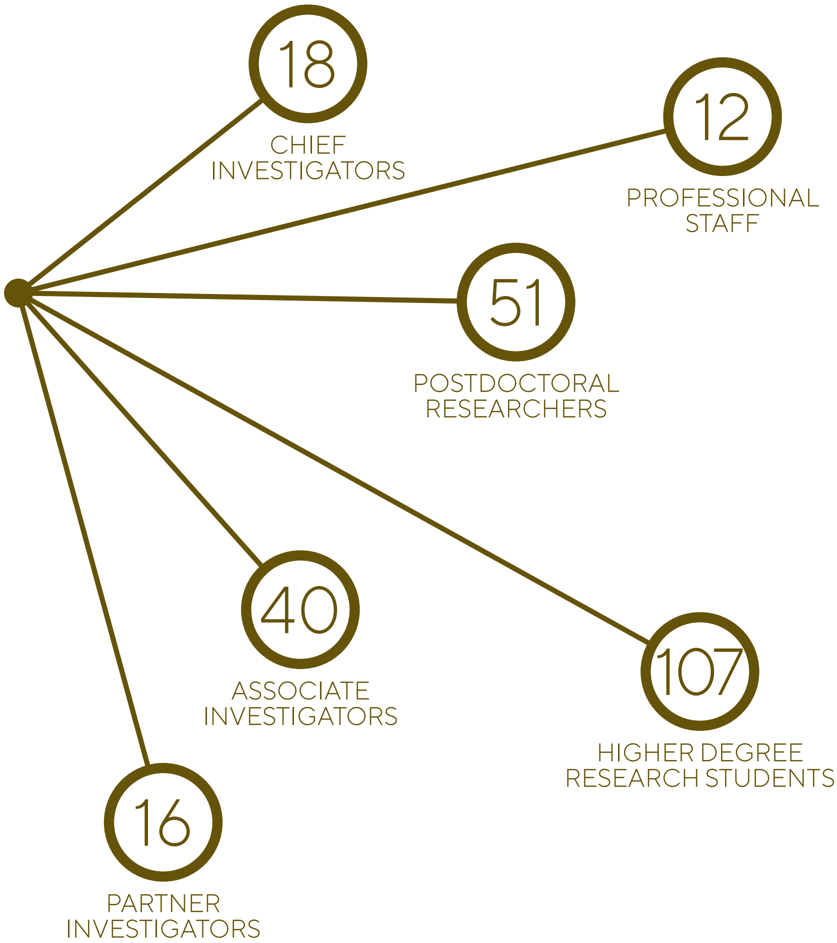
ADVISORY COMMITTEE

The Advisory Committee contributes to the development of strategies and vision for the Centre's future and supports linkages between academia, industry and government. The committee met three times in 2019.

The Advisory Committee consists of:

- Professor Vicki Sara FAA FTSE, respectively former CEO of the Australian Research Council; Director of the Australian Institute of Commercialisation; Director of the Australian Centre for Plant Functional Genomics; and Chancellor of the University of Technology Sydney (Chair)
- Dr Bronwyn Evans, CEO of Engineers Australia; former CEO of Standards Australia; Chair of the Growth Centre for Medical Technologies and Pharmaceuticals; Member of the Australia-Japan Foundation; and VP (Finance) of the International Standards Organisation, ISO
- Professor Jim Williams, former Director of the ANU Research School of Physical Sciences and Engineering; and Director of UWA, Centre for Atomic, Molecular and Surface Physics (CAMSP)
- Dr Ben Greene, the founder and CEO of Electro Optic Systems (EOS); and CEO of the Space Environment Research Centre (SERC)
- Dr Gregory J Clark AC, scientist, technologist and businessman. Currently the Chairman of KaComm Communications
- Dr Anthony P Szabo, Research Leader, Electronic Surveillance and Coordination in DST Group's Cyber and Electronic Warfare Division (CEWD).

Team

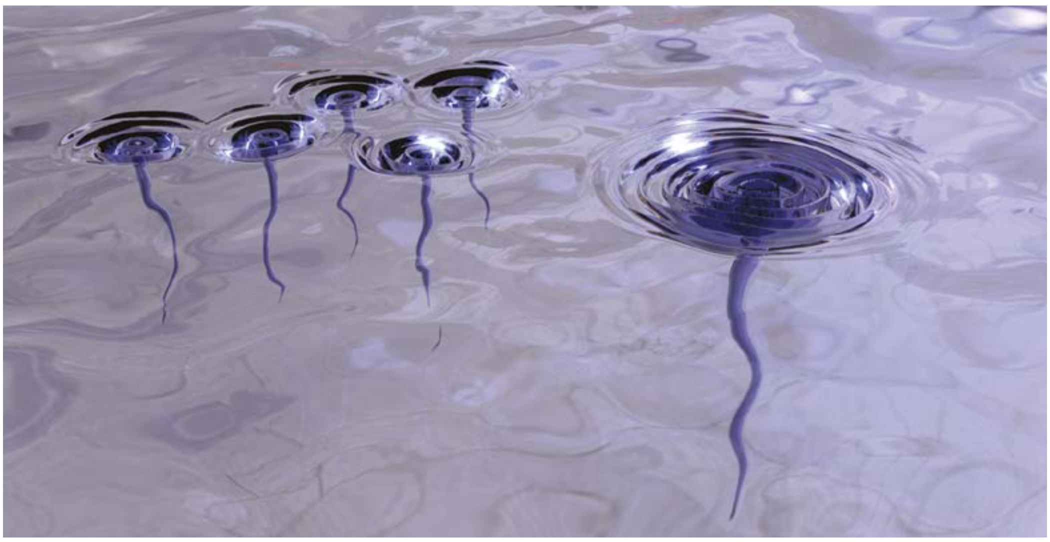


CHIEF INVESTIGATORS

Andrew White *UQ*
Tom Stace *UQ*
Stephen Bartlett *USYD*
Michael Biercuk *USYD*
Warwick Bowen *UQ*
Gavin Brennan *MQ*
Matthew Davis *UQ*
Andrew Doherty *USYD*
Arkady Fedorov *UQ*
Steven Flammia *USYD*
John McFerran *UWA*
Gerard Milburn *UQ*
David Reilly *USYD*
Halina Rubinsztein-Dunlop *UQ*
Daniel Shaddock *ANU*
Michael Tobar *UWA*
Jason Twamley *MQ*
Thomas Volz *MQ*

PROFESSIONAL STAFF

Lisa Walker *UQ*
Linda Barbour *UWA*
Angela Bird *UQ*
Christina Dobson *UQ*
Deb Gooley *USYD*
Michael Harvey *UQ*
Kellan Pomeroy *UQ*
Sareh Rajabi *ANU*
Tara Roberson *UQ*
Satpal Sahota *USYD*
Belinda Wallis MQ
Joyce Wang UQ



Left
Artist's impression of quantum vortices in a liquid. These are the quantum equivalent of vortices in water or a tornado. Their interactions with each other cause dynamics analogous to that of a cyclone.
Photo by Dr Christopher Baker

Team

POSTDOCTORAL RESEARCHERS

Paul Altin *ANU*
Marcus Appleby *USYD*
Christopher Baker *UQ*
Mark Baker *UQ*
James Bennett *UQ*
Raditya Weda Bomantara *USYD*
Ben Brown *USYD*
Adrian Chapman *USYD*
Joshua Combes *UQ*
Fabio Costa *UQ*
Terry Farrelly *UQ*
Torsten Gaebel *USYD*
Christina Giarmatzi *UQ*
Maxim Goryachev *UWA*
David Gozzard *ANU*
Arne Grimsmo *USYD*
Robin Harper *USYD*
Glen Harris *UQ*
Cornelius Hempel *USYD*
John Hornibrook *USYD*
Mattias Johnsson *MQ*
Alexis Jouan *USYD*
Kamil Korzekwa *USYD*
Cyril Laplane *MQ*
Lars Madsen *UQ*
Nicolas Mauranyapin *UQ*
Benjamin McAllister *UWA*
Nathan McMahon *UQ*
Guillermo Muñoz-Matutano *MQ*
Tyler Neely *UQ*
Marcelo Pereira de Almeida *UQ*
Lyle Roberts *ANU*
Reece Roberts *MQ*
Lachlan Rogers *MQ*
Jacqui Romero *UQ*
Arghavan Safavi *UQ*
Yuval Sanders *MQ*
Andreas Sawadsky *UQ*
Lorenzo Scarpelli *MQ*
Sally Shrapnel *UQ*
Deniz Stiegemann *UQ*
Aidan Strathearn *UQ*
Ting Rei Tan *USYD*
Matthew van Breugel *MQ*
David Waddington *USYD*
Walter Wasserman *UQ*
Till Weinhold *UQ*
James Witt *USYD*
Robert Wolf *USYD*
Wei-Wei Zhang *USYD*
Magdalena Zych *UQ*

Below
Attendees at the 2019 EQUS Annual Workshop

TECHNICAL AND SUPPORT STAFF

Peggy Atkinson *UWA*
Eric Howard *MQ*
Steven Osborne *UWA*
Ritayan Roy *MQ*
Alexander Sharp *USYD*
Yuanyuan Yang *USYD*

Team

PHD STUDENTS

Raphael Abrahao *UQ*
Nor Azwa Zakaria *UQ*
Samuel Bartee *USYD*
Christiaan Bekker *UQ*
Thomas Bell *UQ*
Thomas Boele *USYD*
Larnii Booth *UQ*
Catxere Casacio *UQ*
Jihun Cha *UQ*
Iftekher Chowdhury *MQ*
Christopher Chubb *USYD*
Ignazio Cristina *USYD*
Jovian Delaforce *UQ*
Benjamin Dix-Matthews *UWA*
Claire Edmunds *USYD*
Timothy Evans *USYD*
Graeme Flower *UWA*
Stefan Forstner *UQ*
Virginia Frey *USYD*
Guillaume Gauthier *UQ*
Jemy Geordy *MQ*
Parth Girdhar *USYD*
Kwan Goddard-Lee *UQ*
Alejandro Gomez Frieiro *UQ*
Kaumudibikash Goswami *UQ*
Hamish Greenall *UQ*
Riddhi Gupta *USYD*
Brendan Harlech-Jones *USYD*
Rob Harris *UQ*
Xin (Eric) He *UQ*
Lewis Howard *UQ*
Marie Claire Jarratt *USYD*
Angela Karanjai *USYD*
Michael Kewming *UQ*
Anatoly Kulikov *UQ*
Sarah Lau *UQ*
Miles Malone *UQ*
Christian Marciniak *USYD*
Chao Meng *UQ*
Bradley Mommers *UQ*
Leonardo Morais *UQ*
Pradeepkumar Nandakumar *UQ*
Rohit Navarathna *UQ*
Hakop Pashayan *USYD*
Sebastian Pauka *USYD*
Elija Perrier *USYD*
Jason Pillay *UQ*
Varun Prakash *UQ*
Alex Pritchard *UQ*
Mahdi Qaryan *UQ*
Kemian Qin *UQ*
Maria Quadeer *UTS*
Sarath Raman Nair *MQ*
Alexander Rischka *USYD*
Sam Roberts *USYD*
Alistair Robertson Milne *USYD*
Erick Romero Sanchez *UQ*
Andres Rosario Hamann *UQ*
Yauhen Sachkou *UQ*
Abithaswathi Muniraj Saraswathy *UQ*
Leo Sementilli *UQ*
Yasmine Sfendla *UQ*
Paul Sibley *ANU*
Thomas Smith *USYD*
Benjamin Snowdon *MQ*
Juliette Soule *USYD*
James Spollard *ANU*
Ming Su *UQ*
Natasha Taylor *UQ*
Alex Terrasson *UQ*
Dat Thanh Le *UQ*
Stefano Tomasi *USYD*
David Tuckett *USYD*
Amy van der Hel *UQ*
Harshit Verma *UQ*
Steven Waddy *USYD*
Elisabeth Wagner *MQ*
Prahlad Warszawski *USYD*
Paul Webster *USYD*
James White *MQ*
Andrew Wood *MQ*
Carolyn Wood *UQ*
Nick Wyatt *UQ*
Akram Youssry *UTS*

Team

MASTERS STUDENTS

Elrina Hartman *UWA*
Naijiao Jin *UWA*
Campbell McLauchlan *USYD*
Omar Muhieddine *MQ*
Timothy Newman *USYD*
Alan Robertson *USYD*
Nabomita Roy-Mukty *MQ*
Ignasius Setiaputra *UWA*
Mushfiq Shah *UWA*
Catriona Thomson *UWA*
Raymon Watson *UWA*
Cong Yi *UWA*

HONOURS STUDENTS

Anghad Bedi *USYD*
Jack Berry *USYD*
Juan Pablo Bonilla Ataides *USYD*
Joel Brown *USYD*
William Campbell *UWA*
Nicholas Fazio *USYD*
Joshua Guanzon *UQ*
Evan Hockings
Martin Arlette Giselle Illing-Kelly *USYD*
Jacob Ma *UWA*
Ben Macintosh *USYD*
Callam Manning *UQ*
Matthew O'Brien *USYD*
Aaron Quiskamp *UWA*
Mackenzie Shaw *USYD*
Samuel Smith *USYD*
Stefanus Edgar Tanuarta *USYD*
Felix Thomsen *USYD*
Katie Ward *ANU*

NEW STUDENTS' THESIS TITLES

PHD

Dat Thanh Le
Superconducting circuits

Mahdi Qaryan
Quantum information

Alexander Rischka
Quantum information

Abithaswathi Muniraj Saraswathy
Many-body quantum engines with ultracold gases

Leo Sementilli
Precision sensing with dissipation engineered nanomechanical devices

Alex Terrasson
Quantum bio-sensing using optical tweezers

Amy van der Hel
Distribution of microwave entanglement

Harshit Verma
General relativistic effects in quantum systems

Elisabeth Wagner
Quantum cellular automata in spin lattices

James White
Optofluidic sorting of fluorescent nanodiamonds

MASTERS

Cong Yi
Performance limits of a synchronous frequency-to-voltage converter

HONOURS

Anghad Bedi
Foundational issues of quantum mechanics

Jack Berry
Foundational issues of quantum mechanics

Team

Juan Pablo Bonilla Ataides
Theoretical quantum physics

Nicholas Fazio
Quantum information theory

Joshua Guanzon
Quantum error correction for quantum computation

Evan Hockings
Quantum information theory

Martin Arlette Giselle Illing-Kelly
Theory of quantum computing

Callam Manning
Ultracold atom optics

Mackenzie Shaw
Theory of quantum computing

Katie Ward
Continuous-wave light detection and ranging (LiDAR) for advanced perception in autonomous applications

PARTNER INVESTIGATORS

Markus Aspelmeyer *University of Vienna*
Alexia Auffeves *Institut Néel*
Alessandro Fedrizzi *Herriot-Watt University*
Fedor Jelezko *Ulm University*
Holger Mueller *UC Berkeley*
Wolfram Pernice *Universität Münster*
Oriol Romero-Isart *IQOQI*
Jörg Schmiedmayer *TU Wien*
Pascale Senellart-Mardon *CNRS*
Robyn Starr *CNRS*
Lorenza Viola *Dartmouth College*
Andreas Wallraff *ETH Zürich*
Ian Walmsley *University of Oxford*
Peter Wolf *CNRS*
Michael Wouters *National Measurement Institute*
Peter Zoller *IQOQI*

ASSOCIATE INVESTIGATORS

Alain Aspurru-Guzik *University of Toronto*
Ben Baragiola *RMIT University*
Daniel Burgarth *MQ*
Robert Casson *University of Adelaide*
Joshua Combes *UQ*
Chris Ferrie *University of Technology, Sydney*
Victor Flambaum *University of NSW*
Alexei Gilchrist *MQ*
Jacinda Ginges *UQ*
Jonathan Home *ETH Zürich*
Samantha Hood *Imperial College, London*
Michael Hush *USYD*
Ivan Kassal *USYD*
Nicholas King *USYD*
Nathan Langford *University of Technology, Sydney*
Joan Leach *ANU*
Lawrence Lee *University of NSW*
Peter Lodahl *University of Copenhagen*
Lute Maleki *OEwaves Inc.*
Ian Manchester *USYD*
Felix Miranda *NASA*
Kavan Modi *Monash University*
Clemens Muller *ETH and IBM, Zürich*
William Munro *NTT Basic Research Laboratories*
Kae Nemoto *NII Tokyo*
Jennifer Ogilvie *University of Michigan*
Sujatha Raman *ANU*
Markus Rambach *UQ*
Maxime Richard *CNRS*
Martin Ringbauer *University of Innsbruck*
Jacqui Romero *UQ*
Terence Rudolph *Imperial College, London*
Yuval Sanders *MQ*
Sascha Schediwy *UWA*
Salah Sukkarieh *USYD*
Marco Tomamichel *University of Technology, Sydney*
Behnam Tonekaboni *Griffith University*
Michael Vanner *Imperial College, London*
Jingbo Wang *UWA*
Matt Woolley *University of NSW*

Life after EQUS

COMPLETIONS

HONOURS

Joel Brown
Joshua Guanzon
Matthew O'Brien
Ben Macintosh
Samuel Smith
Stefanus Edgar Tanuarta
Katie Ward

POSTGRADUATE STUDIES

Thomas Bell
Christopher Chubb
Claire Edmunds
Graeme Flower
Virginia Frey
Xin (Eric) He
Marie Claire Jarratt
Naijiao Jin
Angela Karanjai
Christian Marciniak
Campbell McLauchlan
Hakop Pashayan
Sebastian Pauka
Reece Roberts
Sam Roberts
Alan Robertson
Yuchen Sachkou
Ignasius Setiaputra
Mushfiq Shah
Natasha Taylor
Stefano Tomasi
David Tuckett
Raymon Watson

PROFILES

Dr Behnam Tonekaboni

Griffith Centre for Quantum Dynamics

After completing his PhD, Dr Behnam Tonekaboni moved to Griffith University to work as a postdoctoral research fellow in the Centre for Quantum Dynamics.

Katie Ward

Microsoft

Katie Ward completed her honours at EQUS in 2019 and has since been employed at Microsoft as a Cloud Solution Architect.

Dr Kamil Korzekwa

Jagiellonian University, Krakow, Poland

After completing his postdoctoral research fellow, Dr Kamil Korzekwa joined the Jagiellonian University in Krakow, Poland as a Junior Group Leader.

Dr Jeremy Bourhill

IMT Atlantique, France

After completing his postdoctoral research fellow, Dr Jeremy Bourhill moved to IMT Atlantique in France where he is a Research Associate.

Life after EQUS

ALUM UPDATE

DR SAMANTHA HOOD

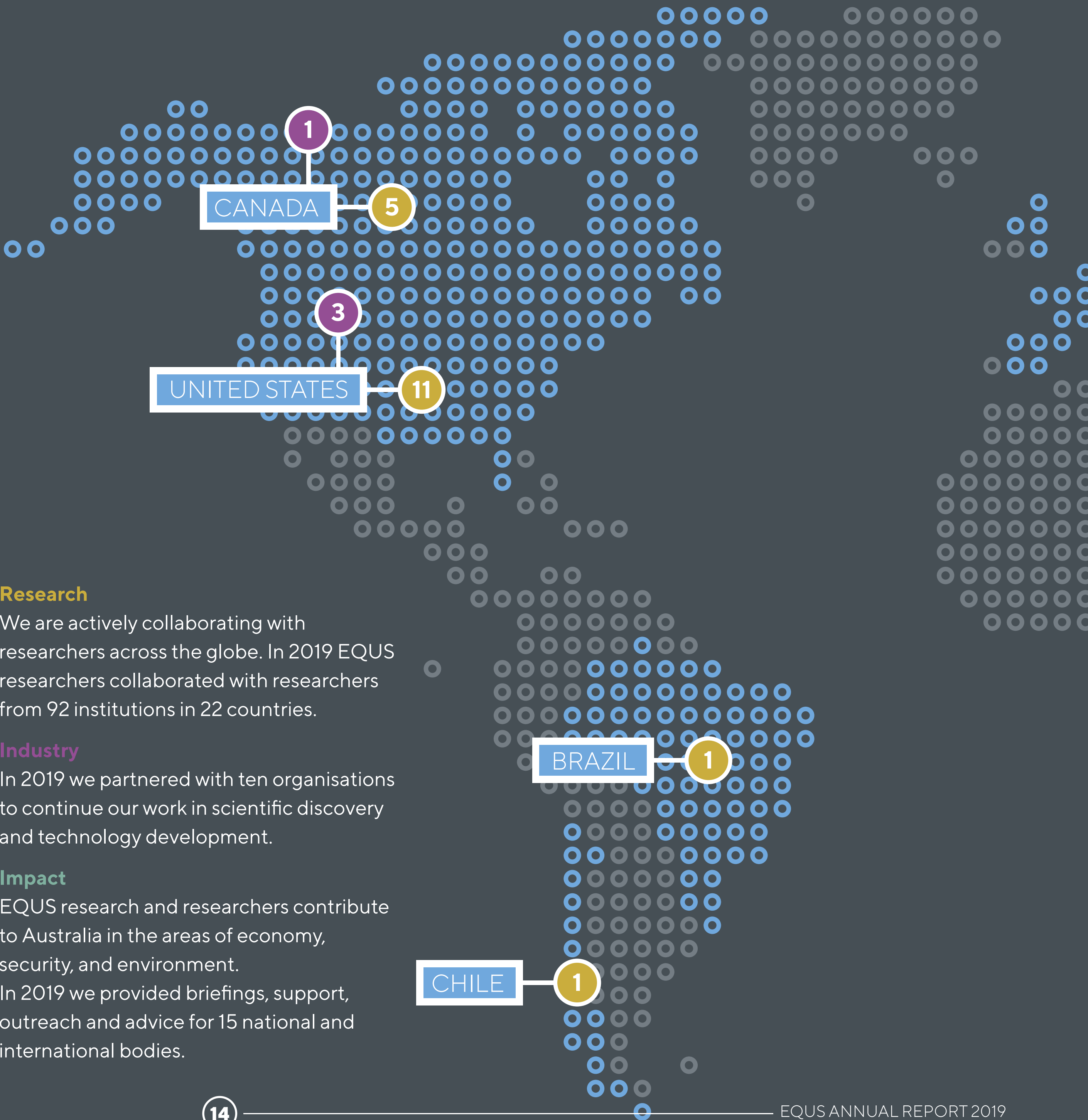
Samantha is a postdoctoral researcher in the Materials Design Group at Imperial College London designing new, sustainable materials for thin-film solar technology. In particular, she is searching for earth-abundant materials with the ability to absorb sunlight and efficiently transport charges to generate electricity.

Her PhD (with the Kassal Group at EQUS) was focussed on charge separation in organic solar cells (OSCs). OSCs are flexible, light-weight and cheaper to produce than conventional solar panels, but they are not yet efficient enough for large scale applications. Samantha developed a model to solve a long-standing puzzle in this field, explaining how charges can separate in these devices given that they ought to be strongly bound.

Samantha's work could also shed light on the mechanics of photosynthesis, as well as provide important foundations for emerging quantum technology. In 2017, she was recognised as an "Australian Science Superhero" by Australia's Chief Scientist for her work in this field as well as her passion for science communication and advocating for women in STEM.

Collaborators

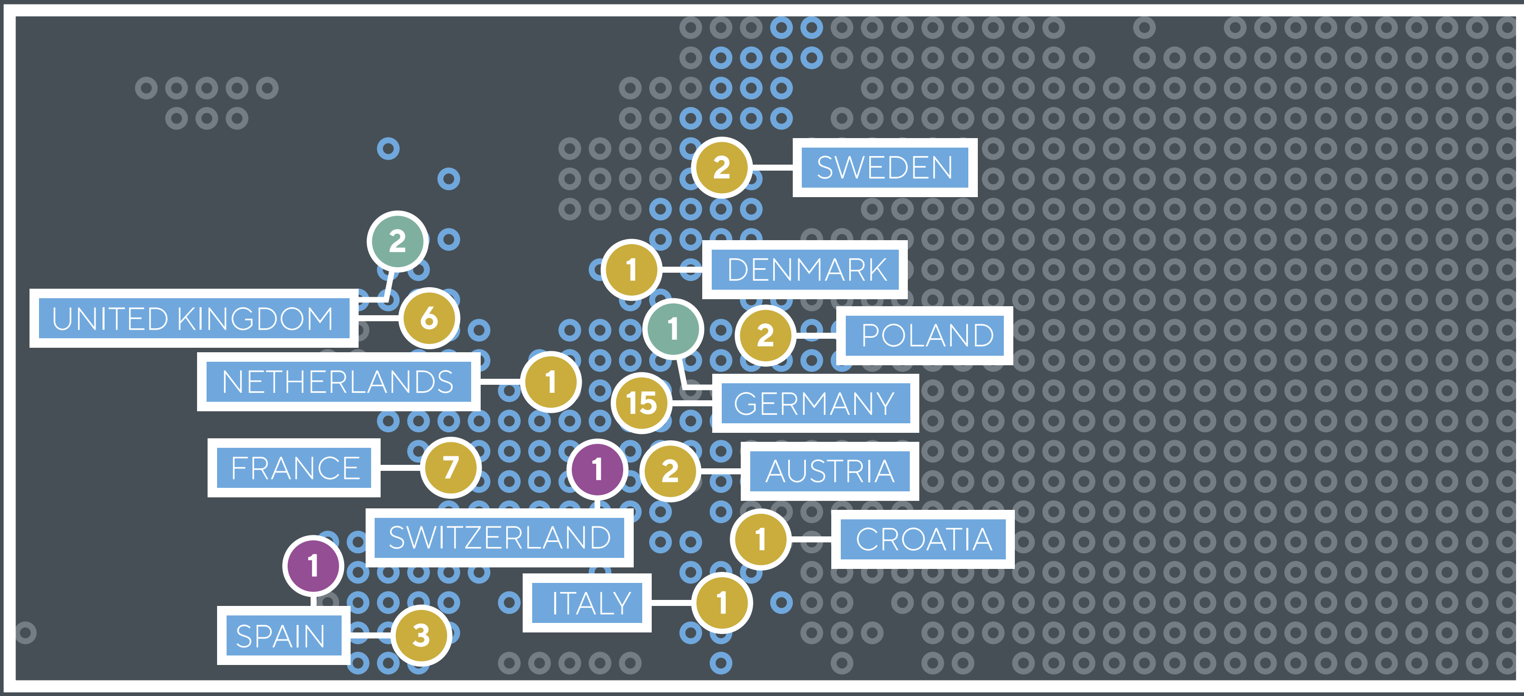
EQUS is continuously developing national and international connections to foster a world-leading research community and drive the development of quantum machines through collaborations with industry and society at large.



Research
We are actively collaborating with researchers across the globe. In 2019 EQUS researchers collaborated with researchers from 92 institutions in 22 countries.

Industry
In 2019 we partnered with ten organisations to continue our work in scientific discovery and technology development.

Impact
EQUS research and researchers contribute to Australia in the areas of economy, security, and environment.
In 2019 we provided briefings, support, outreach and advice for 15 national and international bodies.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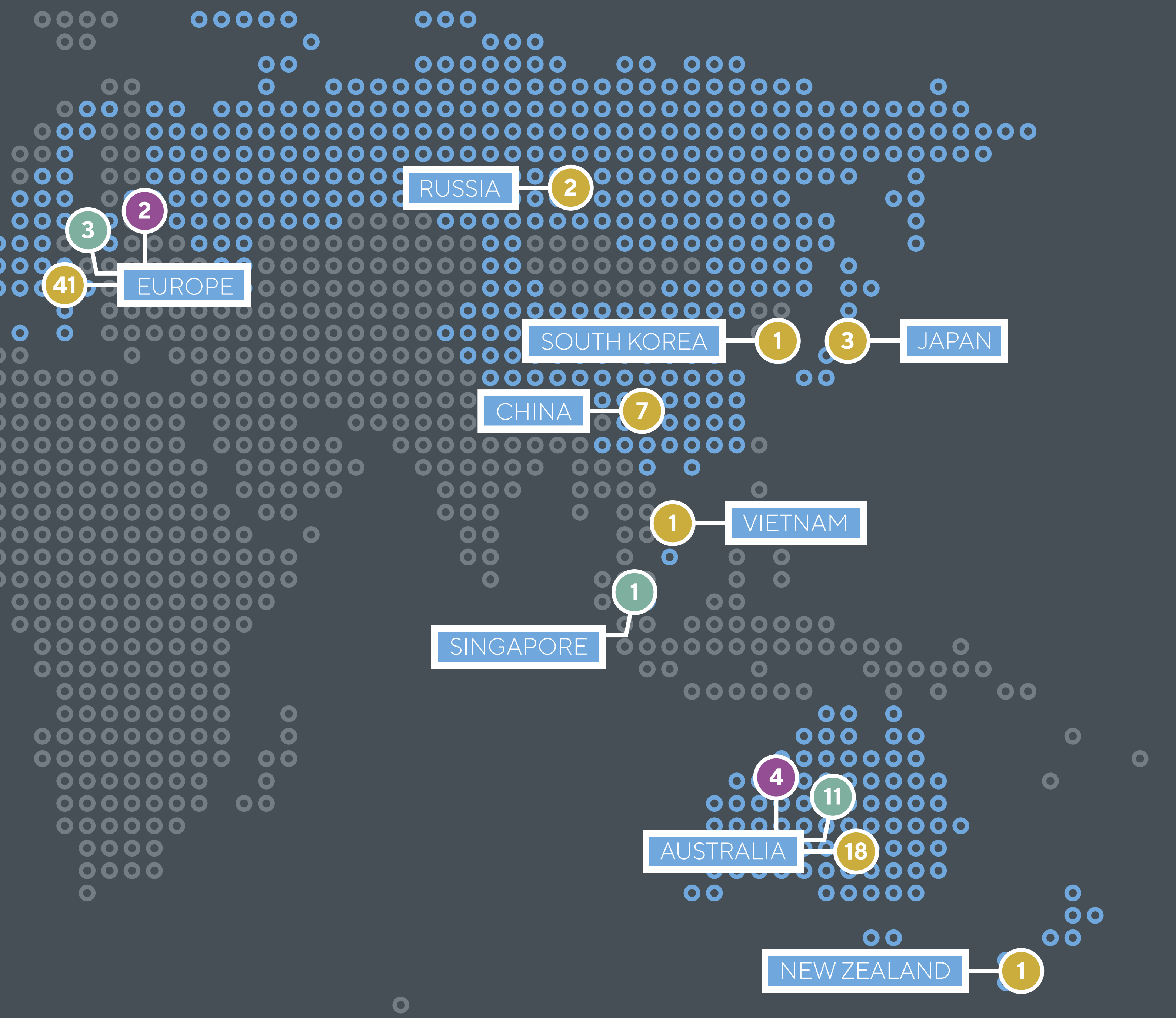
ITALY 1
SPAIN 1 3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EUROPE 3 2 41
SOUTH KOREA 1
JAPAN 3
CHINA 7
VIETNAM 1
SINGAPORE 1
AUSTRALIA 4 11 18
NEW ZEALAND 1

2019 highlights

GROWING AUSTRALIA'S QUANTUM TECHNOLOGY INDUSTRY

The discussion paper can be viewed at **research.csiro.au/quantum/discussion-paper**

Following on from the Parliamentary Friends of Science held in November 2018 by EQUS and Science and Technology, Australia, CSIRO has worked with stakeholders across Australia to produce a discussion paper on developing a quantum technology industry.

The discussion paper summarises findings from initial consultations and desktop research. It describes the challenges and opportunities related to advancing the Australian quantum technology sector.

A national strategy for quantum technologies is due to launch in 2020.

QUANTUM TECHNOLOGY MASTERS DEGREE LAUNCHES

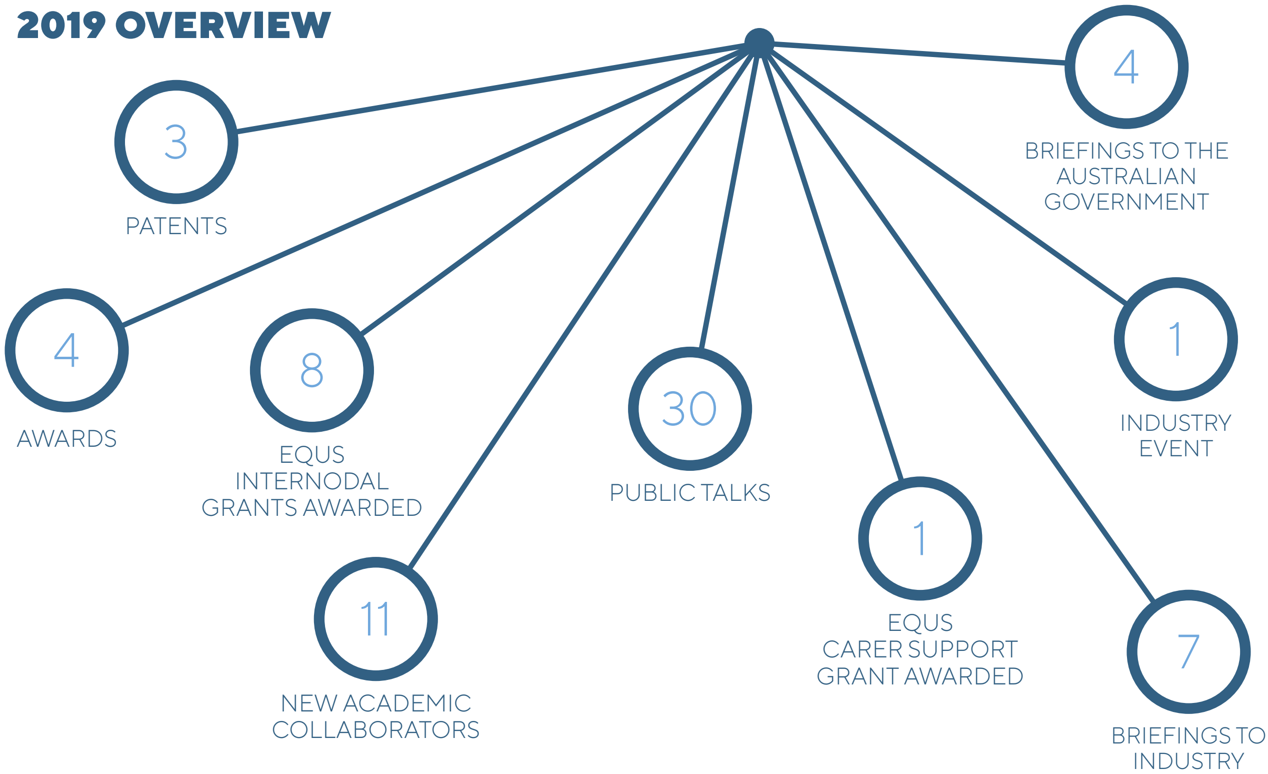
An exciting new quantum technology program launched in 2019 as Microsoft, Google, IBM and other companies clamber for qualified talent.

The University of Queensland's Master of Quantum Technology began enrolling students from mid-2019, preparing them for highly-skilled, highly-paid positions.

EQUS Chief Investigator Tom Stace said the introduction of the course was timely, given quantum physics had grown from an almost exclusively university-based field to a booming commercial industry.

The program combines lecture-based theory featuring research projects in leading experimental labs, with an emphasis on high-tech experiments with cryogenics, superconductors, quantum gases, quantum optics and quantum optomechanics.

2019 OVERVIEW



2019 highlights

EQUS LAUNCHES DEBORAH JIN FELLOWSHIPS

Deborah S Jin was a brilliant American physicist who was one of the world's foremost experts on how ordinary atoms and molecules change their behaviour at extraordinarily low temperatures.

Her visionary and methodical approach made it possible to use these ultracold gases as model systems to tease out the quantum principles that lead to behaviours in real materials, such as superconductivity.

The EQUS Deborah Jin Fellowship honours her legacy by supporting and encouraging early-and mid-career women physicists. Two new fellows will commence in 2020.

Left
Masters students Jemy (far left) and Nabomita receive awards for their work

SYDNEY QUANTUM ACADEMY

The NSW Government announced support for the establishment of a new Sydney Quantum Academy with $15.4 million in funding, bringing together four leading universities in NSW. These include two EQUS partner organisations: Macquarie University and the University of Sydney.

The Sydney Quantum Academy will help train the next generation of engineers and scientists in quantum computing, cementing Sydney's place as the leading global city for quantum technology and ensuring NSW is a world centre for jobs in the emerging quantum economy.

The funding, combined with current university and future industry support, means the total investment in the Sydney Quantum Academy will be up to $35 million.

Above
The Sydney Quantum Academy is a collaboration of four NSW universities

2019 highlights

PRIMARY CARER SUPPORT AWARDS

EQUS recognises that many students and researchers have caring responsibilities that may limit their access to opportunities for the development of their careers. In 2018 EQUIP established a new program to help primary carers with the cost of carer management while pursuing their careers.

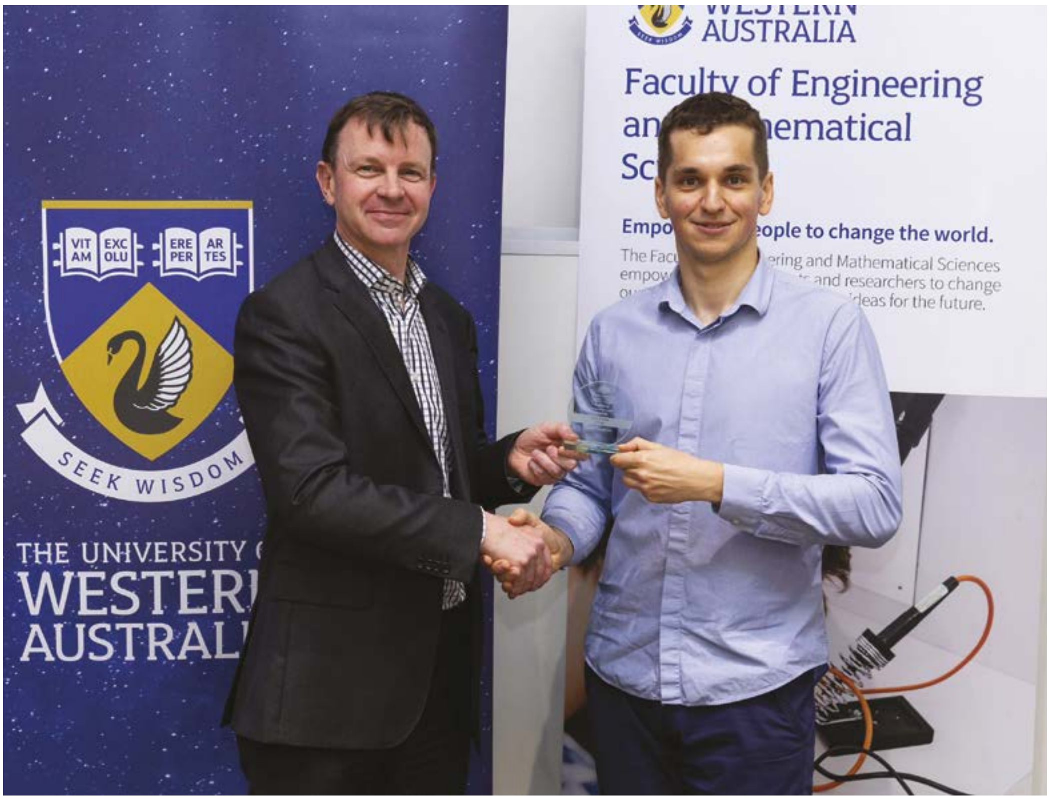
Angela Karanjai, a PhD student awarded the Primary Carer Award, said "The EQUS Primary Carer Award has greatly helped my family and me. It has allowed me the freedom to choose to stay home to look after my daughter in her first few months and made going back to work more manageable."

Right
Welcome Maya
#teamEQUS

EQUS POSTDOCTORAL FELLOW WINS 2019 NMI PRIZE

The National Measurement Institute Prize recognises outstanding achievement in the field of measurement.

EQUS researcher Dr Maxim Goryachev was awarded this prize for his PhD work on low loss acoustical cavities: from solid state to fundamental physics.



Right
Dr Maxim Goryachev receives the NMI award

2019 highlights

EQUS ASSOCIATE INVESTIGATOR AWARDED WESTPAC SCHOLARS FELLOWSHIP

Physicist Dr Jacqui Romero was awarded a Westpac Scholars Research Fellowship to advance the development of revolutionary data privacy systems.

Romero, an EQUS Associate Investigator and former EQUS postdoctoral fellow, is seeking to use quantum physics to secure future communications systems using a 'quantum alphabet' made from different shapes of light.

This was Dr Romero's second award in 2019. She was also one of 15 women worldwide to be named a L'Oréal-UNESCO International Rising Talent.

Left
EQUS Associate Investigator Dr Jacqui Romero

EQUS CHIEF INVESTIGATOR AWARDED PAWSEY MEDAL

The Australian Academy of Science Pawsey Medal recognises outstanding research in physics.

Chief Investigator Steven Flammia was awarded the 2019 medal for his work bringing together the classical theory of compressed sensing with quantum tomography.

By marrying the classical theory of compressed sensing with quantum tomography, CI Flammia's work has succeeded in drastically reducing the number of measurements required to learn the types of quantum states and processes commonly found in laboratory experiments aimed at building scalable quantum computers.

This work is significant as, firstly, it has had a real practical impact, with numerous experiments already performed that show the advantages of his new approach and, secondly, the methods introduced have had an impact beyond physics in the machine learning community where the idea of compressed sensing originated.

Below
A glowing pile of diamonds
Photo by Dr Lachlan Rogers

2019 highlights

CENTRE PRIZES

In 2019, the EQUS Director's Prize for Exceptional Contributions to the Centre was awarded to PhD researcher Riddhi Gupta.

Right
Riddhi Gupta

This award recognises the EQUS researcher or team that has contributed most to the Centre as a whole. This might be through the Centre-wide activities, enriching the research culture of the Centre, or a combination of both.

The nomination for Riddhi said that she "exemplifies what EQUS is all about".

"Riddhi is an excellent scientist who champions a better research community. Riddhi's work this year on autonomous learning applied to quantum systems has inspired new research directions. Her April paper introduced a framework that can identify regions within a device that share common noise and then adapts future measurements to reduce uncertainty, resulting in three times fewer measurements overall in a confirmatory experiment.

Later in the year, Riddhi formalised her learning framework in another paper, making direct links to classical engineering theory and providing a path for future research efforts. This work is being actively used in the Centre.

Riddhi brings her original insights to bear on difficult problems. For example, she initiated the EQUS Webinar series to help Centre members more regularly communicate our science to each other. She has brought her considerable nous to bear in EQUS Portfolios, asking penetrating questions on what it is the Portfolio team wish to achieve, and following up by providing clever techniques and tools.

Riddhi is constantly thinking of new ways to make EQUS a better Centre. She listens, leads, and inspires!"

2019 highlights

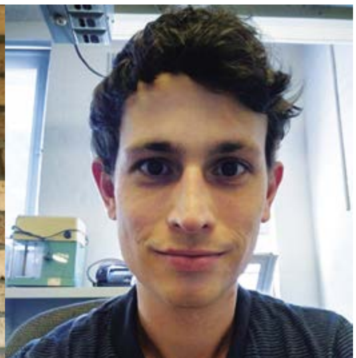
Above
#teamEQUS gathers for our Annual Workshop

At the Annual Workshop, prizes were also awarded for posters presented in the poster session. The recipients were:

PhD recipients

1st place
CLAIRE EDMUNDS

2nd place
SAM BARTEE



3rd place
BRAD MOMMERS

Postdoc recipients

1st place
REECE ROBERTS

1st place
DENIZ STIEGEMANN

Centre strategy: Update

OUR MISSION

is to engineer the quantum future.

OUR VISION

is to conduct world-leading research to exploit the potential of quantum science and develop a range of transformational technologies that will benefit society.

1 BUILDING QUANTUM MACHINES BY ENGINEERING MULTI-COMPONENT QUANTUM SYSTEMS

2019 ACHIEVEMENTS

Experimental and theoretical work in the Designer Quantum Materials theme saw numerous successes (pages 28-33).

Our national and international research collaborations continued to build (pages 14-15).

2020 PLANS

Research to advance the Centre's theoretical and experimental goals (pages 50-53).

Centre researchers made significant progress across the full span of the Quantum-enabled Diagnostics and Imaging program (pages 36-41).

2 DEVELOPING PRACTICAL QUANTUM TECHNOLOGIES WITH SOCIETAL IMPACT

2019 ACHIEVEMENTS

Our first industry showcase ran in July 2019. The Translation Research Laboratory is building on this momentum with exciting new initiatives (pages 54-55).

The Idea Factory provided training in entrepreneurship, innovation and collaboration to EQUS and FLEET attendees (page 62).

2020 PLANS

Collaboration with CSIRO in Responsible Innovation is underway following the launch of the CSIRO Quantum Technologies Roadmap for Australia.

Training in communication and collaboration to help translate discoveries into social and economic benefits.

Centre strategy: Update

3 GROWING AUSTRALIA'S WORLD-LEADING RESEARCH COMMUNITY IN QUANTUM ENGINEERING

2019 ACHIEVEMENTS

Our Mentoring and Career Development Committee supported EQUS postdocs and students through our mentoring program and Summer School (page 60 & 63).

Our Equity in Quantum Physics Committee ran events and launched the Deborah Jin Fellowship (page 56).

2020 PLANS

Industry engagement targeted to Sydney, NSW and a Centres of Excellence industry event at the biennial Australian Institute of Physics conference in Adelaide.

Diversity and inclusion training for all EQUS students and researchers.

4 TRAINING A NEW GENERATION OF VERSATILE AND KNOWLEDGEABLE QUANTUM ENGINEERS

2019 ACHIEVEMENTS

Our Translation Research Committee launched a Centre-wide equipment register to facilitate access to world-class technologies and capabilities (pages 54-55).

A graduate program to support technical capabilities and build capacity was launched at EQUS' University of Queensland node (page 16).

2020 PLANS

Additional funding to support collaborations between EQUS nodes and partner investigators through the Mentoring and Career Development committee.

Collaboration with science teachers to provide curriculum-aligned content on quantum physics for classrooms around Australia.

Research overview

EQUS is building sophisticated quantum machines to harness the quantum world for practical applications. Our research is evenly split between theoretical advances and experimental developments, in seven different physical architectures: neutral atoms, superconducting electronics, trapped ions, optomechanics, photonics, polaritonics and quantum dots.

Our research is conducted in three programs:

1. the **Designer quantum materials** program, to create new phases of quantum matter from which quantum machines can be built;

2. the **Quantum-enabled diagnostics and imaging** program, to develop prototypes of the sensing and imaging components required for a quantum machine to interact with their environment; and

3. the **Quantum engines and instruments** program, to develop understanding of quantum engines and instruments so that we can design and manipulate quantum machines that have tens or hundreds of individual components.

Research programs

EQUS research is organised around carefully crafted research themes and individual projects

Research Program 1
DESIGNER QUANTUM MATERIALS

Research Program 2
QUANTUM-ENABLED DIAGNOSTICS AND IMAGING

Research Program 3
QUANTUM ENGINES AND INSTRUMENTS

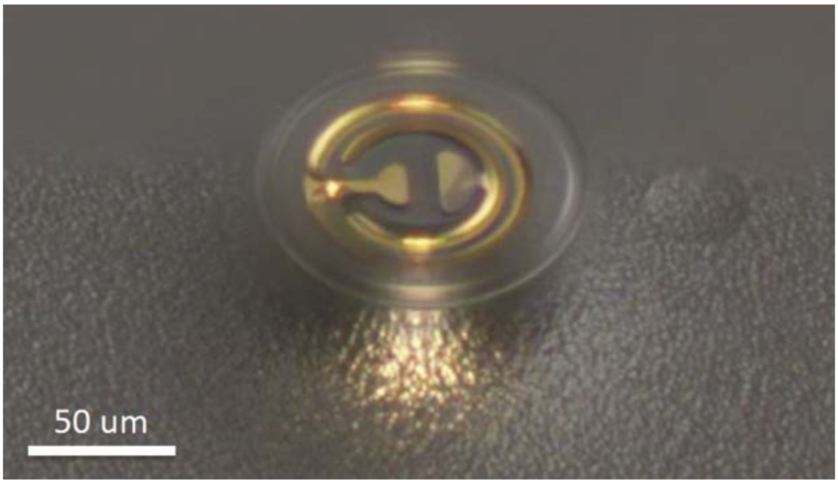
DESIGNER QUANTUM MATERIALS

This program aims to realise new phases of quantum matter by scaling up today's isolated quantum components and engineering highly-entangled, strongly-interacting quantum systems with individual control and measurement of each component.

Research Program 1

QUANTUM PHOTONICS AND POLARITONICS

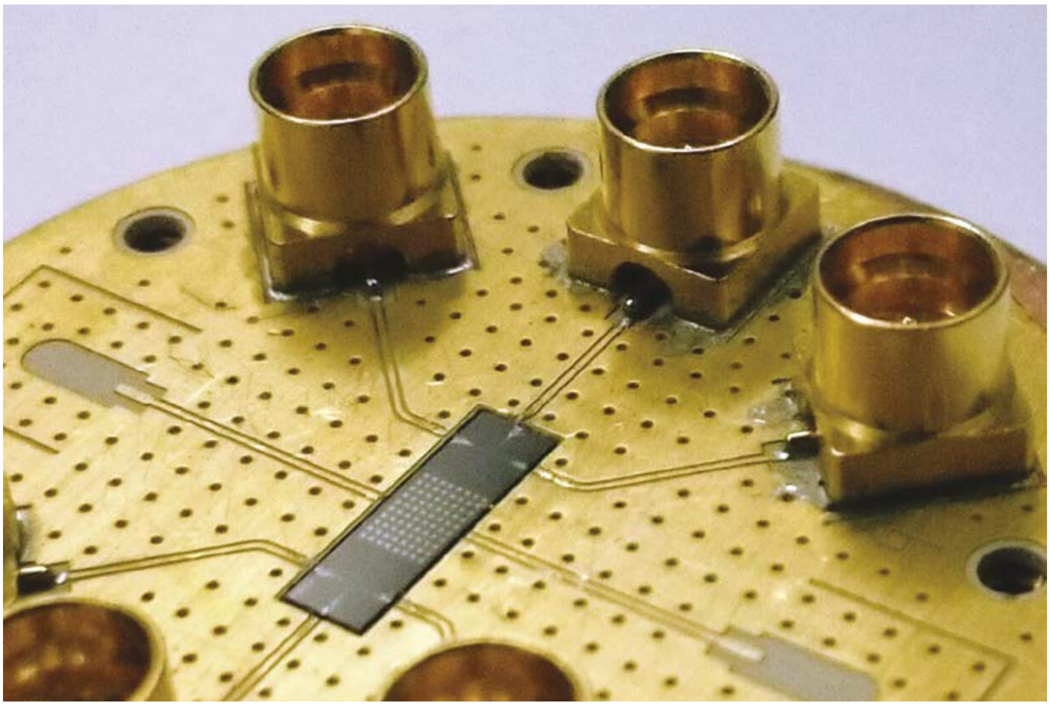
Chief Investigator Volz's lab had numerous successes in this program in 2019, following on from the publication early this year of their key result in *Nature Materials*[1]. A key achievement was significant progress on quantum correlated photons from our fibre-cavity system under off-resonant pumping. Experiments were undertaken with improved photon frequency filtering, both in pulsed and continuous pumping mode. The group installed new high-resolution electronics with their SSPDs and are now able to reach a jitter in autocorrelation measurements of around 20ps with single-detector quantum efficiency > 90%. Further, they have built a new independent confocal system that enables zero-delay calibration with a quantum emitter.



In Centre Director Andrew White's lab, researchers have used machine-learning control of pump-energy to optimise the quantum properties of single-photon sources, specifically multiphoton suppression and photon indistinguishability.

Above
Superfluid optomechanics in quantum

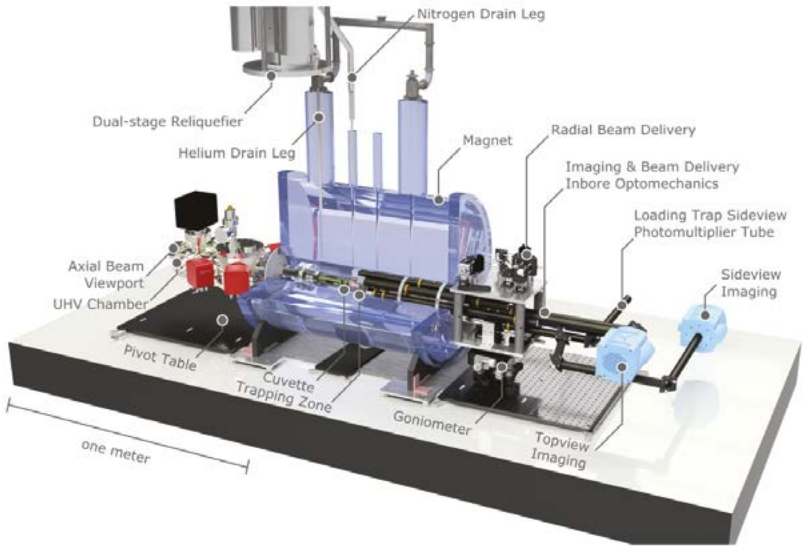
Right
Inside the quantum nanoscience lab



1 G Muñoz-Matutano *et al.* *Nature Materials* 18, 213–218 (2019)

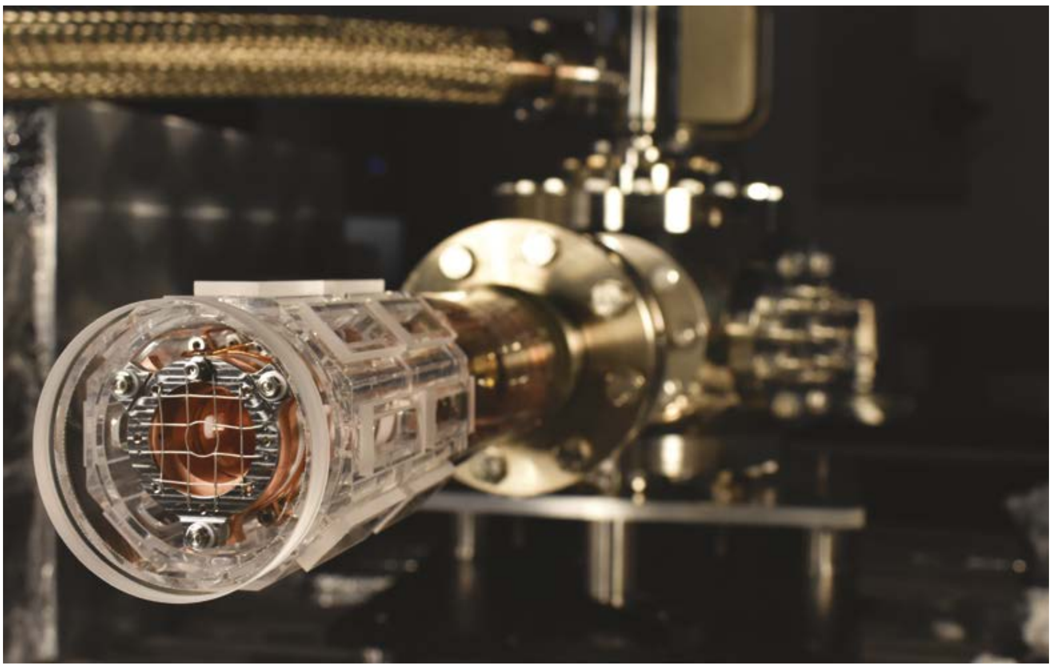
TRAPPED IONS

Chief Investigator Biercuk's team implemented advanced control techniques using trapped ions leading toward novel quantum simulation experiments. This work is carried out across two distinct experimental platforms, each of which gives unique advantages. First, a Penning-trap system allows the realisation of two-dimensional ion crystals for studies of magnetic frustration and the dynamics of entangled systems. The experiment saw major progress in the commissioning of the Penning trap apparatus for large-scale quantum simulations[1]. Second, a linear Paul trap provides capabilities demonstrated to enable novel forms of quantum simulation for chemical structure and dynamics. With the Paul trap system, the laboratory has focused on the establishment of novel tools and critical infrastructure for the realization of quantum simulation of chemistry using trapped ions. Specifically, they have focused on problems in chemical dynamics, rather than traditional studies of ground-state energies.



Above
Experiment overview

Below left
Vacuum system assembly



1 H Ball, ChD Marciniak, RN Wolf, AT-H Hung, K Pyka and MJ Biercuk *Review of Scientific Instruments* 90, 053103 (2019)

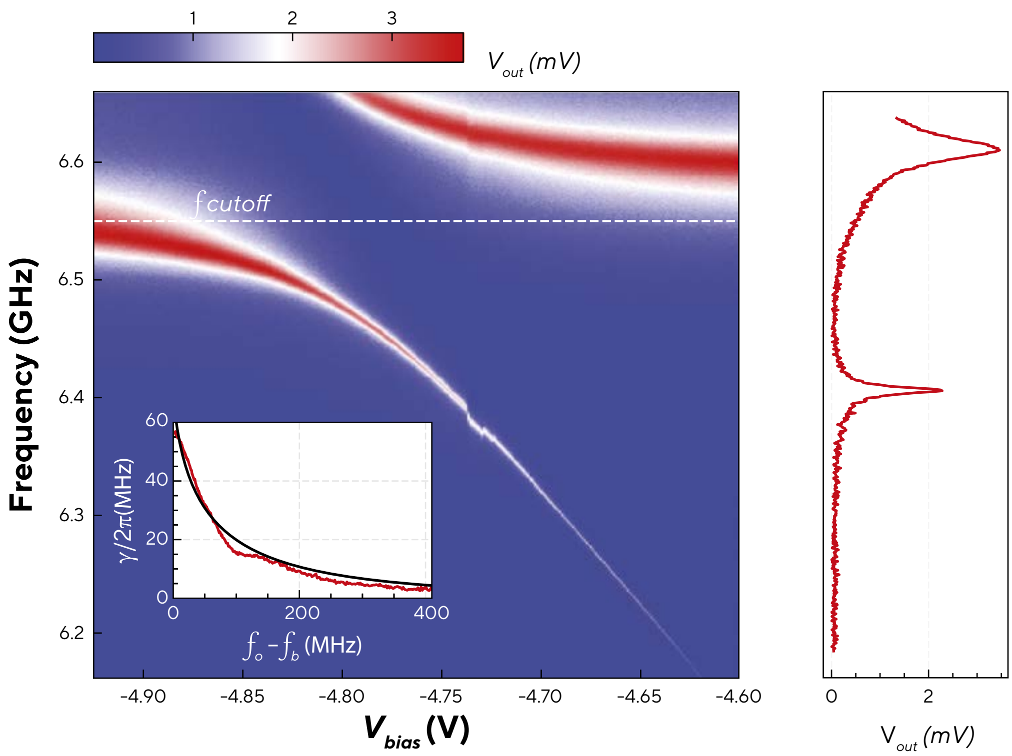
CIRCUIT QED

Chief Investigator Fedorov's team observed bound states of a photon with single and pairs of transmon qubits inserted in a three-dimensional rectangular waveguide, which naturally exhibit low-frequency cut-off. Within the stopband, where the density of states is zero, no travelling modes are allowed through the waveguide. However, evanescent modes, exponentially localised around the atoms' position can give rise to atom-photon bound states as theoretically predicted in 1991 and experimentally observed in a photonic crystal configuration on a chip in 2017. Chief Investigators Fedorov and Stace developed an experimental effort to fabricate and measure an on-chip microwave circulator, based on Stace's earlier theoretical work.

QUANTUM DOT SPIN QUBITS AND SCALE-UP

Chief Investigator Reilly's team established a platform comprising 30 quantum dots with several hundred gates to tune the potentials, controlled by a proximal cryo-CMOS chip [1]. The laboratory has also demonstrated a scalable approach to controlling quantum systems with large numbers of gates, implementing an integrated circuit that can generate thousands of control signals from just four input wires [2].

Right Frequency response of a qubit in a waveguide below the waveguide cutoff frequency, as a function of the qubit resonance frequency. The qubit line width becomes narrower as the photon becomes bound.



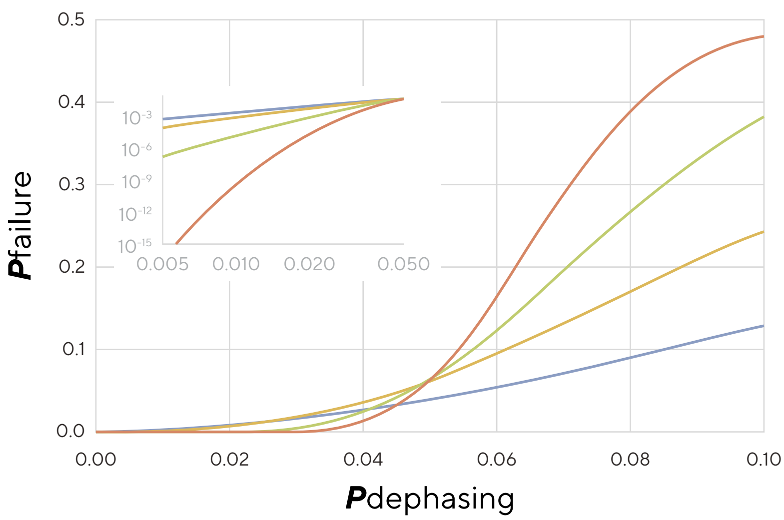
1 SJ Pauka *et al. arXiv:1908.07685* (2019)

2 SJ Pauka *et al.* submitted to *Nature Electronics*

Research highlights

ERROR CORRECTION

Chief Investigators Stace and Brennen continued their collaboration, exploring a new class of engineered holographic materials known as 'holographic codes'. Key results include a recipe for generating holographic codes from local cluster states and the first error threshold estimates of around 5% for local Pauli errors in these codes (see figure). This result is based on a new integer programming decoder and is comparable to the known threshold of around 10% for the surface code.



Chief Investigators Bartlett and Flammia continued their research program into developing new tailored quantum error-correcting codes to mitigate the types of noise processes that appear in actual experimentally relevant quantum systems[1]. These results have been extended to the fault-tolerant regime, meaning they apply to noisy decoding processes, and are currently the best in the world for performance [2]. Along with considering biased (dephasing) noise, they have extended our investigation to correlated errors such as those that appear when performing entangling gates.

Above
Logical failure rate of holographic code as a function of the physical dephasing rate of each qubit, for increasingly large code sizes (blue is smallest, red is largest). An error correction threshold appears around $p_{dephasing}$=0.05.

Left
Diamond nanoscience

1 DK Tuckett *et al. Physical Review* X 9, 041031 (2019)

2 DK Tuckett, SD Bartlett, ST Flammia and B Brown *arXiv:1907.02554*

A NEW APPROACH FOR TURNING ORDINARY LASER LIGHT INTO QUANTUM LIGHT

optics.org[1]

An international team of researchers led out of Macquarie University has demonstrated a new approach for converting ordinary laser light into genuine quantum light.

Their approach uses nanometre-thick films made of gallium arsenide, which is a semiconductor material widely used in solar cells. They sandwich the thin films between two mirrors to manipulate the incoming photons.

While these quantum signatures are weak at the moment, the work opens up a new avenue for producing single photons on demand.

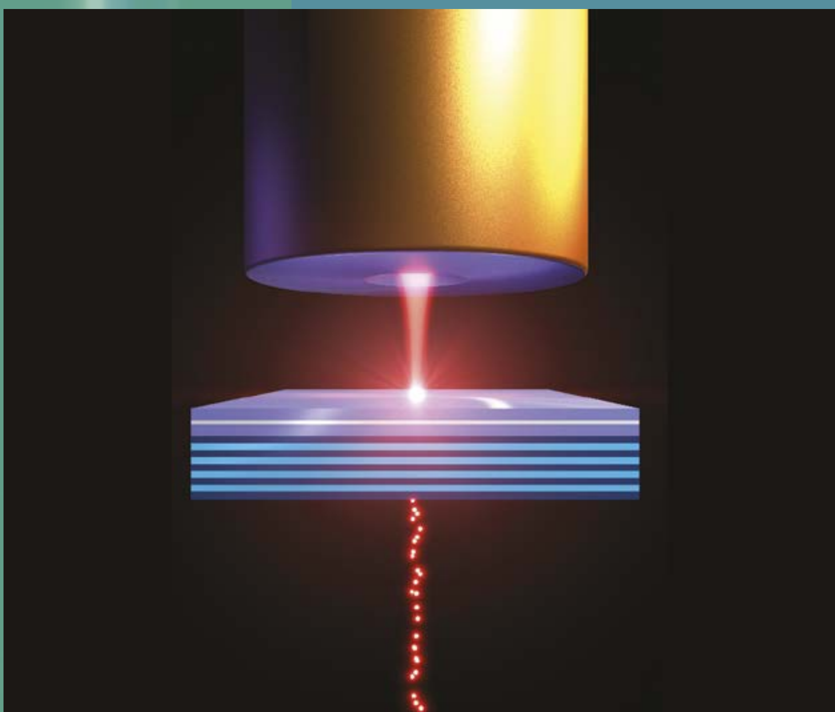
Currently single-photon emitters are typically created by materials engineering — where the material itself is assembled in such a way that the 'quantum' behaviour is built in.

But this standard approach faces serious limitations at smaller and smaller scales because producing identical single-photon emitters by pure materials engineering is extremely challenging.

"This means our approach could be much more amenable to massively scaling up, once we're able to increase the strength of the quantum signatures we're producing. We might be able to make identical quantum emitters from semiconductors by photon nanostructure engineering, rather than by direct materials engineering," said EQUS researcher Dr Guillermo Muñoz-Matutano.

"While real-world applications are still a fair bit away, our paper describes a major milestone that the polariton community in particular has been waiting on for the last ten to fifteen years. The regime in which polaritons interact so strongly that they can imprint quantum signatures on photons has not been accessed to date and opens up a whole new playground for researchers in the field," said Chief Investigator Thomas Volz.

Below
Artist's impression of the polaritonic photon conversion platform. Laser photons enter through the top mirror and leave through the bottom mirror exhibiting quantum 'granularity' – after interacting with the semiconductor layer.
Photo by Andrew Wood



1 G Muñoz-Matutano, A Wood, M Johnsson, X Vidal, BQ Baragiola, A Reinhard, A Lemaître, J Bloch, A Amo, G Nogues, B Besga, M Richard and T Volz "Emergence of quantum correlations from interacting fibre-cavity polaritons" *Nature Materials* (February 2019)

CODING DROPS QUANTUM COMPUTING ERROR RATE BY ORDER OF MAGNITUDE

Alan Duffy, COSMOS Magazine[1]

Errors in quantum computing have limited the potential of the emerging technology. Now, however, EQUS researchers at the University of Sydney have demonstrated a new code to catch these bugs.

The promised power of quantum computing lies in the fundamental nature of quantum systems that exist as a mix, or superposition, of all possible states.

A traditional computer processes a series of "bits" that can be either 1 or 0 (on or off). The quantum equivalent, called a "qubit", can exist as both 1 and 0 simultaneously and can be "solved" together.

One outcome of this is an exponential growth in computing power. A traditional computer central processing unit is built on 64-bit architecture. The equivalent-size quantum unit would be capable of representing 18 million trillion states, or calculations, all at the same time.

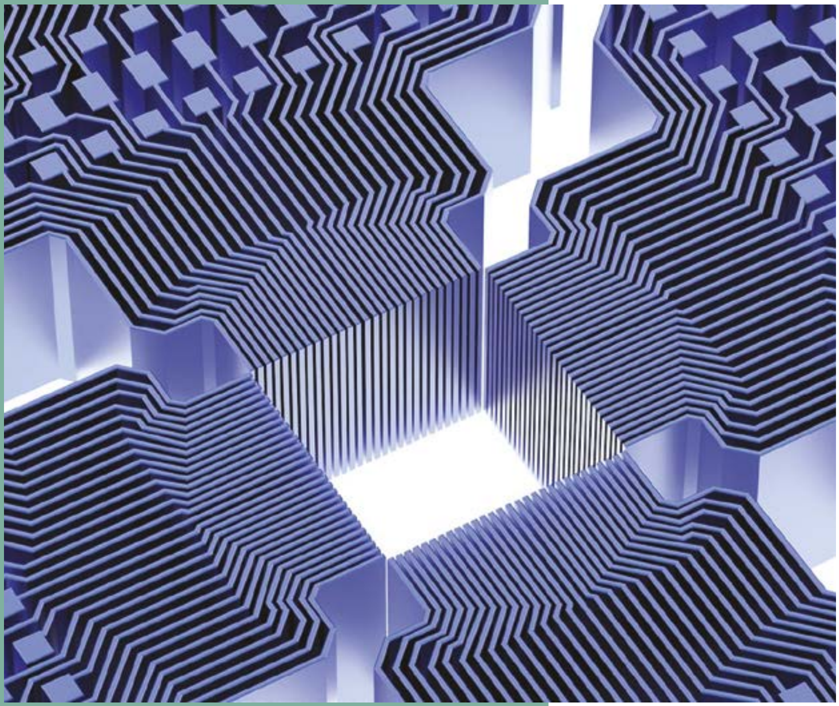
The challenge with realising the exponential growth in qubit-powered computing is that the quantum states are fragile and prone to collapsing or producing errors when exposed to the electrical 'noise' from the world around them. If these bugs could be caught by software it would make the underlying hardware much more useful for calculations.

"This is really the first time that the promised benefit for quantum logic gates from theory has been realised in an actual quantum machine," said EQUS researcher Robin Harper, lead author of a new paper published in the journal *Physical Review Letters*.

Harper and Chief Investigator Steven Flammia implemented their code on one of tech giant IBM's quantum computers, made available through the corporation's IBM Q initiative. The result was a reduction in the error rate by an order of magnitude.

The test was performed on quantum logic gates, the building blocks of any quantum computer, and the equivalent of classical logic gates.

Below
Quantum computing holds great promise, but its fundamental process is delicate and prone to error.
Photo by Alfred Pasieka/ Science Photo Library/ Getty Images

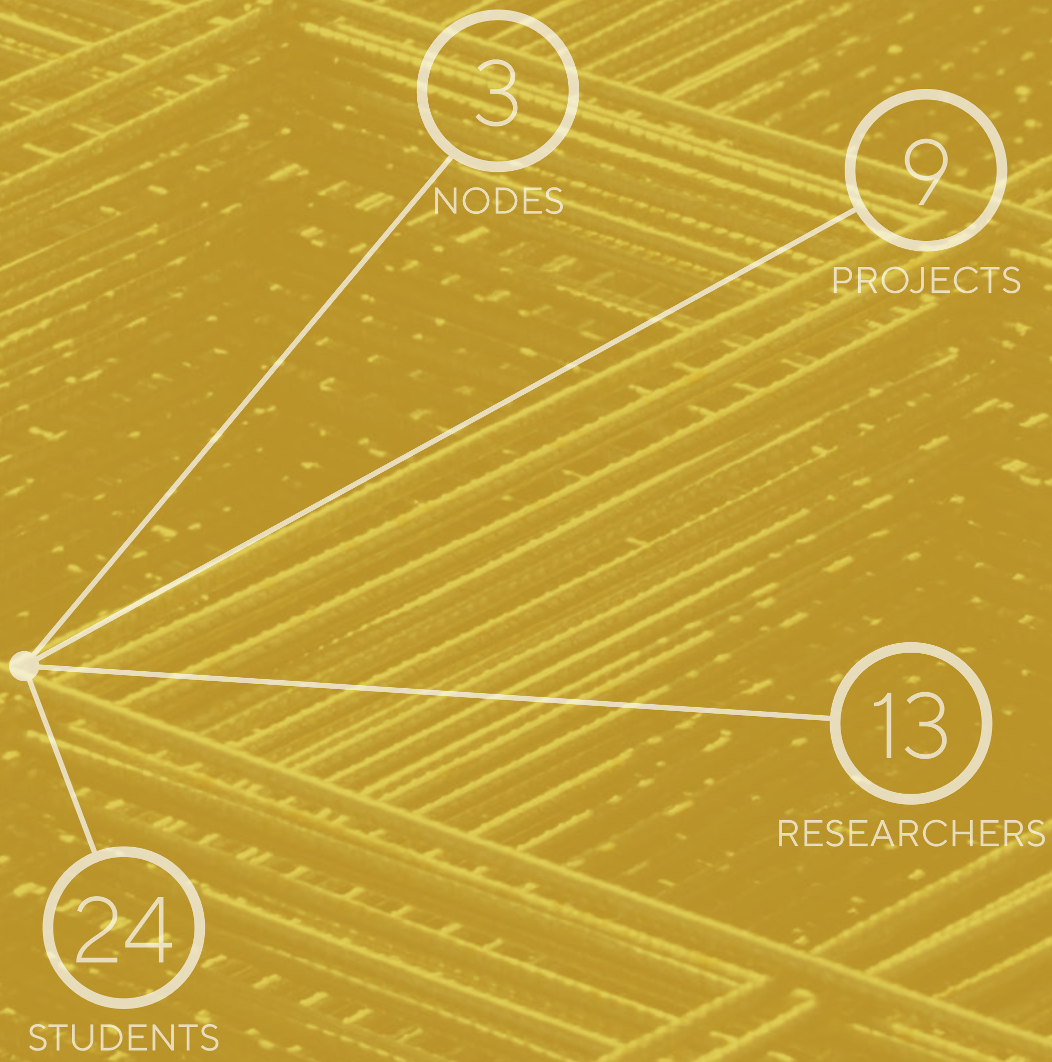


1 C Hempel, C Maier, J Romero, J McClean, T Monz, H Shen, P Jurcevic, BP Lanyon, P Love, R Babbush, A Aspuru-Guzik, R Blatt and CF Roos *Physical Review* X, 8, 031022 (2018)

QUANTUM-ENABLED DIAGNOSTICS AND IMAGING

Sensors are ubiquitous in modern technology: from examining our bodies, through our local environments, to the galaxy and beyond. This program seeks to exploit quantum mechanics to engineer new probes, sensors and techniques that enhance capabilities across a range of applications, from diagnosis and detection in medical imaging to the accuracy of navigation.

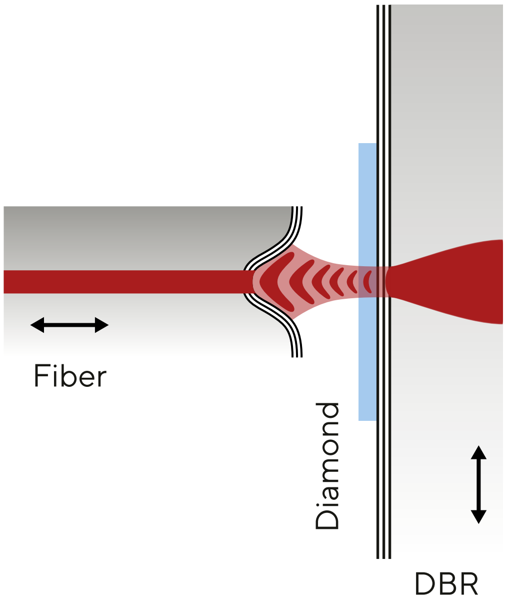
Research Program 2



ELECTROMAGNETIC SENSORS

Chief Investigators Volz and Brennen, with Associate Investigator Burgarth at Macquarie University, theoretically and experimentally explored cooperative effects using diamond colour centres, including preparation for NV laser threshold magnetometers, using superabsorption of highly entangled quantum states of many emitters, with applications in quantum-limited metrology[1], and Raman nanodiamond thermometry.

Chief Investigator Twamley worked on the theory and analysis of experimental work on superabsorption in Si-vacancy centres in diamond membranes undertaken at the University of Ulm by the team of Prof Kubanek[2], and demonstrations of passive levitation of micro-diamonds in an ultra-high-vacuum[3]. Twamley showed that under reasonable conditions, a mechanically oscillating qubit initially in the electromagnetic vacuum will become excited and emit microwave photons in a manner similar to the Unruh effect.



Right
Schematic of the optical microcavity made from the concave end of an optical fibre and a flat mirror (known as a distributed Bragg reflector –DBR)

OPTICAL AND MECHANICAL SENSORS

Optical and mechanical systems have reached the regime where the quantum nature of the systems, or their interactions, are dominant. EQUS developments in the preparation and control of these systems have led to new advances and capabilities for precision measurement.

Chief Investigator Bowen and his team continued their development of superfluid helium optomechanical quantum devices and sensors. This includes observing coherent vortex dynamics for the first time in a strongly-interacting two-dimensional superfluid in collaboration with Chief Investigator Davis[4], crucial for understanding how superflows can be used in superfluid helium matter-wave inertial sensors; and the demonstration of Brillouin lasing with a record low threshold which allowed mechanically-mediated strong optical coupling for the first time[5], this paves the way for on-chip superfluid helium gyroscopes. Chief Investigator

1 M Johnsson, NR Mukty, D Burgarth, T Volz, GK Brennen *arXiv:1908.01120* (2019)

2 S Häußler *et al. Physical Review* B 99 165310 (2019)

3 MC O'Brien, S Dunn, E Downes, J Twamley *Applied Physics Letters* 114, 053103 (2019)

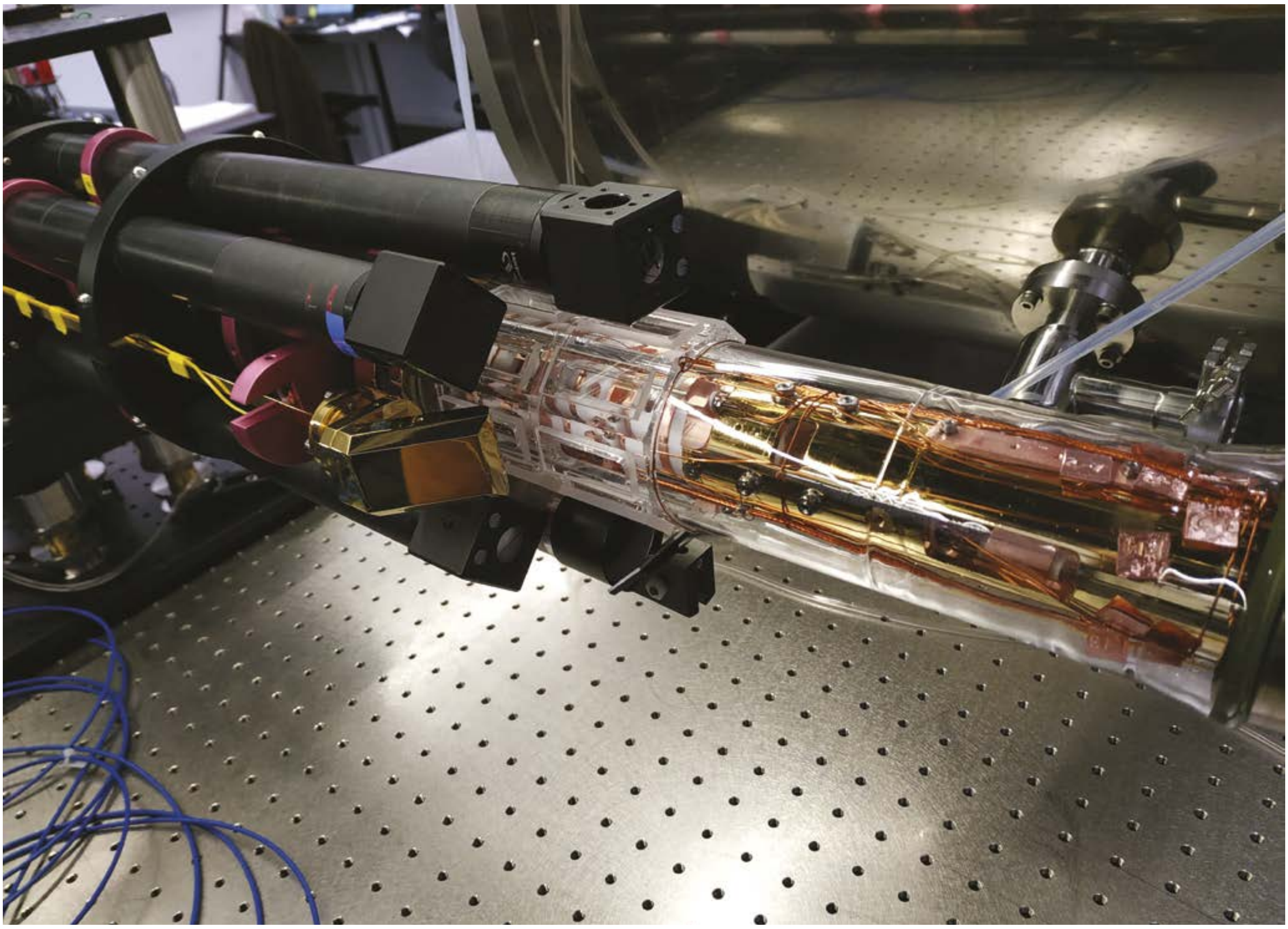
4 YP Sachkou *et al. arXiv 1902.04409* (2019), accepted *Science*

5 X He *et al. arXiv:1907.06811* (2019)

Bowen's lab also demonstrated the first ultrasound measurements using cavity optomechanics, achieving 100 times improved sensitivity over all previous air-coupled ultrasound[1], and performed new theory showing that continuous measurements allow room temperature quantum squeezing of a mechanical oscillator.

Centre Director White and his team developed a variety of quantum and quantum-inspired techniques for enhanced imaging and communication. They introduced quantum hypercube states[2] which exhibit phase-space features much smaller than Planck's constant, making them sensitive to perturbations at extremely small scales and an attractive potential practical resource for sensing applications. In a high-temperature proof-of-principle experiment they observed, and matched to theory, the signature outer-edge vertex structure of hypercube states. This group also demonstrated a new imaging method

Below
Vacuum system assembly



1 S Basiri-Esfahani, A Armin, S Forstner, WP Bowen *Nature Communications* 10 132 (2019)

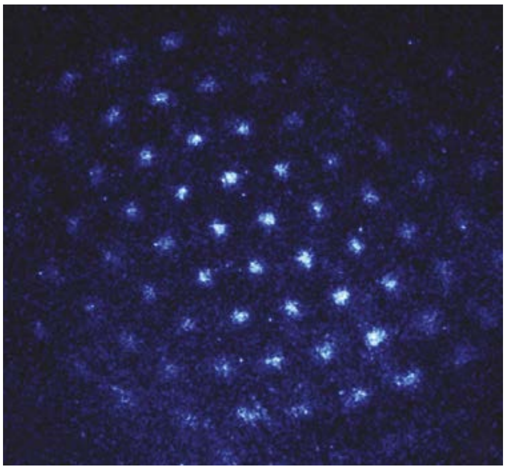
2 LA Howard, TJ Weinhold, F Shahandeh, J Combes, MR Vanner, AG White, M Ringbauer *Physical Review Letters* 123 020402 (2019)

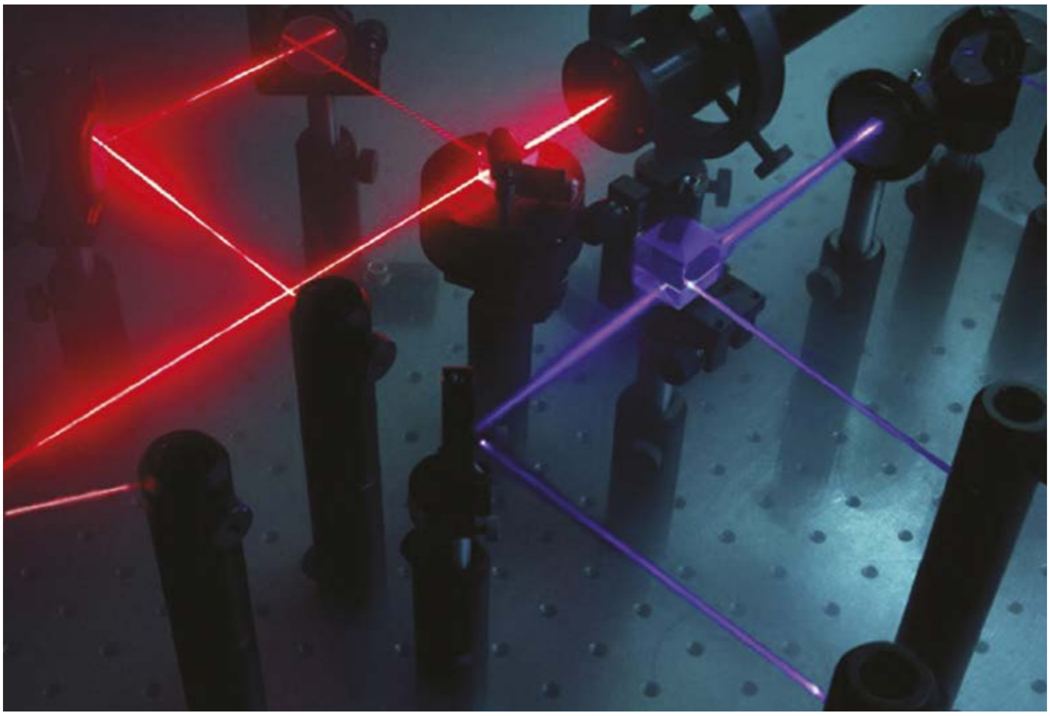
based on the complex coherence of light[1], and used this technique to infer the size and position of a small distant source of pseudo-thermal light, outperforming traditional imaging methods by an order of magnitude in precision. They also were able to exploit superpositions of causal order to demonstrate communications over completely noisy channels – those with classically zero channel capacity[2].

Associate Investigator Woolley worked on novel approaches to force sensing in quantum optomechanical systems, combining time-dependent control with nonclassical state preparation. He also generalised recent work on entangling two massive mechanical oscillators to lattices of many oscillators using two-body reservoir engineering and passively coupled oscillators[3], which provides a mechanism for generating arrays of entangled oscillators, with applications in quantum force sensing[4] and simulation[5].

Right
Ions in an ion trap at USyd

Below right
Inside the Quantum Technology Lab





1 LA Howard, GG Gillett, ME Pearce, RA Abrahao, TJ Weinhold, P Kok, AG White *Physical Review Letters* 123 143604 (2019)

2 K Goswami, Y Cao, GA Paz-Silva, J Romero, AG White *arXiv:1807.07383* (2018)

3 S Ma and MJ Woolley *The Journal of Physics A: Mathematical and Theoretical* 52, 325301 (2019)

4 S Bernal-García and MJ Woolley "Nonstationary force sensing under dissipative mechanical quantum squeezing"

5 *The Journal of Physics A: Mathematical and Theoretical* (online December 6)

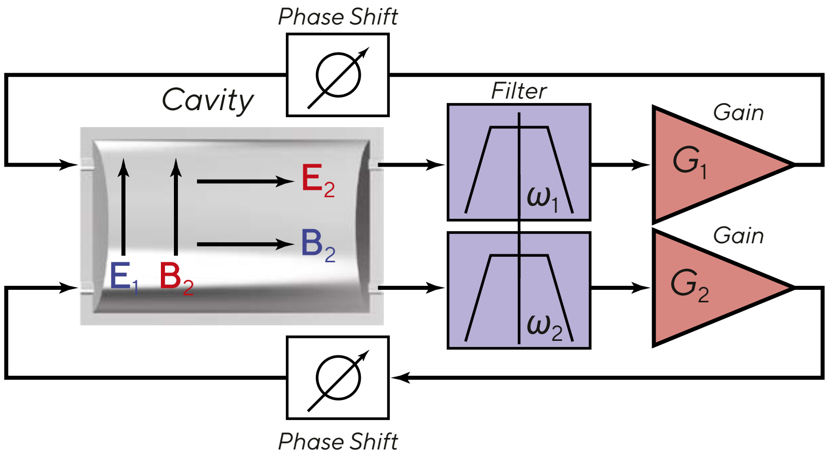
APPLICATIONS OF QUANTUM SENSORS

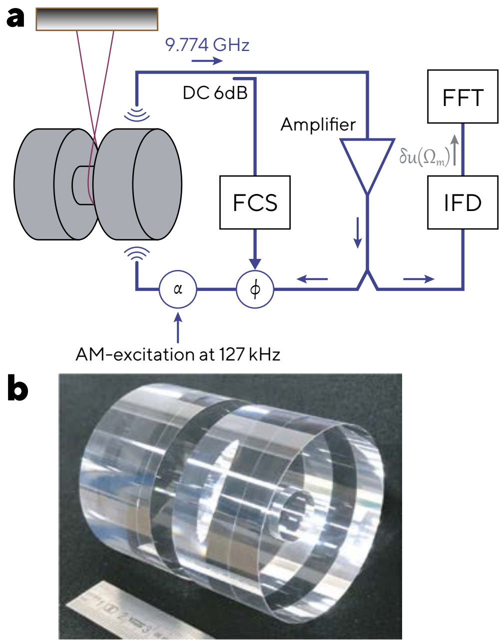
EQUS is working towards applications of quantum sensing techniques, including developing new clock technologies and for tests of fundamental physics.

Chief Investigator Stace worked on theory associated with a DST-funded portable atomic beam clock, using monolithic optical chips for state preparation, readout and error suppression. Chief Investigator McFerran has measured the $^1S_0$–$^3P_1$ inter-combination line for the Yb optical lattice clock[1].

EQUS researchers worked on novel tests of fundamental physics, including a proposal by Chief Investigator Bowen on using optomechanical systems to test spontaneous collapse models[2].

Chief Investigator Tobar's group has demonstrated a new technique to test generalisations of the Heisenberg uncertainty principle (GUP)[3], and for detecting the hypothesised axion field using high-precision frequency metrology, which has the potential to overtake traditional techniques. This latter work has led to further funding through the new ARC Centre of Excellence for Dark Matter Particle Physics and the US-funded Axion Dark Matter experiment.





Above
Schematic of CI Tobar's cavity-based test system for detecting axion dark-matter candidates

Left
Schematic and photo of CI Tobar's resonator for testing generalisations to Heisenberg's uncertainty principle

1 PE Atkinson, JS Schelfhout and JJ McFerran *Physical Review* A 100 042505 (2019)

2 S Forstner, M Zych, S Basiri-Esfahani, KE Khosla and WP Bowen *arXiv 1909.01608* (2019)

3 PA Bushev, J Bourhill, M Goryachev, N Kukharchyk, E Ivanov, S Galliou, ME Tobar and S Danilishin *Physical Review* D 100 066020 (2019)

IMPROVING ULTRASOUND WITH QUANTUM PHYSICS

As seen on Channel 7 News – bit.ly/ch7quantum[1]

EQUS researchers at The University of Queensland have combined modern nanofabrication and nanophotonics techniques to build the ultraprecise ultrasound sensors on a silicon chip.

Chief Investigator Warwick Bowen, from UQ's Precision Sensing Initiative and the Australian Research Council Centre of Excellence for Engineered Quantum Systems, said the development could usher in a host of exciting new technologies.

"This is a major step forward, since accurate ultrasound measurement is critical for a range of applications," he said.

"Ultrasound is used for medical ultrasound, often to examine pregnant women, as well as for high resolution biomedical imaging to detect tumours and other anomalies.

"It's also commonly used for spatial applications, like in the sonar imaging of underwater objects or in the navigation of unmanned aerial vehicles.

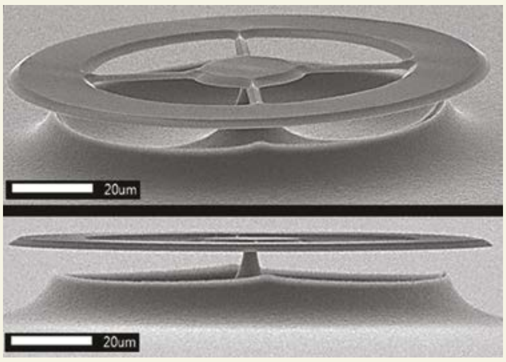
"Improving these applications requires smaller, higher precision sensors and, with this new technique, that's exactly what we've been able to develop."

Research leader Dr Sahar Basiri-Esfahani, now at Swansea University, said the accuracy of the technology could change how scientists understand biology.

"We'll soon have the ability to listen to the sound emitted by living bacteria and cells," she said.

"This could fundamentally improve our understanding of how these small biological systems function.

"A deeper understanding of these biological systems may lead to new treatments, so we're looking forward to seeing what future applications emerge."



Right
Microscale device developed to generate an ultraprecise image
Source: engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/18305/Ultrasound-Breakthrough-Allows-Researchers-to-Listen-to-Cells-in-Action.aspx

1 S Basiri-Esfahani, A Armin, S Forstner and WP Bowen *Nature Communications* 10: 132 (2019)

PHYSICISTS DISCOVER FAMILY MEMBERS OF SCHRÖDINGER'S CAT

UQ News[1]

It has been said that the internet exists chiefly to show videos of cats interacting with boxes.

An international team of researchers led by the University of Queensland has extended cats and boxes into the quantum realm, discovering that Schrödinger's famous dead-and-alive cat is just one of an infinite family of quantum states.

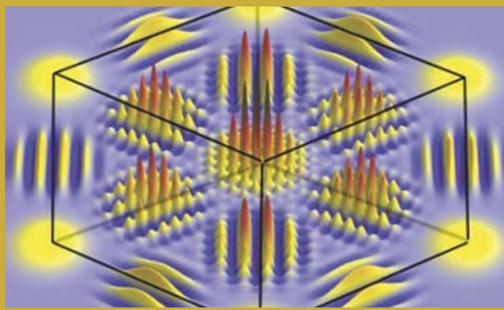
EQUS PhD researcher Lewis Howard said the states were all generated using multidimensional boxes called hypercubes.

"We found that as the hypercubes become larger, they generated Schrödinger-cat-like states with increasingly finer features in phase space, making them more powerful for quantum applications," Mr Howard said.

"Think striped tigers as opposed to tabbies."

Creating these hypercube states – in this case using single particles of light and a tiny mechanical drum – is an important ingredient in quantum technologies.

"The Schrödinger Cat state, discovered in 1935, is a quantum superposition of two states, normally referred to as 'dead' and 'alive'.

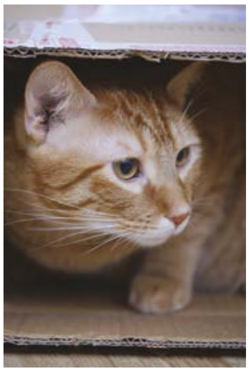


"In 2001, a relative of the cat was introduced – the compass state, which is made up of a superposition of four different quantum states arranged in a compass form."

The study showed that the cat and the compass state are just the smallest two members of an infinitely large family of hypercube states.

University of Innsbruck researcher and EQUS Associate Investigator Dr Martin Ringbauer, who guided the research, said that hypercube states consist of multiple quantum superpositions that map out the corners of multidimensional cubes.

"We discovered these quantum hypercube states by accident while experimenting with methods to create quantum states that could be useful in quantum sensors," Dr Ringbauer said.



Above left
The first new quantum state in the family of hypercubes states shown in position, momentum space

1 L. A. Howard, T. J. Weinhold, F. Shahandeh, J. Combes, M. R. Vanner, A. G. White, and M. Ringbauer *Physical Review Letters* 123, 020402 (2019)

QUANTUM ENGINES AND INSTRUMENTS

This program develops tools and design approaches that will enable us to piece together complex quantum machines out of their disparate components and aims to pioneer a new generation of instruments tailored to the demanding requirements of quantum science, from precision clocks, oscillators and time-bases to high-speed cryogenic electronics.

Research Program 3

OPTICAL AND ATOMIC SYSTEMS

Chief Investigator Shaddock made progress in developing optical phased arrays technologies for solid-state laser beam steering and sensing and for free-space communications and ground-to-space Quantum Key Distribution systems under development around the world.

Chief Investigator Stace and members of Chief Investigator Shaddock's group have also made progress on a 'quantum-inspired' solid-state coherent LiDAR system for integrated ranging and velocimetry[1], with applications in autonomous vehicles.

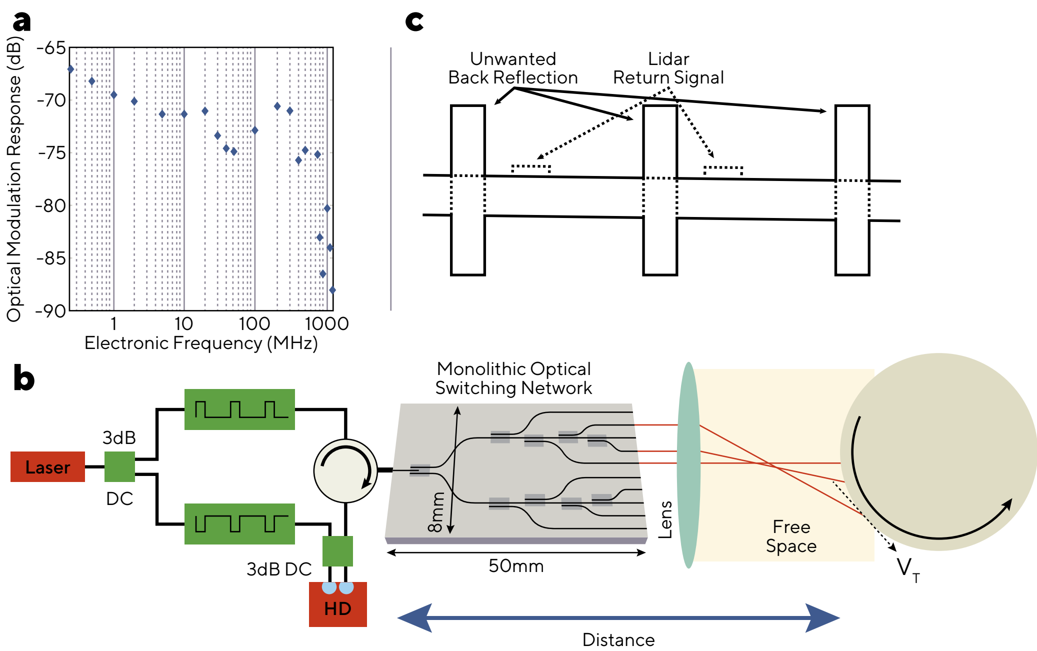
Centre Director White developed a custom FPGA that analyses Transition Edge Sensor signals in real time – recording only specific characteristics such as signal area, height and length – allowing near real time photon-number resolution and reducing memory requirements by orders of magnitude.

They are able to correctly assign photon numbers with high certainty, e.g. the probability of correctly assigning 2 photons to a 2-photon state is 99.9999996%; similarly for 12 photons the probability is 98.5%.

Chief Investigator Rubinsztein-Dunlop and team made progress on:

- universal expansion of vortex clusters in a dissipative two-dimensional superfluid;
- using machine-learning to realise optimal stirring parameters to produce rapidly-circulating persistent currents;
- classical rotation of a 2-component BEC superfluid, demonstrating rotation of an immiscible two-component BEC superfluid in a ring trap; and
- successfully demonstrating spin-dependent optical barriers in multi-component BEC.

Right
The switch architecture allows for temporal multiplexing of the detection electronics since all pixels are measured by a single detector

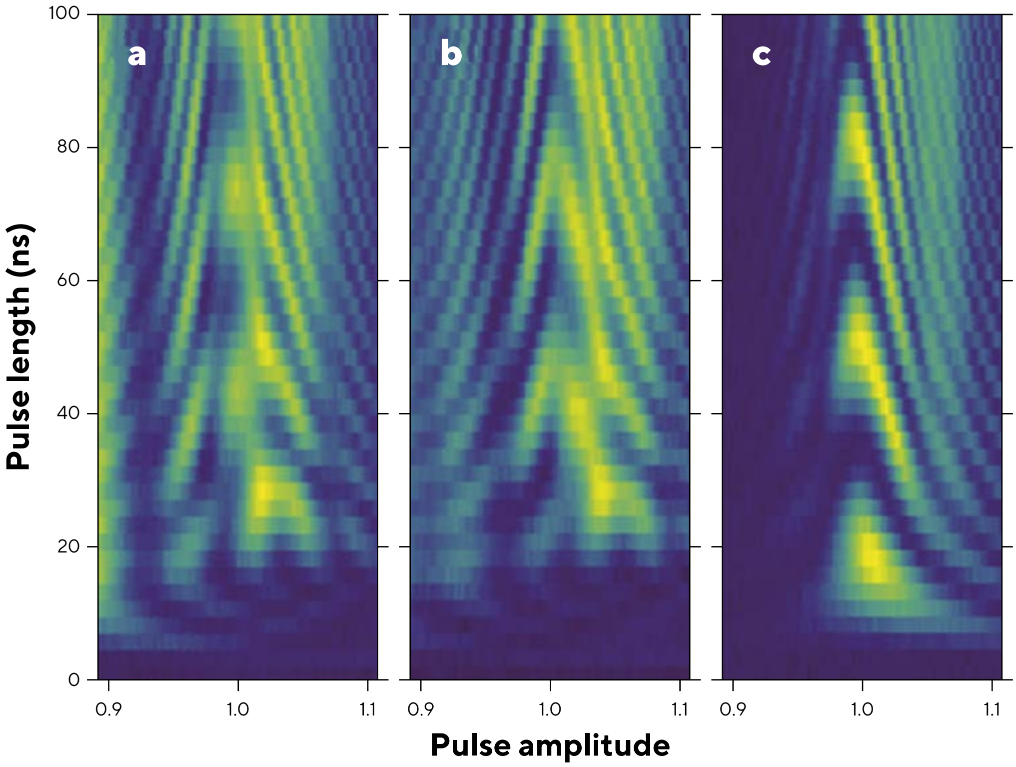


1 B Haylock, MA Baker, TM Stace, M Lobino *Applied Physics Letters* 115, 181103 (2019)

MICROWAVE DEVICES

Chief Investigator Tobar implemented several experimental implementations of cavity-magnon systems, realising the ultra-strong coupling regime, finding a strong candidate system for dark matter detection, and developing a system useful for precision frequency applications.

Chief Investigator Fedorov 's team proposed, and experimentally realised, a method of in-situ direct reconstruction of the response of a control line of a qubit in a large frequency range using the qubit itself (see figure). They demonstrated this by characterising the 'flux' control line of a superconducting transmon qubit in the range from 1 to 450 MHz, and using this characterisation to improve the fidelity of an entangling CPHASE gate between two Transmon qubits[1]. This allowed an increase of fidelity of the two-qubit CPHASE gate from 83% to 88%.



Left
Vacuum Rabi oscillation between the |11> and |20> states of two transmon qubits assuming

a
a perfect impulse response,

b
the impulse response measured at room temperature, and

c
the impulse response measured using the qubit.

1 M Jerger, A Kulikov, Z Vasselin and A Fedorov *Physical Review Letters* 123, 150501 (2019)

Research highlights

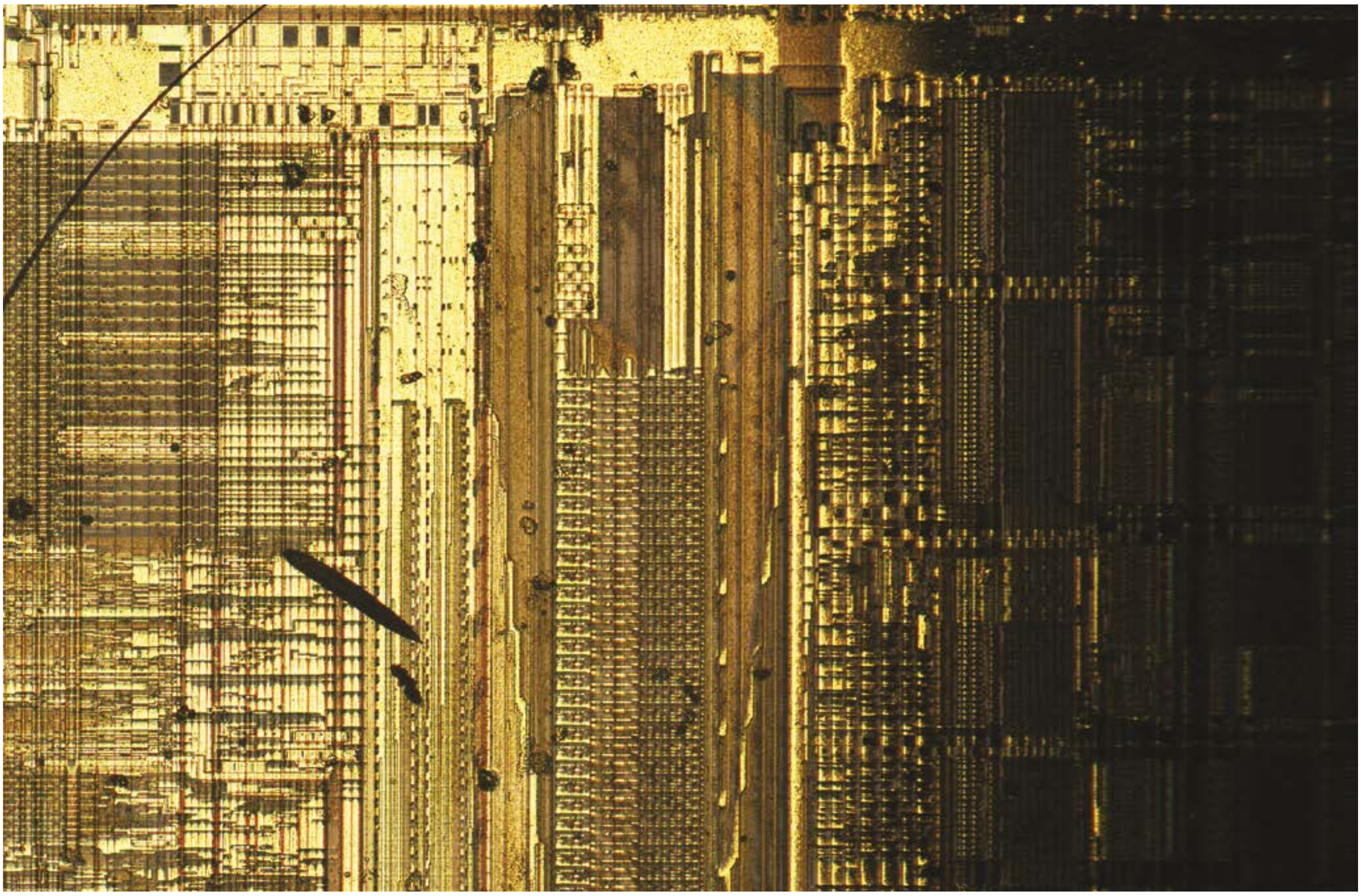
QUANTUM SIMULATORS AND COMPUTERS

Chief Investigator Milburn and Associate Investigator Shrapnel initiated a new project on coherent Ising machines with PhD student Michael Kewming. In contrast to the original idea by Yamamoto that was based on degenerate optical parametric amplification, the new scheme is based on parametrically pumped Kerr nonlinear devices. Using quantum trajectory methods they were able to identify the possible quantum advantage such machines offer for learning[1].

Chief Investigators Flammia and Bartlett — in collaboration with the group of Andrew Dzurak at UNSW — are developing benchmarking tools for the next generation of two- and three-qubit devices. They also continue to collaborate with Quantum Benchmark to develop tools for industry to assess the performance of near-term quantum devices.

Chief Investigator Flammia and co-authors have written two new preprints that give a scalable method to estimate error rates in quantum devices. This method is expected to be essential for characterising quantum computers and for enabling software quantum error correction.

Below
Silicon skyline



1 M Kewming, S Shrapnel, G Milburn "Quantum Correlations in the Kerr Ising Model" submitted to *New Journal of Physics*

Research highlights

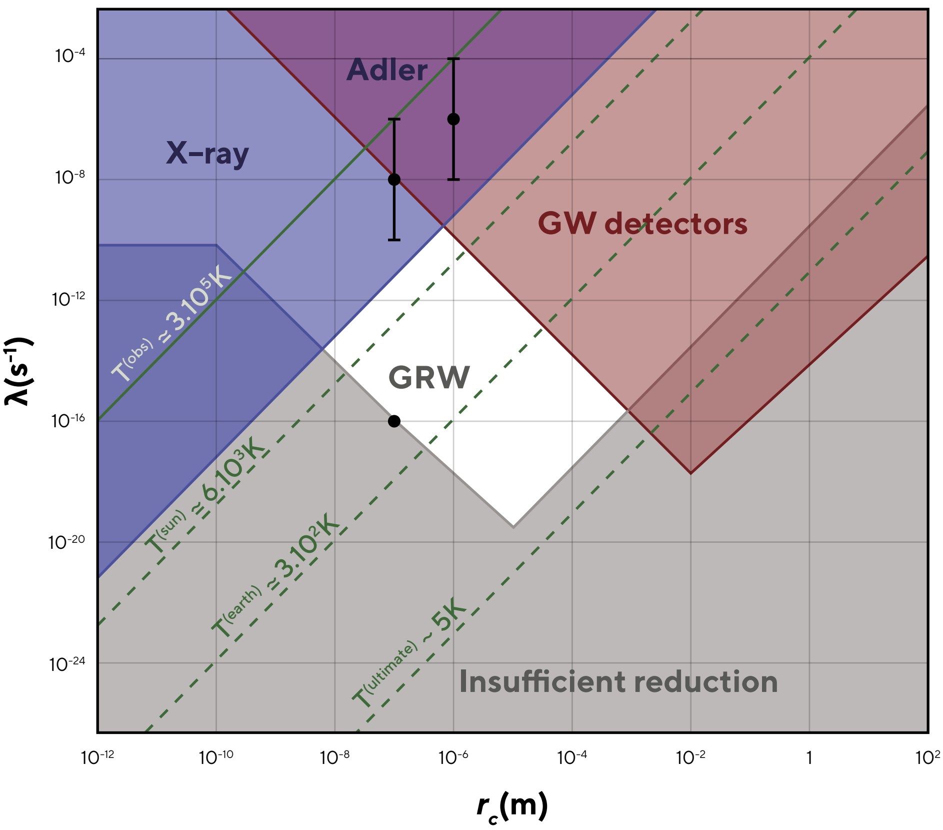
FUNDAMENTAL PHYSICS

Chief Investigators Tobar and Stace have begun developing the theory for a new class of microwave photon counters designed to detect anomalous photons from axion-photon conversion in superconducting axion detectors. Chief Investigator Stace derived new bounds on parameters in gravitational collapse models, based on thermal radiation from neutron stars[1].

THERMODYNAMICS

Associate Investigator Gilchrist studied the effect of the coherence on power and efficiency in a system where quantum coherence between energetically degenerate ground states is used to drive an engine out of the quasistatic limit; and the evolution of coupled qubit systems where the possible dynamics is induced by an environment that contains entanglement.

Associate Investigator Gilchrist developed a formal resource theory of quantum measurements that quantifies the usefulness of a measurement device finding that, surprisingly, the ability to acquire information is insufficient to characterise such devices.



Left
Parameter exclusion plot for state collapse model parameters set by hypothetical future neutron star temperature observations

1 A Tilloy, TM Stace *Physical Review Letters* 123, 080402 (2019)

PHYSICS MASH QUANTUM AND GRAVITY AND FIND TIME, BUT NOT AS WE KNOW IT

UQ News[1]

An international team of researchers say they have discovered "a new kind of quantum time order".

Above
Quantum events can unfold in a "new time order", the researchers say

UQ physicist Dr Magdalena Zych said the discovery arose from an experiment the team designed to bring together elements of the two big – but contradictory – physics theories developed in the past century.

"Our proposal sought to discover: what happens when an object massive enough to influence the flow of time is placed in a quantum state?" Dr Zych said.

She said Einstein's theory described how the presence of a massive object slowed time.

"Imagine two space ships, asked to fire at each other at a specified time while dodging the other's attack," she said.

"If either fires too early, it will destroy the other."

"In Einstein's theory, a powerful enemy could use the principles of general relativity by placing a massive object – like a planet – closer to one ship to slow the passing of time."

"Because of the time lag, the ship furthest away from the massive object will fire earlier, destroying the other."

Dr Zych said the second theory, of quantum mechanics, says any object can be in a state of "superposition"

"This means it can be found in different states – think Schrödinger's cat," she said.

Dr Zych said using the theory of quantum mechanics, if the enemy put the planet into a state of "quantum superposition", then time also should be disrupted.

"There would be a new way for the order of events to unfold, with neither of the events being first or second, but in a genuine quantum state of being both first and second," she said.

1 uq.edu.au/news/article/2019/08/physicists-mash-quantum-and-gravity-and-find-time-not-we-know-it

THIS MONA LISA RECREATION IS THE WIDTH OF A HUMAN HAIR

Stuart Layt, Brisbane Times

As part of their work researching ways to manipulate quantum material, EQUS researchers have been taking pictures of the material which had been manipulated into different patterns.

Dr Tyler Neely, from the University of Queensland-based research team, said his fellow scientists landed on the realisation they could put anything they wanted on the tiny canvas available to them.

"The image is made up of the atoms themselves. It's kind of like a sand painting, where you have a flat canvas where you can place the sand and you can build up an image using the grains of sand," he said.

"We realised we could do all these experiments by manipulating it with this technology using this projected light to make a picture."

The researchers are working with what's called a Bose-Einstein condensate, formed when an element – in this case rubidium – is supercooled all the way down to almost absolute zero.

Under the right conditions, the atoms stop acting in a "normal" way and instead clump together and behave more like photons, existing in a quantum state between a particle and a wave.

Using this "quantum paint" the researchers project an image of the masterpiece in question, including Van Gogh's Starry Night and Da Vinci's Mona Lisa, backwards through a microscope onto the material, which forms the shape of the picture.

Top
The quantum rendition of the Mona Lisa, approximately 100 microns wide

Above
UQ quantum physics researcher Dr Tyler Neely next to a blown up version of a microscopic recreation of the same photo created with quantum technology

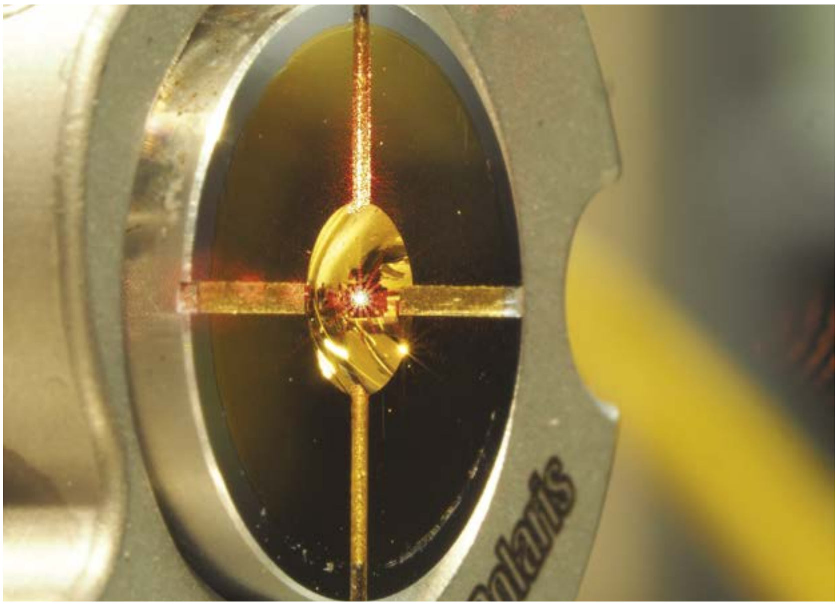
2020 research plan

DESIGNER QUANTUM MATERIALS

Experimental platforms

Chief Investigator Volz will continue pursuing polariton/photon blockade with new tools and samples.

Centre Director White will continue work on engineering high-quality large-scale photonic entanglement and publishing results from the machine learning project.



Above
A parabolic mirror
Photo by Cyril Laplane

Development in the Penning trap of the in-bore opto-mechanics needed for laser-driven Raman interactions will be finished by Chief Investigator Biercuk. This will enable commencement of engineered spin-motional interactions in large 2D ion crystals. With the Paul trap, his lab will implement the first simulation of chemical dynamics of the pyrazine molecule.

Chief Investigator Fedorov will finalise results for the observed atom-photon states, investigate topological bound state in the band gap and continue to develop on-chip microwave.

Theory

Chief Investigators Bartlett and Flammia will develop new tailored codes to mitigate correlated noise in experimentally relevant systems and explore how topological symmetries emerge naturally, rather than being enforced.

Chief Investigators Stace and Brennen will continue exploring holographic codes, particularly an improved Pauli decoder for holographic codes based on tensor networks. They are developing proposals for implementing these codes in ion trap systems with Professor Blatt's group in Innsbruck.

Chief Investigator Brennen's group, together with Associate Investigator Gilchrist, will develop a theoretical framework to describe the dynamics of non-unitary quantum cellular automata.

Chief Investigator Bartlett will research the use of symmetry to identify new designer quantum materials that can protect quantum information without the need for active error correction.

Chief Investigator Stace will continue developing Bloch encodings for new superconducting qubits.

2020 research plan

QUANTUM-ENABLED DIAGNOSTICS AND IMAGING

Experimental platforms

Chief Investigator Bowen will develop silicon photonics capabilities and apply them both into miniaturised superfluid circuitry and quantum optomechanics experiments.

Centre Director White will explore photonic sensing and imaging applications.

Chief Investigator Volz will start quantum control experiments on single and ensembles of NV spins in diamond to investigate masing and Floquet dynamics in time crystals.

Chief Investigator Tobar will continue working on fundamental tests of Lorentz invariance and Generalised Uncertainty Principles, developing new dark-matter axion detection schemes with Chief Investigators Stace & Fedorov, and will begin working with the SmartSat CRC with Al Shediwy on free-space frequency transfer for phase-stabilised ground-to-space laser link.

Chief Investigator McFerran will continue working on Yb atomic beams, and measure King plots of Yb spectra.

Theory

Chief Investigator Brennen's group will further develop geometric control strategies for precision metrology, and with Chief Investigators Volz and Fedorov on implementing geometric quantum control in hybrid NV-superconducting systems.

Chief Investigator Stace will work on new avenues for using the monolithic optical chips in atomic beam clocks to reduce systematic noise in the beam clock.

Chief Investigator Twamley will focus on developing novel methods for quantum-limited magnetometry using nonlinear interferometers.

Associate Investigator Wooley will work on back-action evading force measurement protocols for tests in fundamental physics and on quantum state control in levitated optomechanical systems as gravitational probes for signal detection.

Above
Diamonds at Macquarie University.
Photo by Dr Lachlan Rogers

2020 research plan

QUANTUM ENGINES AND INSTRUMENTS

Experimental platform

Chief Investigator Shaddock will continue work on the optical fibre OPA to develop aspects of the internally sensed architecture and high-power handling. Further work will be undertaken to progress the development of the on-chip OPA towards a fully integrated implementation.

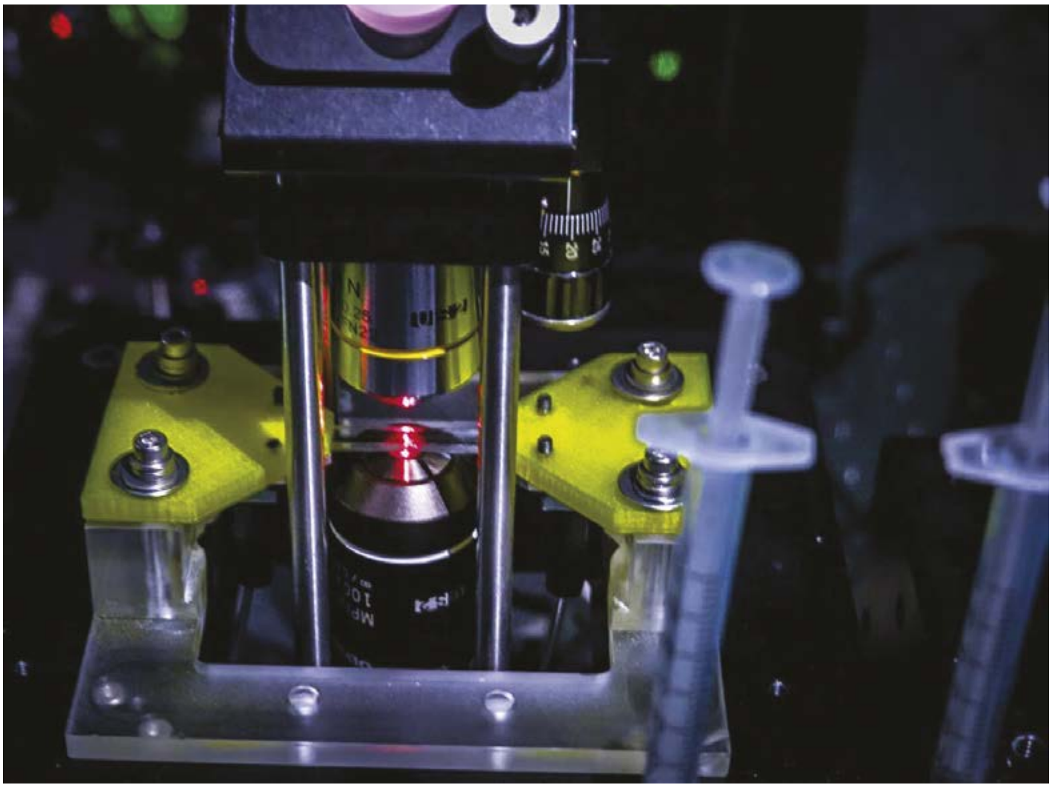
Chief Investigators Stace and Shaddock will continue on development of LiDAR, working towards critical technology demonstration.

Chief Investigator Tobar is planning joint experiments with John Martinis at Google on the properties of silicon at low temperatures.

Chief Investigator Rubinsztein-Dunlop's primary goals will be projects that are connected to the recent implementation of the green sheet, which will produce a 2D 'box' trap free from harmonic confinement. This will enable improved control of the BEC temperature, as well as enabling reliable preparation of multiple condensates at different temperatures. Furthermore, increased uniformity of the system will enable vortex studies with larger statistical ensembles

Chief Investigator Fedorov's direct reconstruction method will be extended to the 'charge' control line. His team will also look to use their methods and machine learning techniques to increase fidelities of single and two-qubit gates.

Right
A quantum snap from a Macquarie lab
Photo by Dr Reece Roberts



2020 research plan

Theory

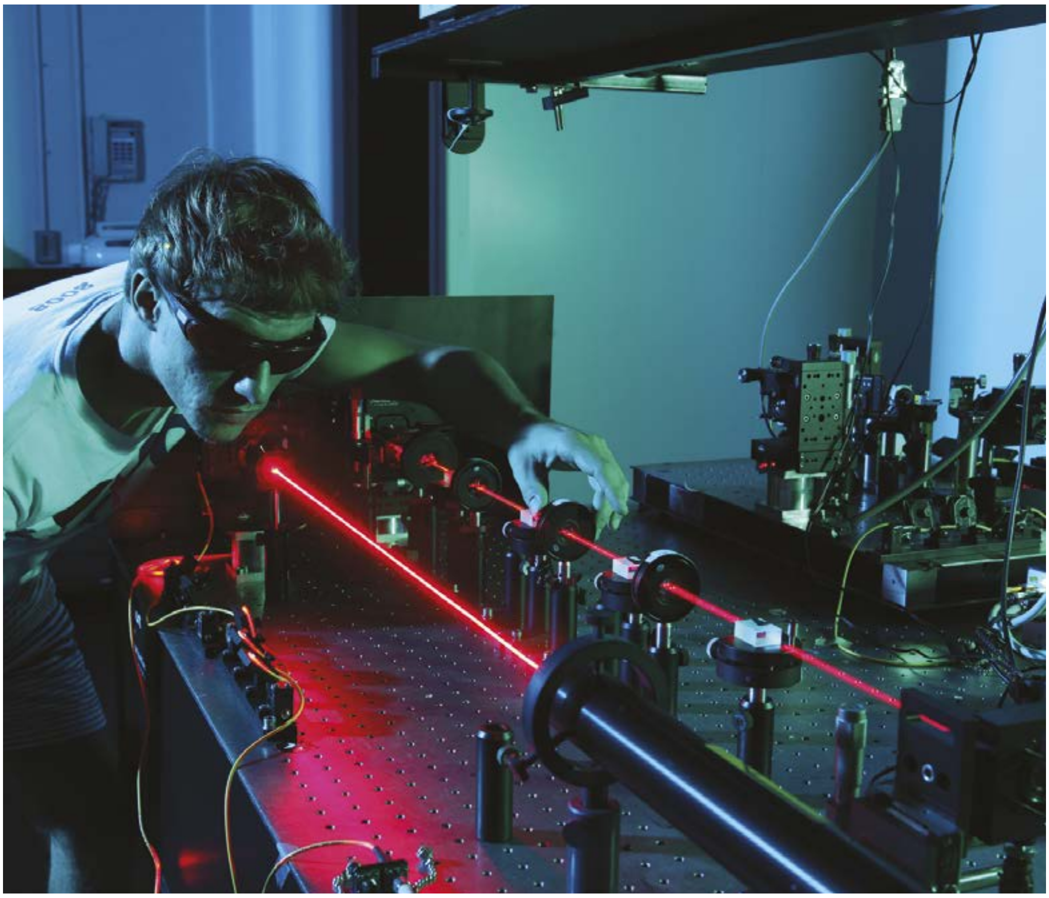
Associate Investigator Gilchrist will develop the resource theory of quantum measurements to clarify the minimum set of resource monotones that are necessary and to extend the theory to include measurement back-action.

Chief Investigators Stace and Tobar will continue to work on modelling dark-matter photon detectors.

Chief Investigator Stace will begin discussions with astronomers to develop survey proposals to find cool, nearby neutron stars.

Chief Investigator Milburn will extend the learning machine model based on parametrically pumped Kerr devices to pulsed regime enabling greater connectivity, increase in the number of sites and study the Pott's model using quantum phase transitions in engineered superconducting quantum networks.

Chief Investigator Davis will continue working on a quantum heat engine with Bose-Einstein condensates.



Left
Hard at work inside the Quantum Technology Lab

Research translation

EQUS is working to move our research beyond the lab towards practical prototypes and commercial applications.

The Translational Research Laboratory (TRL) is a flagship program within EQUS with the strategic objectives of: providing technical support and carrying out the feasibility studies required to see applications realised as practical prototypes, carrying out industry engagement activities to connect researchers with new partnerships; and building a culture of innovation and entrepreneurship in the Centre.

EQUS FABRICATION CAPABILITIES ASSESSMENT

Dr Matthew van Breugel completed an internal survey of equipment and fabrication capabilities for the TRL in 2019. The resulting database of 110 pieces of equipment is now deployed to the Centre Hub and available to all staff.

TRL GRANTS

A round of grants was awarded to internal Centre projects via a written application and assessment process. Six projects were funded. The projects were:

1. Electronically switched, doppler ranging LiDAR (UQ, ANU)
2. The Power of One Qubit (MQ, UWA)
3. Translating software for quantum error correction (USyd, MQ, UQ)
4. Stabilisation of stratospheric and LEO coherent optical links (UWA)
5. Compact high-resolution Echelle spectrograph (MQ, Redback Systems, see page 55)
6. Low Phase Noise Tuneable Probe Field for Classical and Quantum Sensing (UWA).

The funds were to be used for developing a research product to some proof-of-principle or conceptual demonstration in order to allow these projects to be in a ready state for the appropriate. All the projects are underway and so far two of these projects are proceeding to early stage commercialisation at their universities and one is moving to trials with external partners.

Below
The inaugural EQUS Industry Showcase in Brisbane

Research translation

BRISBANE INDUSTRY SHOWCASE

We ran a successful event in Brisbane showcasing the Centre's research themes to an audience of business and government. The event also provided opportunities for Centre staff to show technologies which have wider and potentially commercial applications. A total of sixteen Centre projects, across six industry themes, were presented. This event was the first of a series of events, which will occur over the life of the Centre.

REDBACK SYSTEMS MAKES IT TO ON ACCELERATE

Researchers across almost every scientific discipline utilise spectroscopic techniques to interrogate light – probing its intensity as a function of its wavelength. By collecting this information, researchers can probe many physical systems – from the material composition of stars and galaxies and the detection of previously undiscovered exoplanets, to the probing of atomic scale defects in next-generation nanomaterials and even to interact with quantum hardware.

The Redback Systems team is building a compact, affordable and robust ultra high-resolution spectrograph to enable researchers to conduct precision experiments. By using a modified echelle spectrograph design we can achieve broad-spectrum, single exposure imaging with high spectral resolution.

At ON Accelerate, the team will validate and develop their innovative venture with commercialisation specialists.

Left
The Redback Systems team at ON Prime

Equity and diversity

Addressing issues of equity and diversity is a priority for EQUS. The Centre is underpinned by a commitment to equal opportunity and diversity. Centre members strive to treat everyone in an unbiased and inclusive manner, and to remove barriers of disadvantage for all members and the wider research community.

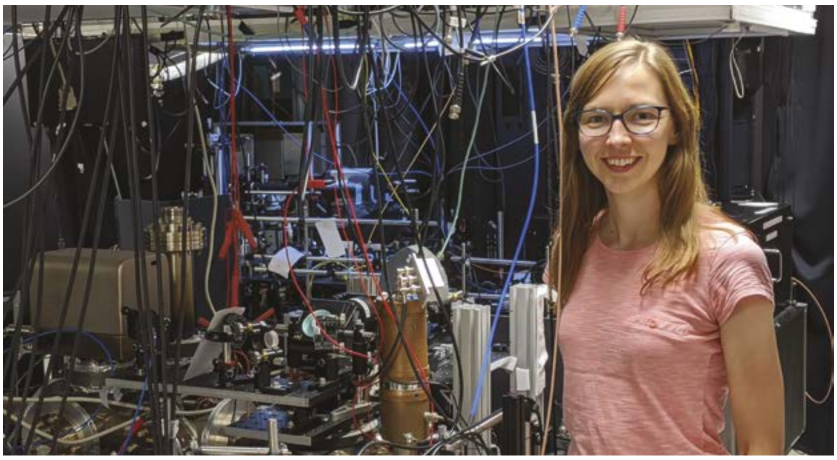
Right
UWA LGBT STEM cakes

DEBORAH JIN FELLOWSHIP

EQUS created an initiative to recruit to women-only Postdoctoral Research Fellows. This initiative was called the Deborah Jin Fellowship.

Deborah S. Jin was a brilliant American physicist who was one of the world's foremost experts on how ordinary atoms and molecules change their behaviour at extraordinarily low temperatures. Her visionary and methodical approach made it possible to use these ultracold gases as model systems to tease out the quantum principles that lead to behaviours in real materials, such as superconductivity.

Below
Dr Elizabeth Bridge



The Deborah Jin Fellowship honours her legacy by supporting and encouraging early- and mid-career women physicists.

Dr Elizabeth Bridge was awarded the fellowship and will be working with Chief Investigator Bowen at UQ.

Dr Cindy Zhao was awarded the fellowship and will be working with Chief Investigator Tobar at UWA.

Equity and diversity

INDIGENOUS ATTENDEES AT SCIENCE MEETS PARLIAMENT

In partnership with Science & Technology Australia and the Australian Academy of Science, EQUS supported scholarships to STEM practitioners with an Indigenous background to attend Science Meets Parliament in Canberra.

Two Indigenous scientists were selected. The recipients were:

Professor Chris Matthews, Associate Dean Science Faculty, University of Technology Sydney – Aboriginal and Torres Strait Islander Mathematics Alliance (ATSIMA)

Mr Djarra Delaney, Aboriginal and Torres Strait Islander Community Engagement Coordinator, Bureau of Meteorology – Australian Meteorological & Oceanographic Society (AMOS)

The scholarships covered travel, accommodation, meals and transfers, as well as full registration for the event including the gala dinner in the Great Hall at Parliament House. Financial assistance for childcare was also available upon application.

EQUS ALLIES

A number of EQUS researchers have completed LGBTIQA+ training at their host universities. Anyone who has completed this training now has a rainbow EQUS logo on their website profile.

Below
Example profiles of EQUS Allies

PROF. ANDREW WHITE
Centre Director

LISA WALKER
Chief Operating Officer

PAUL ALTIN
Research Fellow

YASMINE SFENDLA
PhD Student

TARA ROBERSON
Communications Specialist

EQUIP EVENTS PROGRAM

The committee coordinated events across all five nodes for various international days of recognition including: International Day for LGBT persons in STEM, International Day of Women and Girls in Science, and Ada Lovelace Day.

These regularly include short thoughtful addresses by local node members to encourage conversations.

Communication and outreach

EQUS researchers engaged diverse audiences with quantum science and technologies over the past twelve months.

The Centre promoted new research, public events, and other activities and achievements through media releases, the EQUS website and on social media. Our researchers provided multiple briefings to government, industry and other end-user groups, and supported professional development opportunities for science teachers across Australia.

The following are selected highlights from 2019.

QUANTUM SHORTS

Following the announcement of the Quantum Shorts quantum-themed films shortlist, EQUS held two Quantum Shorts screenings in Sydney and Brisbane during April. Altogether 110 people attended these events.

Right
Quantum Shorts film screening in Brisbane

PINT OF SCIENCE

Pint of Science is a public engagement initiative that sees events held in venues across Australia during May. In 2019, EQUS researchers presented in capital cities around Australia, including Brisbane, Sydney, Canberra and Perth.

PINT OF SCIENCE

Communication and outreach

SOAPBOX SCIENCE

EQUS selected PhD researcher Riddhi Gupta to speak at Soapbox Science Sydney on 10th August with the talk: "Machine Learning and Quantum Control – Using our engineering past to navigate a quantum future".

Left and below left
PhD researcher Riddhi Gupta presents at Soapbox Science

QUANTUM GAMES

Quantum Games is a competition for quantum-themed computer game development. Planning is underway with the intent of exhibiting shortlisted video games at the World Science Festival Brisbane in March 2020. Quantum Games launched in September 2019 with a short workshop run in Brisbane (October 2019) to help game developers work on their concepts. Promotion will continue until submission for the competition closes on January 31, 2020.

Below
EQUS attendees – Sarah Lau (back, second from left), Prof Tom Stace (back, far right) and Prof Michael Tobar (front, second from right) – at Science Meets Parliament 2019

SCIENCE MEETS PARLIAMENT

In collaboration with the equity and diversity portfolio, the public engagement committee has supported sponsorship of scholarships for Aboriginal and Torres Strait Islander researchers to attend Science meets Parliament. In addition, four EQUS representatives will attend the event and engage with parliamentarians and policy makers. The EQUS representatives were: Chief Investigators Tom Stace and Michael Tobar as well as Sarah Lau and Tara Roberson.

Mentoring and career development

EQUS provides training for graduate students and Early Career Researchers across all five nodes. This training supports the advancement of their research skills and broader knowledge of the field. Training opportunities also address skills that will assist our students and researchers in their academic and industry careers.

In addition to running professional development events during 2019, EQUS continued its mentoring program to provide career-oriented support for students as well as Centre collaboration grants for postgraduate students and ECRs and summer projects for undergraduates.

The following are highlights from 2019.

EQUS WEBINARS

This year saw the launch of EQUS webinars, broadcast to all EQUS nodes. EQUS PhD researcher Riddhi Gupta and postdoc researcher Dr Yuval Sanders developed the series to share knowledge and foster collaboration amongst EQUS researchers. Riddhi and Yuval presented a web-based tutorial-style lecture intended as a kick-off for what is planned to be regular event in 2020.

Three webinars have been delivered to date: the first on Mathematica with Dr Yuval Sanders, the second on developing mentoring relationships with Dr Samantha Hood, and finally Measurement Noise Filtering and Time-Series Prediction in Python by Riddhi Gupta.

These were recorded and are available for viewing on the EQUS Hub.

Right
EQUS provides training and mentoring for students and ECRs

Mentoring and career development

COLLABORATION GRANTS

EQUS awarded eight Collaboration Grants to support students and ECRs to develop new research collaborations with affiliated EQUS researchers. EQUS' mentoring program, where students and ECRs are linked with more experienced researchers, has expanded in 2019 to find mentors for postdocs and academic staff associated with EQUS.

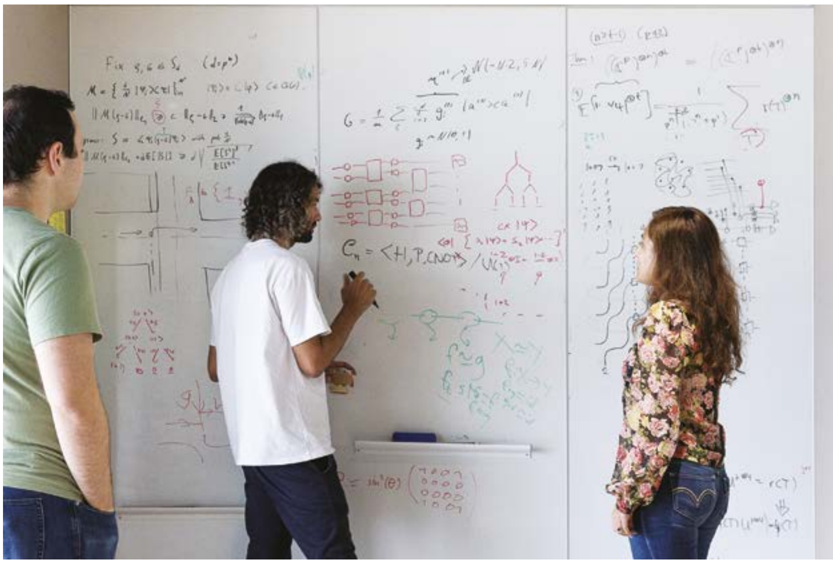
The Mentoring and Career Development committee plan to continue to grow the program and help to nurture the relationships.

WORK EXPERIENCE PROGRAM

EQUS offers summer and other casual research opportunities for talented and enthusiastic undergraduate students or recent graduates. These projects are an opportunity to get a taste for real scientific research and learn new skills.

Nine projects were awarded in 2019.

The research projects will run between November and March. Projects typically last 4 - 8 weeks and the successful students are offered a $400 per week stipend to cover costs with additional support for travel and accommodation also available.



Centre events

PYTHON WORKSHOP

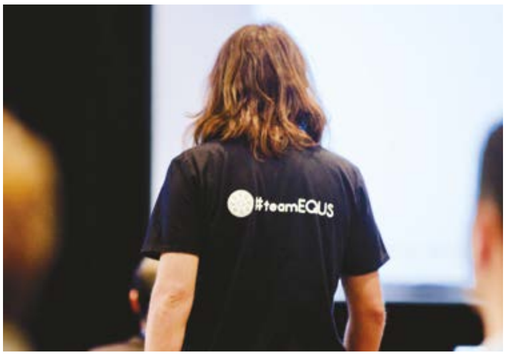
In January 2019, a Python workshop was organised by EQUS students and researchers (Virginia Frey, Dr Yuval Sanders, Alan Robertson, and Dr Lachlan Rogers).

The workshop had three objectives: introduce the Python programming language, learn how to write reliable and understandable code, and connect to the large community creating research-grade code.

The team invited speakers from Google, IBM, Microsoft and QxBranch as well as non- corporate speakers from Sandia National Labs and University of Technology, Sydney.

Fifty people attended the workshop and the team received a great deal of informal feedback indicating an eagerness in the community to hold another similar event in 2020.

Below
#teamEQUS Summer School and Annual Workshop



IDEA FACTORY

The fourth annual Idea Factory was held in June 2019 in Caloundra and run in collaboration with the ARC Centre of Excellence in Future Low-Energy Electronics Technologies (FLEET) with about 35 attendees.

Past Idea Factories had focussed on scientific communication and writing academic grants. In 2019, the focus was entrepreneurship – still largely about communication, but this time to a different audience.

"Angel Investor" Dean Alle facilitated an short version of the CSIRO-sponsored ON Prime program over two days. Participants went through the process of converting research into an investable product and identifying potential customers.

The culmination was a three-minute pitch to separate groups of teenagers and members of the public, and gathering feedback on what worked and what didn't.

A quote from a student that attended:

"… despite my scepticism about attending, I left the workshop glad I had done so. I felt that bit more confident about communicating science to the public, and that bit more knowledgeable about how to critically think about what is important about the research we do."

Centre events

SUMMER SCHOOL

The Summer School was held directly before the annual workshop in December at the Novotel Hotel, Wollongong. With 50 student and three international speakers, the event was both challenging and insightful to attendees. The speakers were:

- **Dr Martin Ringbauer** (University of Innsbruck)
- **Prof Ajit Srivastava** (Emory College of Arts and Science, Atlanta)
- **Prof Liang Jiang** (University of Chicago).

The Summer School was concluded with a round table discussion titled "Life after your PhD" in which the speakers participated in an open-floor discussion that revolved around:

- What to think about in the last year of your thesis
- Applying for a postdoc vs finding funding for a research project
- Careers outside of academia.

ANNUAL WORKSHOP 2019

The EQUS Annual Workshop is the primary forum for the collaborative nature and exchange of ideas that the Centre depends on. The Workshop included over 140 attendees ranging from PhD students to Chief Investigators and also included members of our Scientific Advisory Committee.

The highlights from the event included:

- The internationally renowned invited speakers included **Ajit Srivastava** from Emory College of Arts and Science, **Elisabetta Barberio** from the University of Melbourne, **Janet Anders** of the University of Exeter, **Liang Jiang** from the University of Chicago and **Dr Laura Greene**, the chief scientist at the National MagLab
- The announcement of the new Centre prize winners.

Below
Attendees at the EQUS Summer School and Workshop in 2019

Publications

DT Le, A Grimsmo, C Mueller and TM Stace **'A Doubly non-Linear Superconducting Qubit'** *Physical Review A* vol 100 issue 6 10.1103/PhysRevA.100.062321

N McMahon, S Singh and GK Brennen **'A Holographic Duality Using Lifted Tensor Networks'** *Physical Review D* vol 97 issue 2 10.1103/PhysRevD.97.026013

BQ Baragiola, G Pantaleoni, RN Alexander, A Karanjai and NC Menicucci **'All-Gaussian universality and fault tolerance with the Gottesman-Kitaev-Preskill code'** *Physical Review Letters* vol 123 issue 20 10.1103/PhysRevLett.123.200502

K Korzekwa, CT Chubb and M Tomamichel **'Avoiding Irreversibility: Engineering Resonant Conversions of Quantum Resources Avoiding Irreversibility: Engineering Resonant Conversions of Quantum Resources'** *Physical Review Letters* vol 122 issue 11 10.1103/PhysRevLett.122.110403

M Goryachev, B McAllister and ME Tobar **'Axion Detection with Precision Frequency Metrology'** *Physics of the Dark Universe* vol 26 10.1016/j.dark.2019.100345

J Geordy, LJ Rogers, CM Rogers, T Volz and A Gilchrist **'Bayesian estimation of switching rates for blinking emitters'** *New Journal of Physics* vol issue 6 21 10.1088/1367-2630/ab1dfd

G Flower, J Bourhill, M Goryachev and ME Tobar **'Broadening frequency range of a ferromagnetic axion haloscope with strongly coupled cavity–magnon polaritons'** *Physics of the Dark Universe* vol 25 10.1016/j.dark.2019.100306

J White, C Laplane, R Roberts, L Brown, T Volz and D Inglis **'Characterization of optofluidic devices for the sorting of sub-micron particles'** *Applied Optics* vol 59 issue 2 10.1364/AO.59.000271

TM Roberson and AG White **'Charting the Australian quantum landscape'** *Quantum Science and Technology* vol 4 issue 2 10.1088/2058-9565/ab02b4

YP Sachkou, CG Baker, GI Harris, OR Stockdale, S Forstner, MT Reeves, X He, DL McAuslan, AS Bradley, MJ Davis and WP Bowen **'Coherent vortex dynamics in a strongly interacting superfluid on a silicon chip'** *Science* vol 366 issue 6472 10.1126/science.aaw9229

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Key Performance Indicators

	TARGET 2019	RESULT 2019
RESEARCH OUTPUTS AND SERVICE		
Peer-reviewed journal articles	50	67
High impact publications (citations in top 20% most cited papers in fields of physics)	10	7
International and national advisory boards in the research field of the Centre	2	6
Keynote and plenary addresses at international and national conferences	2	12
Editorial boards for international peer reviewed journals in the research field of the Centre	2	6
Program committees for international and national conferences	8	12
Invited talks/papers at international meetings	20	37
Training courses held/offered by the Centre	3	4
Workshops/conferences held/offered by the Centre	3	2
PEOPLE AND TRAINING		
New postdoctoral researchers working on Centre research	4	5
New Honours supervised by Centre researchers	5	10
New PhD supervised by Centre researchers	5	10
New Masters supervised by Centre researchers	0	1
New Associate Investigators	3	6
PhD completions	0	13
Honours completions	5	7
EQUS Mentoring Program	1	1
Delivery of EQUS Induction program	1	1

Key Performance Indicators

	TARGET 2019	RESULT 2019
COMMUNICATION AND OUTREACH		
Talks open to the public	5	30
Talks/presentations/briefings to government	2	5
Talks/presentations/briefings to industry/ business/end-users	2	7
Annual training for STEM teachers	60 teachers	32
Outreach activities for school students	12	16
Industry engagement events	2	1
NEW COLLABORATIONS		
New industry collaborative relationships	0	0
New academic collaborative relationships	0	11
EQUITY		
Female Higher Degree Research (HDR) students	15%	23%
Female postdoctoral researchers	10%	10%

Income and expenditure report

	2019 Actuals $	2020 Forecast $	2021 Forecast $
INCOME			
ARC Centre of Excellence Grant			
ARC Centre of Excellence Grant[1]	4,724,095	4,829,204	4,901,642
Administering and Collaborating Organisation Contributions			
The University of Queensland	538,160	538,160	538,160
The University of Sydney	365,555	365,555	365,555
Macquarie University	151,452	151,452	151,452
Macquarie University – Scholarships[2]	–[3]	–	–
The University of Western Australia	142,207	142,207	142,207
The Australian National University[4]	39,470	52,627	52,627
Partner Organisation Contributions			
Defence Science and Technology	100,000	100,000	100,000
University of Ulm	4,688	4,688	4,688
TOTAL INCOME	**6,065,627**	**6,183,893**	**6,256,331**
EXPENDITURE			
Salaries	2,937,584	4,301,394	3,774,019
Scholarships	419,898	423,985	380,981
Equipment	433,393	229,538	161,000
Research Maintenance & Consumables	275,363	514,886	467,903
Travel	701,678	680,393	635,893
Admin, Operational & Other	322,359	543,222	513,222
TOTAL EXPENDITURE	**5,090,275**	**6,693,418**	**5,933,018**
ANNUAL SURPLUS/(DEFICIT)	**975,351**	**(509,524)**	**323,313**
BALANCE BROUGHT FORWARD FROM PREVIOUS YEAR	**6,581,829**	**7,557,180**	**7,047,656**
TOTAL CARRYFORWARD TO NEXT YEAR[5]	**7,557,180**	**7,047,656**	**7,370,970**

Notes:

1 ARC income forecast for 2020 & 2021 is based on a 1.5% yearonyear indexation increase.

2 MQ will disburse funds to the total of $455,964 for scholarships over the remaining life of the Centre.

3 As at 31 December 2019, MQ funds of $191,593 were recorded in a separate general ledger account at MQ. In accordance with the Participants Agreement, the funds are available to EQUS Chief Investigators for international tuition fee scholarships. The amount of $191,593 is represented by cash contributions for the two years to 31 December 2019 of $227,982, less scholarship expense to the reporting date of $36,389.

4 ANU contributed an additional 25% of its 2019 cash contribution in 2018 ($13,157). Subsequently in Q1 2019, ANU reversed this and is reflected in the Q1 2019 Actuals.

5 The large carryforward from 2019 to 2020 is due to $4,500,000 of the Centre's 2019 budget received in 2018 due to the Centre delaying its commencement to 2018 instead of 2017. Consequently, there will always be a large carryforward to the next year. This also includes $429,857 of ARC indexation for 3 years yet to be distributed.

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