ARC Centre of Excellence for Engineered Quantum Systems

ANNUAL REPORT 2016

eQus

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
The University of Western Australia
UNSW Australia

Microscope construction at EQuS. Photo credit: Patrick Self.

Contents

ANNUAL REPORT 2016

Vision

At the ARC Centre of Excellence for Engineered Quantum Systems (EQuS), we are engineering the quantum future. By discovering how to control and exploit the most exotic phenomena in quantum theory, our Centre is building a new discipline with the potential to radically transform technology.

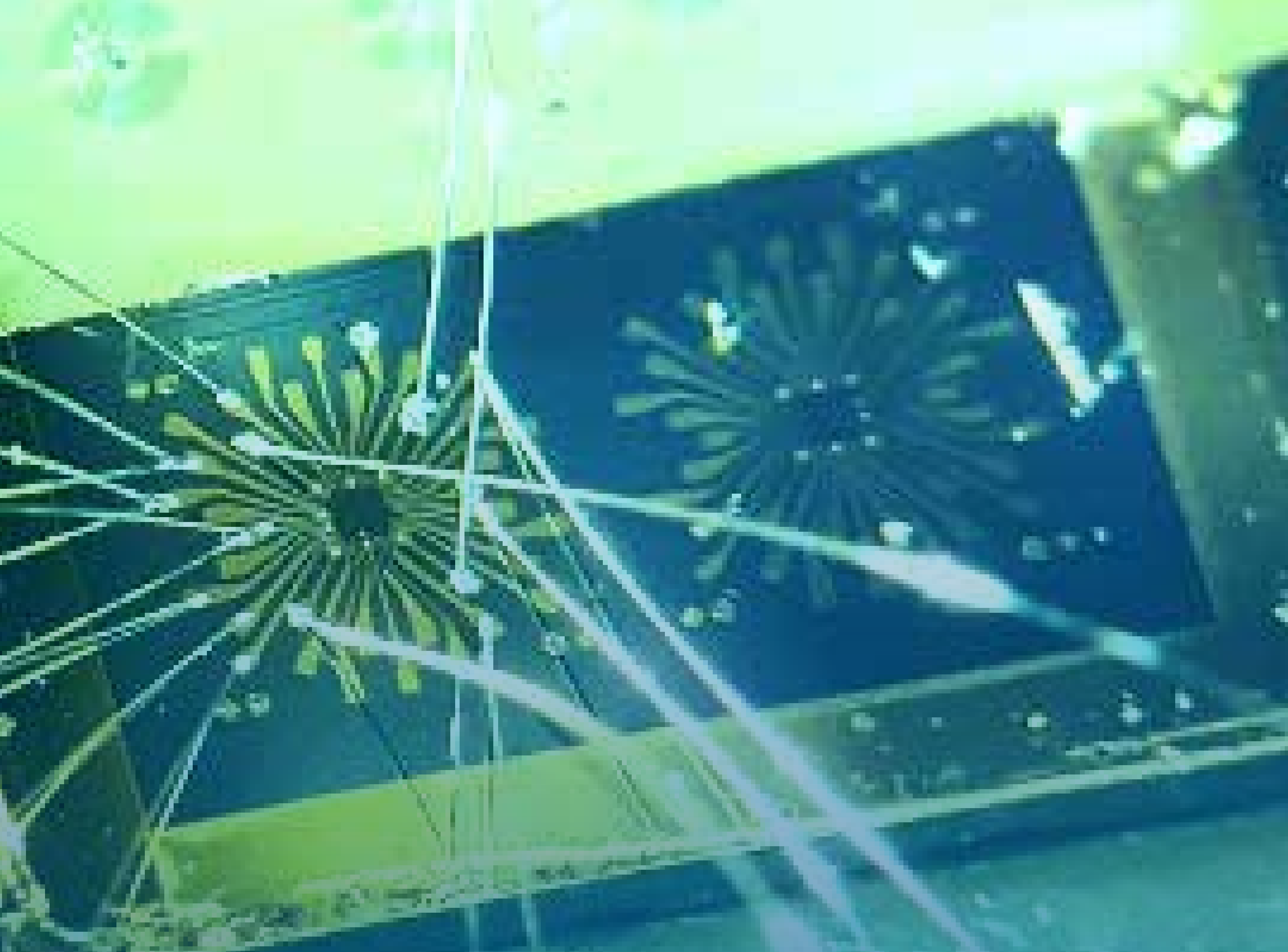
Mission

To exploit the vast resources of the quantum realm to produce new capabilities, new technologies, and new science through the creation of designer quantum systems.

Aims

The primary goals of EQuS are to:

- Establish a world-leading research community driving the development of quantum technologies, with Australia as the focus of international efforts.
- Stimulate the Australian scientific and engineering communities to exploit quantum devices and quantum coherence in next-generation technologies.
- Train a generation of young scientists with the skills needed to lead the future of technology development.
- Demonstrate the potential and capabilities of engineered quantum technologies by realizing technological breakthroughs in novel and useful engineered quantum coherent systems.
- Create a design methodology supporting the development of all new technologies for the Quantum Era.



Overview

The ARC Centre of Excellence for Engineered Quantum Systems (EQuS) seeks to move from Quantum Science to Quantum Engineering – building and crafting new quantum technologies. The University of Queensland, and the collaborating institutions The University of Sydney, Macquarie University, The University of Western Australia and the University of New South Wales, provide the world's first focussed research program on systems engineering in the quantum regime. EQuS is addressing fundamental questions about the benefits and limits of quantum technologies, developing strategies for producing novel quantum-enhanced devices, and exploring new emergent physical phenomena that arise only in the presence of complex, integrated quantum systems.

The Centre's main source of funding is the Australian Research Council (ARC) through the Centres of Excellence program. The ARC provides $3.5 million per annum, and the administering institution, The University of Queensland, and the collaborating institutions The University of Sydney, Macquarie University, The University of Western Australia and the University of New South Wales contribute ~$1.2 million in cash contributions per year.

Background image: A quantum processor by the Quantum Nanoscience Lab team

The research infrastructure, expertise and collaborations we have built up in the first six years of the Centre have positioned Australia at the forefront of this new field.

Image: Electric currents in this copper wiring generate a magnetic field to contain cold atoms. Captioned by Samantha Hood. Photo credit: Patrick Self

Director's update

It is a great pleasure to welcome you to the 2016 annual report of the Australian Research Council Centre of Excellence for Engineered Quantum Systems—EQuS to our friends.

We have once again had a very successful year of research: on pages 20-37 you can find highlights from our three research programs in Quantum Measurement & Control, Quantum-enabled Sensors & Metrology, and Synthetic Quantum Systems and Quantum Simulation. 2017 promises to be an even more successful year, as we outlined in our Activity Programs on pages 25, 31 and 37.

Our students are not only at the heart of our research they are our best ambassadors—notable examples from 2016 include Dr Martin Ringbauer attending the annual gathering of Nobel Laureates in Lindau, Germany as one of only seven Australian attendees, see page 23; and Ms Xanthe Croot being awarded a Startup Catalyst scholarship, which took her on a 10-day immersive trip to the Silicon Valley, see page 29.

Last year we continued not only our regular Centre activities—such as the Winter School, Annual Workshop, Optomechanics Incubator and Coogee Theory Workshop—but introduced events that were conceived and led by our young researchers, notably the Idea Factory and the Python Workshop, see pages 46-51. We expect these will become regular features in the quantum calendar in Australia.

April saw the launch of Australia's first hub for Nanoscale Science and Technology at The University of Sydney: as detailed on pages 16-17. EQuS researchers occupy a majority of the labs in the new hub and are hard at work building quantum devices and running quantum simulations.

A key feature of EQuS is our involvement with industrial partners, from small-to-medium enterprises through to multinationals. In 2016, we were delighted to support CI Reilly in a new partnership with Microsoft, announced in November, see page 30.

At the end of the year, our founding Director, Professor Gerard Milburn, stepped down, and I am thrilled to say will continue in EQuS as an active researcher. I wish to acknowledge the absolutely critical and significant contributions from Gerard in establishing not only our Centre, but the field of quantum engineering, both in Australia and internationally. Gerard's vision of quantum engineering is one that inspired and excited all of us, and indeed was the catalyst for the Centre's formation, starting with a meeting in Cairns a decade ago.

The research infrastructure, expertise and collaborations we have built up in the first 6 years of the Centre have positioned Australia at the forefront of this new field. We are very happy indeed to announce that a new Centre of Excellence for Engineered Quantum Systems will be starting in 2018, running through to 2024. It is one of nine new Centres of Excellence, of which five involve quantum science and technology. We have another exciting decade ahead of us!

Professor Andrew White, Director
March 2017

Scientific Advisory Committee

The Scientific Advisory Committee advises the Centre Director on the strategic direction of current and future scientific programs to ensure that these are of the highest quality. It is comprised of eminent researchers from the US, the UK and elsewhere, and meets once a year. The board evaluates the Centre's progress by reviewing annual reports and offering advice on areas for improvement and new research directions. The Scientific Advisory Committee met at the Annual Workshop in December 2016.

- Professor Sir Peter Knight, FRS (Chair), The Kavli Royal Society International Centre and Imperial College London, UK
- Professor Mikhail Lukin, Harvard University, USA
- Professor John Clarke, University of California, Berkeley, USA
- Professor Alain Aspect, Ecole Polytechnique and Institut d'Optique, Graduate School, France
- Professor Rainer Blatt, Institute for Quantum Optics, University of Innsbruck, Austria
- Dr Rowan Gilmore (Advisory Board Chair), EM Solutions, Pty Ltd, Australia

Advisory Board

The Advisory Board consists of 13 members, including an eminent Chair. The Board met twice in 2016 to help create linkages with relevant associations and practitioners, and provided direction on public relations strategies, communications, and translation of knowledge into outcomes.

Membership consists of representatives of each partner institution and influential people from business and government.

- Dr Rowan Gilmore (Chair), CEO, EM Solutions Pty Ltd
- Dr Ben Greene, Group CEO, Electro Optic Systems (EOS)
- Professor Robyn Ward, DVC Research, The University of Queensland
- Mr Rick Wilkinson, COO, Eastern Region Australian Petroleum Production & Exploration Association Ltd
- Professor Sakkie Pretorius, DVC Research, Macquarie University
- Dr David Pulford, Senior Research Scientist Defence Science and Technology Group, Department of Defence
- Professor Duncan Ivison, DVC Research, The University of Sydney
- Mr Vic Dobos, CEO, Australian Science Teachers Association (ASTA)
- Professor Robyn Owens, DVC Research, The University of Western Australia
- Professor Nicholas Fisk, DVC Research, The University of New South Wales
- Professor Gerard Milburn, EQuS, The University of Queensland
- Professor Andrew White, Deputy Director, EQuS, The University of Queensland
- Ms Lisa Walker, COO, EQuS, The University of Queensland

Team

Chief investigators

CI Gerard Milburn (UQ), Centre Director
CI Andrew White (UQ), Deputy Director
CI Stephen Bartlett (USYD), Node Manager
CI Michael Biercuk (USYD)
CI Warwick Bowen (UQ), Node Manager
CI Gavin Brennen (MQ)
CI Andrew Doherty (USYD)
CI Tim Duty (UNSW), Node Manager
CI Arkady Fedorov (UQ)
CI Steven Flammia (USYD)
CI Alexei Gilchrist (MQ)
CI Ian McCulloch (UQ)
CI Gabriel Molina-Terriza (MQ)
CI David Reilly (USYD)
CI Halina Rubinsztein-Dunlop (UQ)
CI Thomas Stace (UQ)
CI Michael Tobar (UWA), Node Manager
CI Jason Twamley (MQ)
CI Thomas Volz (MQ), Node Manager

Professional staff

Lisa Walker (UQ), Chief Operations Officer
Angela Bird (UQ), Centre Administration Officer
Lynne Cousins (MQ), Node Administrator
Ruth Forrest (UQ), Executive Assistant to Centre Director
Natalie Jagals (UWA), Node Administrator
Tara Roberson (UQ,) Communications Officer
Joyce Wang (UQ), Business Manager
Wicky West (USYD), Node Administrator

Early Career Researchers

Rafael Alexander (USYD)
Ben Baragiola (MQ)
Sahar Basiri Esfahani (UQ)
Jeremy Bourhill (UWA)
Carlo Bradac (MQ)
James Colless (USYD)
Chris Ferrie (USYD)
Maxim Goryachev (UWA)
Chris Granade (USYD)
Cornelius Hempel (USYD)
Ulrich Hoff (UQ)
Markus Jerger (UQ)
Sarah Kaiser (MQ)
Rachpon Kalra (UQ)
Beibei Li (UQ)
Sandeep Mavadia (USYD)

Early Career Researchers

Volodymyr Monarkha (UQ)
Clemens Mueller (UQ)
Stephen Parker (UWA)
Martin Ringbauer (UQ)
Jacqui Romero (UQ)
Stuart Szigeti (UQ)
Marco Tomamichel (USYD)
Robert Wolf (USYD)
Magdalena Zych (UQ)

Researchers

Marcus Appleby (USYD)
Mark Baker (UQ)
Christopher Baker (UQ)
Karin Cedergren (UNSW)
Joshua Combes (UQ)
Leandro De Paula (UWA)
Yaohui Fan (UWA)
Miguel Ferreira (MQ)
Simon Haine (UQ)
Mattias Johnsson (MQ)
Mathieu Juan (MQ)
Ivan Kassal (UQ)
Jean Michel Le Floch (UWA)
Lars Madsen (UQ)
Guilllermo Munoz Matutano (MQ)
Tyler Neely (UQ)
Marcelo Pereira de Almeida (UQ)
Alexander Sharp (USYD)
Suhkbinder Singh (MQ)
Victor Manuel Valenzuela Jimenez (UQ)
Xavier Vidal (MQ)
Till Weinhold (UQ)
Ke Yu Xia (MQ)

Technical staff

Brendan Atlus (USYD)
Kushal Das (USYD)
Deshan Govendor (USYD)
Andrew Kelly (USYD)
Stephen Osborne (UWA)
Yuanyuan Yang (USYD)

Research assistants

Charles Oliver Lotz (USYD)
Nicholas Ranson (USYD)

Team

PhD students

Raphael Abrahao (UQ)
Babatunde Ayeni (MQ)
Harrison Ball (USYD)
Christaan Bekker (UQ)
Thomas Bell (UQ)
James Bennett (UQ)
Thomas Boele (USYD)
Andrew Bolt (UQ)
George Brawley (UQ)
Jacob Bridgeman (USYD)
Alexander Buese (MQ)
Simon Burton (USYD)
Catxere Casacio (UQ)
Chris Chubb (USYD)
Marie Claire Jarratt (USYD)
Ignazio Cristina (USYD)
Xanthe Croot (USYD)
Natalia Do Carmo Carvalho (UWA)
Claire Edmunds (USYD)
Stefan Forstner (UQ)
Virginia Frey (USYD)
Nick Funai (USYD)
Guillaume Gauthier (UQ)
Christina Giarmatzi (UQ)
Geoffrey Gillett (UQ)
Parth Girdhar (USYD)
Todd Green (USYD)
Riddhi Gupta (USYD)
Robin Harper (USYD)
Rob Harris (UQ)
Xin He (UQ)
Samantha Hood (UQ)
MD Akhter Hosain (UWA)
Lewis Howard (UQ)
Clara Javaherian (MQ)
Angela Karanjai (USYD)
Kiran Khosla (UQ)
Nikita Kostylev (UWA)
Anatoly Kulikov (UQ)
Sarah Lau (UQ)
Isaac Lenton (UQ)
Juan Loredo Rosillo (UQ)
Alice Mahoney (USYD)
Christian Marciniak (USYD)
Nicolas Mauranyapin (UQ)
Nathan McMahon (UQ)
Aleksandrina Nikolova (UQ)
Hakop Pashayan (USYD)
Sebastian Pauka (USYD)
Jason Pillay (UQ)
Varun Prakash (UQ)
Sarath Raman-Nair (MQ)
Markus Rambach (UQ)
Ewa Rej (USYD)
Reece Roberts (MQ)
Sam Roberts (USYD)
Alistair Robertson-Milne (USYD)
Erick Romero Sanchez (UQ)
Andres Rosario Hamann (UQ)
Seyed Saadatmand (UQ)
Yauhen Sachkou (UQ)
William Soo (USYD)
Andrea Tabachinni (MQ)
Hossein Tavakoli-Dinani (MQ)
Natasha Taylor (UQ)
Nora Tischler (MQ)
Behnam Tonekaboni (UQ)
David Tuckett (USYD)
Matthew Van Breugel (MQ)
David Waddington (USYD)
Muhammed Waleed (UQ)
Andrew Wood (MQ)
Nick Wyatt (UQ)
Yimin Yu (UQ)
Nor Azwa Zakaria (UQ)
Cindy Zhao (USYD)

Team

Masters students

Oliver Conquest (MQ)
Cameron Duncan (USYD)
Samuel Elman (USYD)
Jake Glidden (UQ)
Bryte Hagan (MQ)
Rochelle Martin (MQ)
Benjamin McAllister (UWA)
Alexander Soare (USYD)
Dean Southwood (MQ)

Honours

Roger Ackroyd (UNSW)
Alex Hung (USYD)
Justin Kruger (UWA)
Kehuan Shi (USYD)
Thomas Smith (USYD)
Paul Webster (USYD)

Undergraduate

Taiga Adair (USYD)
Oliver Alexander (USYD)
Tim Collier (USYD)
Sean Dawson (USYD)
Ruell Domaoal (USYD)
Kwan Goddard (UQ)
Eric Huang (USYD)
Luke James (UQ)
David Long (USYD)
Campbell McLaughlan (USYD)
Matthew O'Brian (MQ)
Fredericio Roy (USYD)

Occupational trainees

Severin Charpignon
Maximillian Zanner
Valentin Stauber

New students PhD

CatxereCasacio, *Quantum enhanced microscopy*
Raphael Abrahao, *Room temperature cavity quantum electrodynamics*
Christiaan Bekker, *Integrated cavity opto-mechanics*
Varun Prakash, *Precision optomechanical magnetometry*
David Tuckett, *Fault tolerant methods for quantum error correcting codes in two dimensional architectures*
Riddhi Gupta, *Control theory*
Claire Edmunds, *Demonstrating the use of phase modulated gates to decouple spin and vibrational modes in trapped ion systems*
Alistair Robertson Milne, *Programmable quantum simulation using trapped ions*
Lewis Howard, *Measuring quantum effects*
Anatoly Kulikov, *Quantum hybrid systems based on macroscopic mechanical resonators and superconducting circuits*
Sarath Raman-Nair, *Coupling single and multiple color centres in diamond to fiber-cavities*

New Masters by research

Oliver Conquest, *Nanoscale raman spectroscopy with diamond*
Cameron Duncan, *Tensor network states in negatively curved space*
Samuel Elman, *Long-distance entanglement of singlet-triplet qubits via quantum hall edge states*
Bryte Hagan, *Quantum simulations of quantum field theory*

New Honours

Roger Ackroyd, *Anomalous critical voltages and sub-gap currents in 1D SQUID chains*
Christiaan Bekker, Whispering-Gallery-mode Integrated Cavity Opto-Electromechanical Systems
Alex Hung, *High-power UV laser system frequency locking by FPGA based PID controller for Beryllium Penning trap*
Justin Kruger, *High-Frequency microwave cavity search for dark matter axions*
Thomas Smith, *Exchange coupling of spin qubits via a system of electronic spins*
Paul Webster, *Fault tolerant logical gates in topological stabilizer codes*

OVERVIEW

19 Chief Investigators
49 Researchers
83 Higher Degree Research
6 New Honours
15 New Higher Degree Research

International visitors

Dimitris Angelakis, Centre for Quantum Technologies
Michael Berry, University of Bristol
Mario Berta, California Institute of Technology
Alexander Bilmes, Karlsruhe Institute of Technology
Ashton Bradley, University of Otago
Helen Cammack, University of St Andrews
Douglas Carmean, Microsoft
Carlton Caves, University of New Mexico
Cristiano Cituti, University Paris Diderot
Animesh Datta, University of Warwick
Doriane Drolet, University of Sherbrook
Joseph Emmerson, University of Waterloo
Tim Evans, University of Auckland
Glen Evenbly, California Institute of Technology
Andrew Ferguson, University of Cambridge
Miguel Ferreria, Universidade de São Paulo
Marcus Frembs, Imperial College
Christopher Fuchs, University of Massachusetts
Erik Gauger, Heriot-Watt University
Jonathan Gross, University of New Mexico
Sebastian Knauer, University of Bristol
George Knee, University of Warwick
Kamil Korzekwa, Imperial College London
Ronnie Kosloff, The Hebrew University of Jerusalem
Aleksander Kubica, California Institute of Technology
Yi-ChanLee, National Tsing Hua University

Team

International visitors

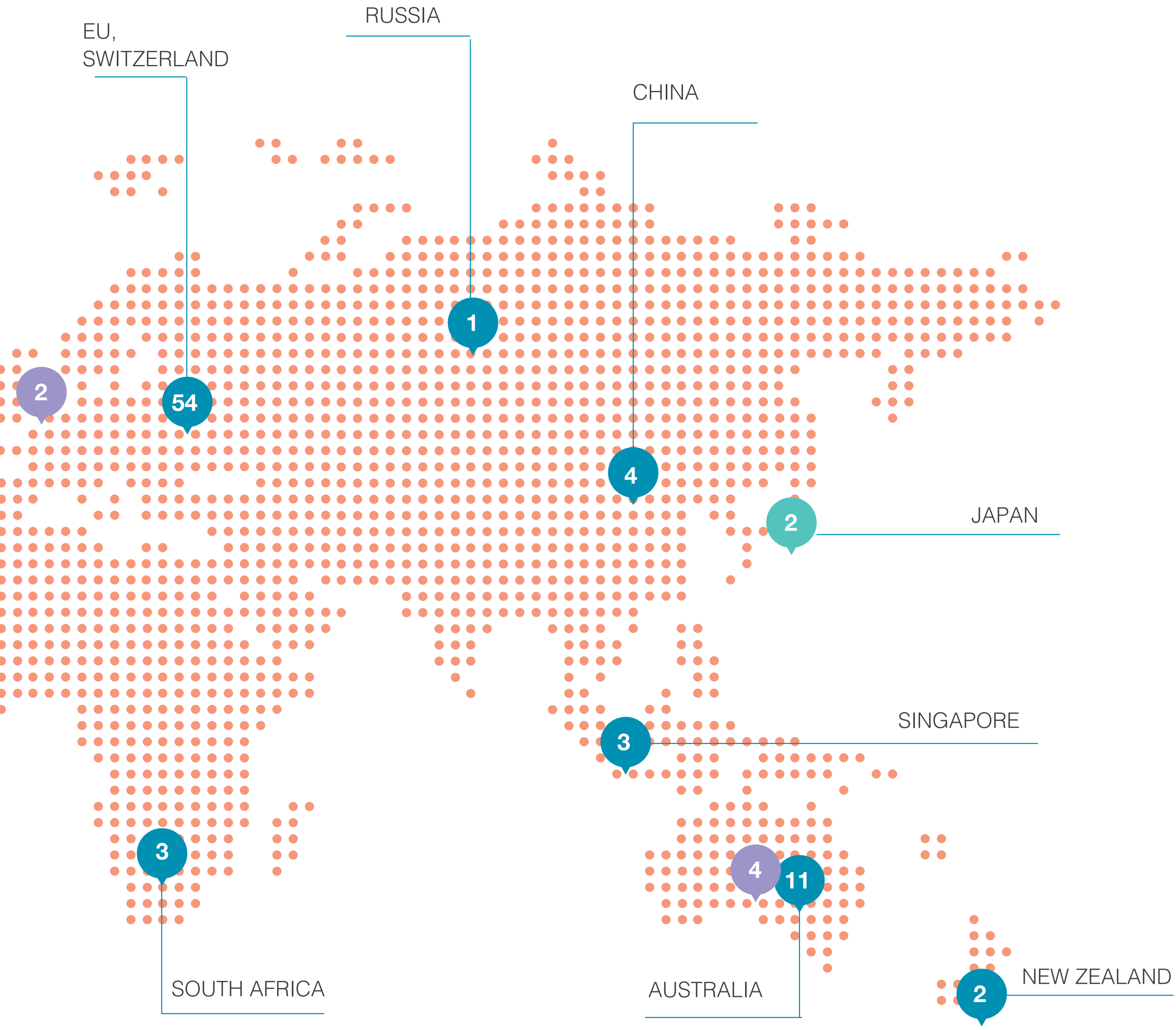
Brendon Lovett, University of St Andrews
Charlie Marcus, University of Copenhagen
Estaban Martinez, University of Innsbruck
Matthew Mckague, University of Otago
Antony Milne, Imperial College London
Tobias Osborne, Leibniz Universität Hannover
Karl Petersson, Niels Bohr Institute
Yehiam Prior, Weizmann Institute of Science
Lachlan Rogers, University of Ulm
Terry Rudolph, Imperial College London
Volkher Scholz, Ghent University
Norbert Schuch, Aachen University
Sergey Shevchenko, Karazin Kharkov National University
Xiaohui Shi, Center for Gravitational Experiment - Huazhong University of Science and Technology
Valentin Stauber, Universitat Vienna
Denis Therien, Canadian Institute for Advanced Research
Martin Van Mourik, University of Innsbruck
Michael Vanner, University of Oxford
Guifre Vidal, Perimeter Institute for Theoretical Physics
Dave Wecker, Microsoft
Stephanie Wehner, DELFT University of Technology
Norman Whitaker, Microsoft
Beni Yoshida, Perimeter Institute
Lingfei Zhao, Nanjing University
Huangjun Zhu, Perimeter Institute

Partners

Research
We are actively collaborating with researchers across the globe. In 2016, EQuS researchers worked with over 110 institutes in 20 countries.

Industry
We partnered with five organisations in 2016 to continue our work in scientific discovery and technology development.

Impact
EQuS research contributes to Australia in the areas of economy, security and environment. Our researchers regularly provide briefings to national and international bodies.



RESEARCH IMPACT

- Our Centre researchers provide advice to the **UK Scientific Advisory Board of the Building Large Quantum States Out of Light Program (UK)**
- CI Gerard Milburn advises the **UK Government Quantum Technology Strategic Advisory Board (UK)**
- CI Halina Rubinsztein-Dunlop sits on the **ARC College of Experts. She is also a Fellow of the Australian Academy of Science (AU)**
- Centre researchers have delivered multiple briefings to **DSTO, DFAT, and other branches of Australian government at all levels (AU)**
- Our CIs have delivered multiple briefings to **DARPA, NASA, the US Department of Defence and the US Airforce Office of Scientific Research (USA)**

Launch of $150m Nanoscience Hub in Sydney

Australia's first hub for nanoscience and quantum technology opened at The University of Sydney. The $150m building allows design, fabrication and testing of devices - all under one roof.

Chief Investigators David Reilly and Michael Biercuk are hard at work on flagship projects in this building. CI Reilly is building quantum devices while CI Biercuk runs quantum simulations.

Australian Academy of Science's President Andrew Holmes AM officially opened the building.

Nanoscience is expected to have more impact this century than the industrial revolution in the 19th century.

"The buildings in which we work, rather than our imaginations, are what's been limiting the science", said CI Michael Biercuk, formerly a consultant to the US government organisation DARPA and now the research leader of a quantum flagship in AINST.

More than six years in the making, the award-winning Sydney Nanoscience Hub was co-funded with $40m from the federal government. It includes teaching spaces alongside publicly available core research facilities that will support fundamental research, as well as the work of start-ups and established industry.

The Institute hosts some of the capabilities of the Australian National Fabrication Facility and of the Australian Microscopy and Microanalysis Research Facility – both co-funded by the National Collaborative Research Infrastructure Strategy (NCRIS). Researchers at the Institute contribute to two Australian Research Council Centres of Excellence: EQuS, the Centre for Engineered Quantum Systems, and CUDOS, the Centre for Ultrahigh bandwidth Devices for Optical Systems.

CI Reilly told the Huffington Post, "We're creating devices that are as small as just a few atoms, if you think about the scale of dust, a skin fleck or something that's come off your clothes that would look like a giant air balloon landing on your nanoscale chip."

IN THE MEDIA

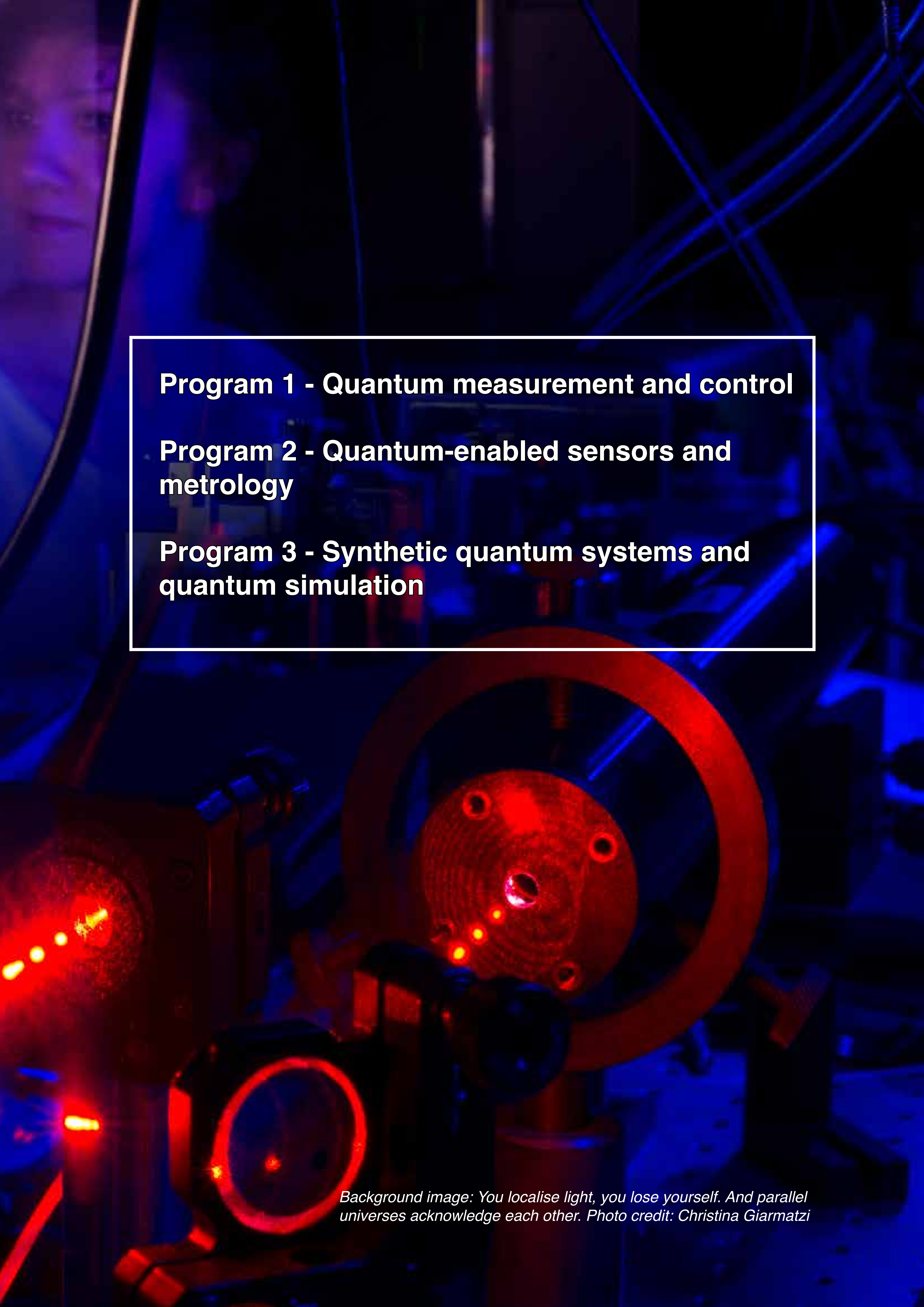
“In a lab engineered within an inch of its life, Michael Biercuk is working to change the world forever, in ways that even he doesn't quite understand.” READ MORE ONLINE

“Australia's newest nanoscience centre, built into the side of a hill, has been opened, paving the way for scientists to study the world's most minute particles and structures.” WATCH ONLINE

“David Reilly, who leads the centre's quantum nanoscience laboratory, said quantum physics was leading to new technologies that would "change the world". READ MORE ONLINE

RESEARCH PROGRAMS

EQuS RESEARCH IS ORGANISED AROUND CAREFULLY CRAFTED RESEARCH THEMES AND INDIVIDUAL PROJECTS

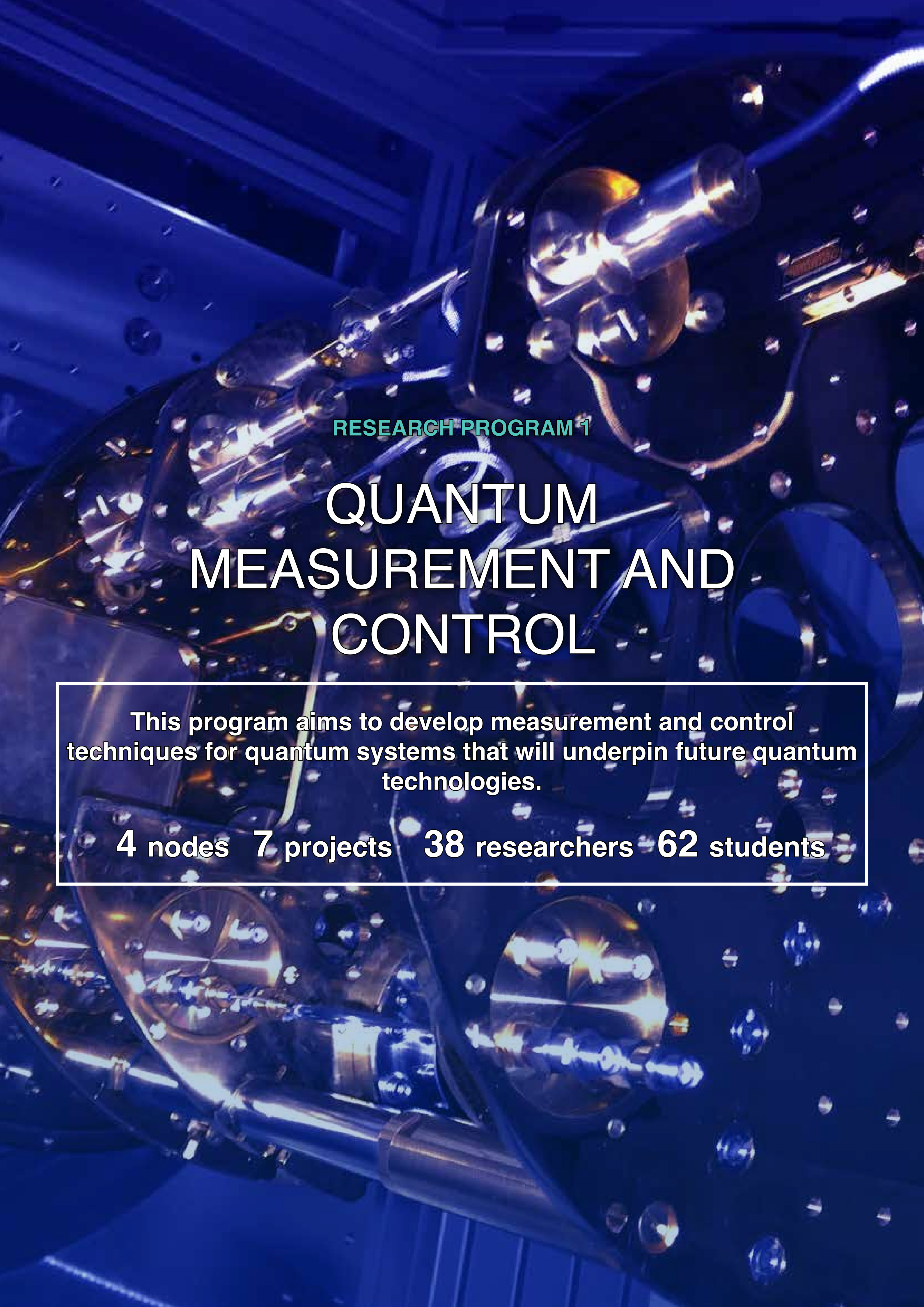


Program 1 - Quantum measurement and control

Program 2 - Quantum-enabled sensors and metrology

Program 3 - Synthetic quantum systems and quantum simulation

Background image: You localise light, you lose yourself. And parallel universes acknowledge each other. Photo credit: Christina Giarmatzi



RESEARCH PROGRAM 1

QUANTUM MEASUREMENT AND CONTROL

This program aims to develop measurement and control techniques for quantum systems that will underpin future quantum technologies.

4 nodes 7 projects 38 researchers 62 students

Effect of noise correlations on randomized benchmarking

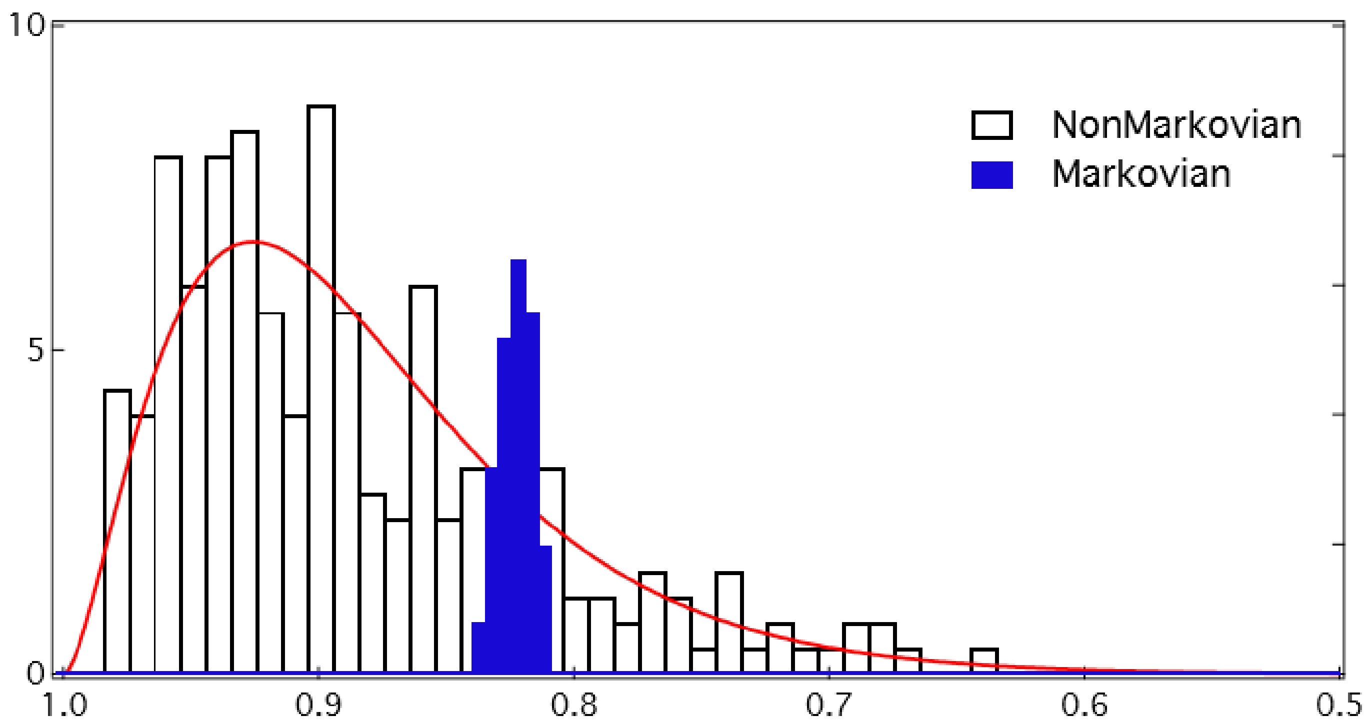
CIs Biercuk and Stace

Published in Physical Review A, 93 022303 (2016)

This project, which involves University of Sydney and University of Queensland nodes of the Centre, was supported by the first round of our inter-node collaboration grants.

Randomized benchmarking (RB) has become a standard tool for characterizing the performance of experimental quantum control experiments. However, most studies of RB either implicitly or explicitly assume that the error and noise processes being studied are Markovian – a condition rarely met in the laboratory. We set out to understand the impact of violating this assumption.

Our work showed that RB systematically underestimates mean error, and that worst-case outcomes can be considerably worse than the mean when noise processes are correlated. In addition, we developed theoretical tools allowing the distribution of *outcomes* over RB sequences to be used to identify non-Markovianity. These results have now been experimentally validated in our group using a single trapped ion, and will be the focus of a forthcoming set of publications. The figure below demonstrates that an analytic formulation for the probability distribution function—using no free parameters—matches experimental data extremely well when errors are correlated.



Laser cooling and control of excitations in superfluid Helium

CI Bowen

Published in Nature Physics 12, 788-793 (2016)

This work demonstrates real-time tracking of thermodynamical fluctuations (see figure below) in superfluid helium and laser cooling of these fluctuations. This is the first demonstration of direct laser cooling of any liquid.

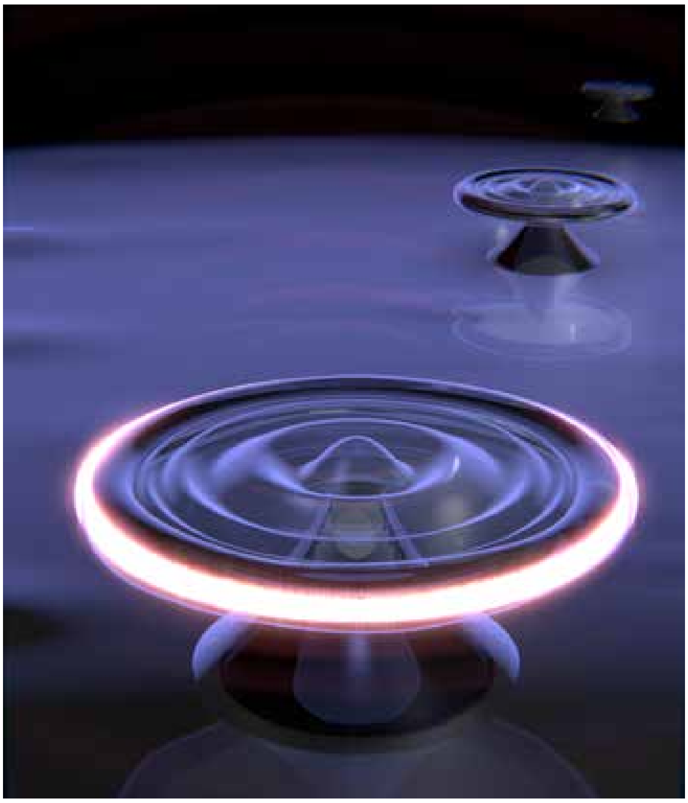
This work not only shows that superfluid helium films are a very promising optomechanical systems with very strong optomechanical coupling to whispering gallery mode optical resonators, but also demonstrates the usefulness of this coupling to probe the physics of superfluid films. This year we have been working on studies of vortex dynamics using this tool.

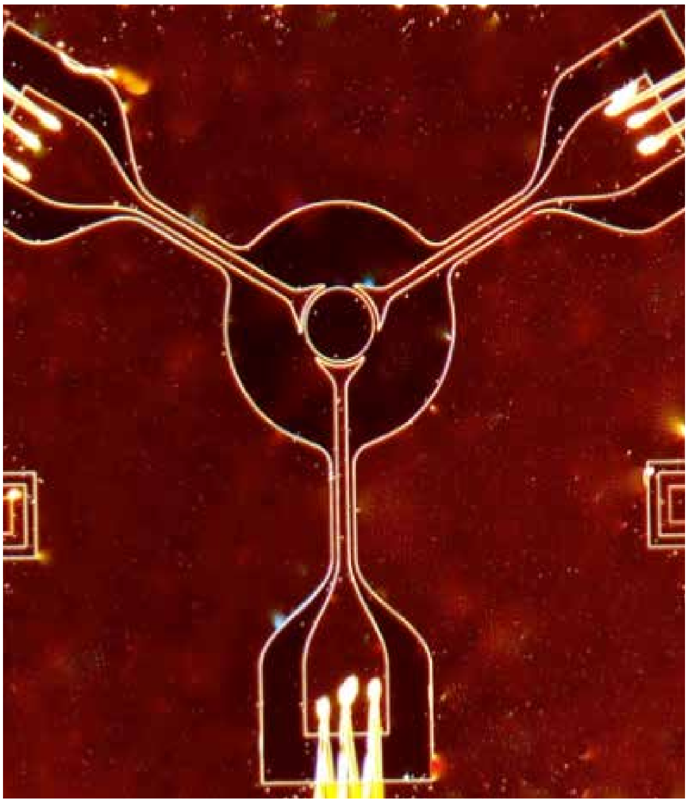
On-chip microwave quantum hall circulator

CIs Reilly and Doherty

To appear in Physical Review X, arXiv:1601.00634

Circulators are non-reciprocal circuit elements integral to technologies including radar systems, microwave communication transceivers, and the readout of quantum information devices. Their non-reciprocity arises from the interference of microwaves over the centimetre-scale of the signal wavelength in the presence of bulky magnetic media that break time-reversal symmetry. This project is developing a completely passive on-chip microwave circulator with size 1/1000th the wavelength by exploiting the chiral, 'slow-light' response of a 2-dimensional electron gas (2DEG) in the quantum Hall regime (Figure below: GaAs on chip circulator).





EQuS Chief Investigator named Australia Academy of Science Fellow

EQuS Chief Investigator Professor Halina Rubinsztein-Dunlop was named among the 21 new Australia Academy of Science Fellows in 2016.

Professor Rubinsztein-Dunlop is recognised internationally for her achievements in laser physics, linear and nonlinear high-resolution spectroscopy, laser micromanipulation, atom cooling and trapping and nano-optics.

CI Rubinsztein-Dunlop is one of the originators of laser enhanced ionisation spectroscopy, and is a pioneer of laser micromanipulation and transfer of angular momentum of light and all optical drive micromechanics. She initiated the experimental programs in laser micromanipulation and atom optics at The University of Queensland that culminated in the demonstration of dynamical tunnelling in a Bose Einstein Condensate (BEC) in a modulated standing wave. She led the team that observed dynamical tunnelling in quantum chaotic systems.

Academy of Science President, Professor Andrew Holmes, congratulated all of the new Fellows elected this year for making significant and lasting impacts in their scientific disciplines.

CI Rubinsztein-Dunlop's lab imprinted images of Einstein and Bose on a super-cold microscopic fluid to demonstrate a physics state first predicted by the famed pair in 1925.

READ MORE ONLINE

"The breadth of scientific talent recognised in this year's election is truly awe-inspiring. From breakthroughs in pure science to spurring scientific innovations, these new Fellows have made an impact on everything from the way we treat disease to how we grow our food to advancing our fundamental knowledge about the world in which we live," Professor Holmes said.

EQuS student selected to attend international summit of Nobel Laureates in Germany

After making his way through a rigorous selection process, PhD student Martin Ringbauer was invited to join the annual gathering of Nobel Laureates at Lindau.

Once a year, Nobel Laureates gather in Lindau, Germany to meet the next generation of young scientists from all over the world. In 2016, the meeting is dedicated to the field of physics.

Martin Ringbauer, a PhD student at the ARC Centre of Excellence for Engineered Quantum Systems (EQuS), said, "Being selected for the 66th Lindau Nobel Laureate Meeting is a unique opportunity and a great honour."

His research aims to explore the boundaries of quantum mechanics.

Martin has tested information causality as candidate principle for why our world is quantum and closed time-like curves as a phenomenon that might give clues as to where and how quantum mechanics and general relativity clash.

Profile

Faces of EQuS - CI Arkady Fedorov

CI Arkady Fedorov's has worked in a variety of roles in the area of quantum physics including a three-year stint at TU Delft, The Netherlands conducting experiments with superconducting flux qubits. He became a research scientist in ETH Zurich to continue research in the area of superconducting quantum devices.

Why did you choose quantum physics?

Like many undergraduates, I learnt about quantum physics at my university. I was surprised that mathematics was very different to what I expected from what I knew of classical physics. I was attracted to research on quantum optics, then quantum computing and, finally, Josephson junction qubits.

I find it exciting. The most interesting part for me is the interplay of the complexity of theory and experimentation in the lab.

What are you researching?

This year we started some new experiments. One is dedicated to build a microwave diode with superconducting qubits. This device is nonreciprocal, which means if you send a microwave through one side, it only travels in one direction. Most devices are reciprocal. Nonreciprocal devices are hard to find in nature. They are typically associated with a magnetic field – as we use magnetic material to break symmetry of the device – but in this experiment, we have built our device without one. We don't know exactly why it works at the moment, so we are continuing our research to develop our understanding.

What are you looking forward to in 2017

First, we want to finish this microwave experiment to understand our results. Second, EQuS quantum physicists at UQ have secured funding to acquire an electron beam lithography machine, to be installed in 2017. It will be one of the most advanced lithography tools in Australia and it will let us, finally, fabricate superconducting quantum devices on campus. We are looking forward to seeing this happen!

Partnership

US Government investment in quantum

An international consortium comprising European groups and The University of Sydney has been awarded a multimillion-dollar research grant from the United States Office of the Director of National Intelligence for research in quantum technology.

EQuS Chief Investigator Michael Biercuk's Quantum Control Laboratory at The University of Sydney is the only team based in Australia that has been selected for funding, but builds on a long history of collaboration between US intelligence agencies and the Quantum Science Group at The University of Sydney.

The new consortium including the Quantum Control Laboratory – led out of cutting-edge laboratories at the new $150m Sydney Nanoscience Hub launched recently – has now been selected by the United States government agency Intelligence Advanced Research Projects Activity (IARPA) as part of its LogiQ program, to help deliver a logical qubit (quantum-bit) based on trapped ions.

"Ions represent a fantastic platform helping us to learn how we can exploit the most exotic phenomena in quantum physics as resources powering a new generation of technologies," CI Biercuk said.

"There remain enormous challenges bringing any quantum computing technology to reality, but trapped-ions have demonstrated the critical building blocks essential for this effort, decades ahead of other proposed technologies."

Activity plan 2017: Quantum Measurement and Control

Work in the **group of CI Biercuk** in 2017 will contribute to the Quantum Measurement and Control Program. This group will complete experiments linked to the grand challenge of developing a Flexible Quantum Control Toolkit. They will be engaged in band-limited control experiments, studies of quantum verification and validation in correlated noise environments as part of the EQuS internode collaboration with the **group of CI Tom Stace** at The University of Queensland, and experiments on optical control of Beryllium ions.

In 2017, **CI Bowen's laboratory** will aim to realise levels of cooperativity in a superfluid optomechanical system that are sufficient, for the first time, to laser cool the motion of the superfluid to its quantum ground state, and then to demonstrate ground state cooling. Ground state cooling of mechanical oscillators was a major milestone of EQuS. The capability to achieve such control of the vibrations of a liquid was totally unanticipated in our original proposal, and will represent the first demonstration of ground state cooling of any liquid.

CI Brennen will work in collaboration with CI Volz on coherent control of collective spins encoded in colour centres in diamond including the study of super-emission/absorption with applications to quantum enhanced metrology.

The group of **CI Fedorov** is going to achieve near ground state cooling of gram scale piezo-acoustic resonator in experiment in 2017. Achieving ground state cooling of a range of mechanical systems is one of the central goals of this program.

CI Tobar and his group will be trying to achieve near ground-state cooling of gram scale mechanical systems (below one phonon average occupancy) in quartz BAW resonators, by coupling a near quantum limited SQUID amplifier made in John Clarke's laboratory at UC Berkeley. This work addresses a major milestone of EQuS. Also, CI Tobar will continue to work on novel microwave cavity designs and coupling to spins in solids. Personnel will be dedicated to these goals.

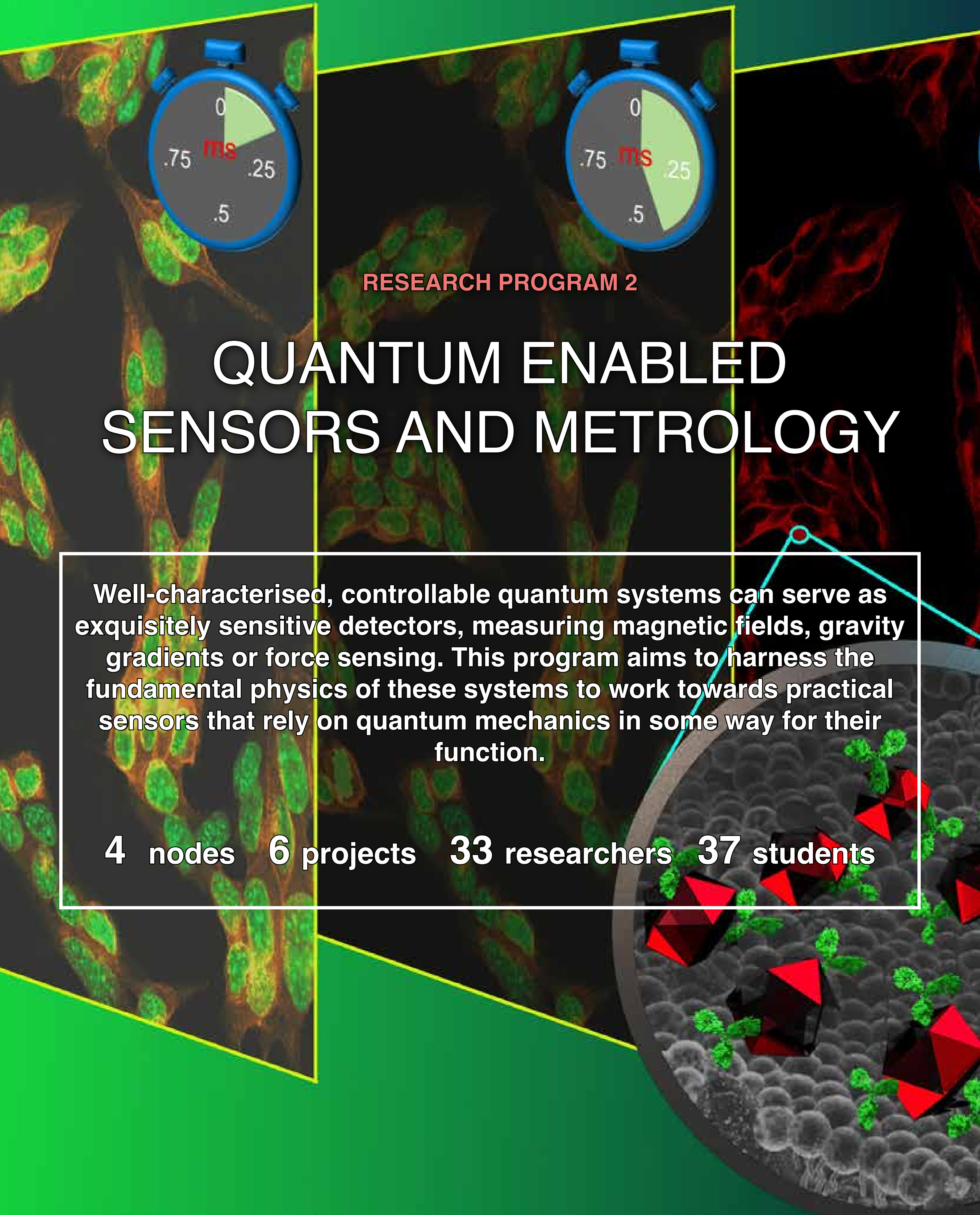
CI Twamley will investigate the feasibility of designing and controlling quantum devices whose mechanical movements can be controlled externally.

The University of Sydney quantum theory team of CIs Bartlett, Doherty and Flammia's research in the Quantum Measurement and Control program specifically relates to the control of spin qubits in quantum dot devices. One of the key EQuS milestones in this area has been to propose new procedures for coupling qubits in such experiments, and several promising new theoretical ideas for this are under investigation. We will complete a careful analysis of these new ideas, specifically calculations related to coupling of spin qubits via (i) quantum Hall droplets and (ii) large mediating quantum dots. As part of this work, CI Tom Stace will continue developing new theoretical techniques to model single electron quantum dot devices.

Other theoretical work in this program includes **CI Gilchrist** working on general quantum limits to the control of quantum devices.

RESEARCH PROGRAM 2

QUANTUM ENABLED SENSORS AND METROLOGY



Well-characterised, controllable quantum systems can serve as exquisitely sensitive detectors, measuring magnetic fields, gravity gradients or force sensing. This program aims to harness the fundamental physics of these systems to work towards practical sensors that rely on quantum mechanics in some way for their function.

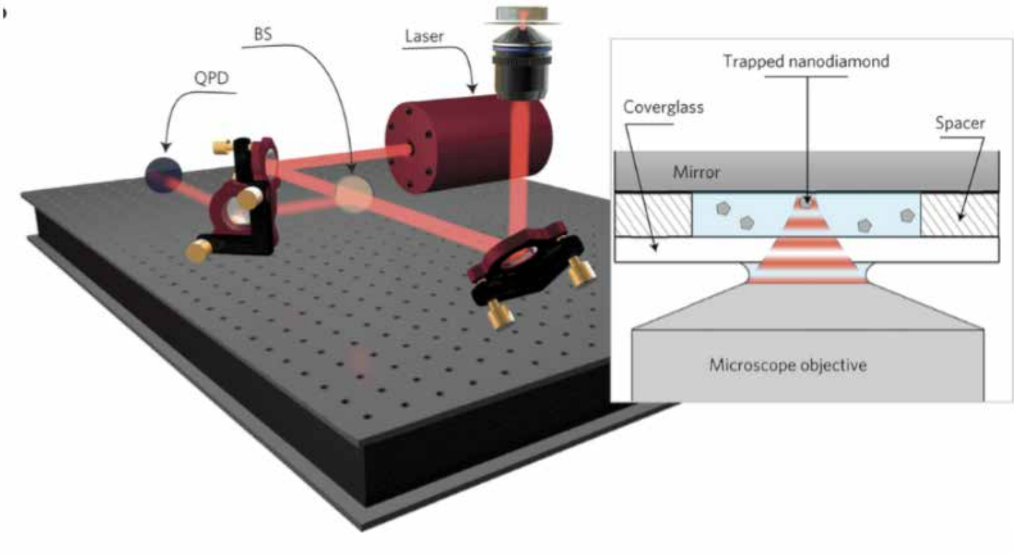
4 nodes 6 projects 33 researchers 37 students

Cooperatively enhanced dipole forces from artificial atoms in trapped nanodiamonds

CIs Volz, Brennen and Molina-Terriza

Published in Nature Physics (2016) doi:10.1038/nphys3940

Optical trapping is a powerful tool to manipulate small particles. In atom trapping, the dominant contribution to the force typically comes from the allowed optical transition closest to the laser wavelength, whereas for mesoscopic particles it is given by the polarizability of the bulk material. Here, we show that for nanoscale diamond crystals containing a large number of artificial atoms, nitrogen–vacancy colour centres, the contributions from both the nanodiamond and the colour centres to the optical trapping strength can be simultaneously observed in a noisy liquid environment (below Figure). For wavelengths around the zero-phonon line transition of the colour centres, we observe a 10% increase of overall trapping strength, due cooperative effects between the artificial atoms modifying the trapping strength. Our approach may enable the study of cooperativity in nanoscale solid-state systems and the use of atomic physics techniques in the field of nano-manipulation and suggests new approaches to using nano-diamonds for sensing applications.



Feature image on previous page: Cover story in Journal of Biophotonics by Carlo Bradac. 'Nanoruby photoluminescent bio-probes are combined with time-gating to image single particles within cultured cells as well as to capture binding kinetics in biological fluids'. (credit: Carlo Bradac/jbio.20167008)

Hyperpolarized nanodiamond surfaces

CI Reilly

Accepted in Journal of the American Chemical Society (2016)

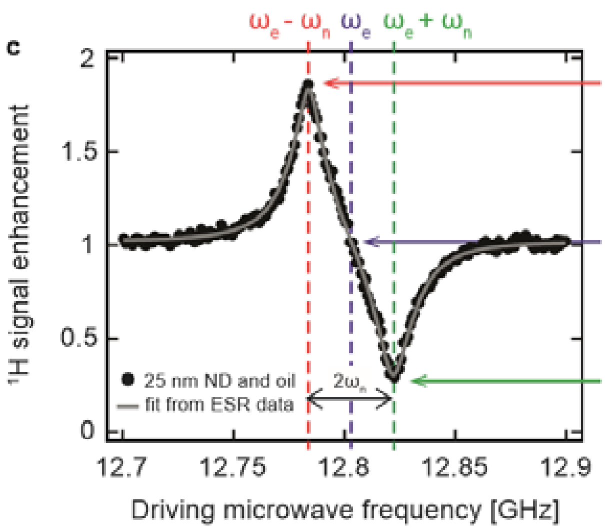
Nanodiamonds are often used as a biomedical platform for drug-delivery, imaging, and sub-cellular tracking applications as a result of their non-toxicity and unique quantum mechanical properties. Here, we extend this functionality to the domain of magnetic resonance, by demonstrating that the intrinsic electron spins on the nanodiamond surface can be used to hyperpolarize adsorbed liquid compounds at room temperature (Figure below). By combining relaxation measurements with hyperpolarization, spins on the surface of the nanodiamond can be distinguished from those in the bulk liquid. These results suggest future biomedical applications for hyperpolarized nanodiamond surfaces, for example in signalling the controlled release of pharmaceutical payloads.

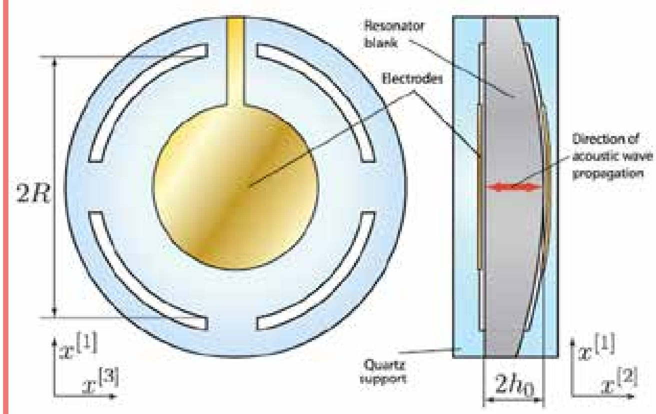
Hybrid high-Q acoustic resonators

CIs Tobar, Fedorov, and Milburn

Published in Physical Review X 6, 011018, (2016) and Physical Review B 93, 224518, (2016)

During 2016, we continued to research single crystal Bulk Acoustic Wave resonators of gram scale mass (Figure below). These are very promising sensors for use in both fundamental physics experiments and as the basis for novel electro-mechanical systems when coupled to transmon qubits. In collaboration with the Müller group at UC Berkeley, we have made first experiment with phonons, using high-Q BAW resonators to enable a high precision test of Lorentz Invariance. With Matt Woolley (Australian Defence Force Academy), CI Milburn and CI Fedorov we developed a proposal to couple to Bulk Acoustic Wave motion via a transmon qubit mediated by a tunable superconducting LC circuit. The analysis suggests that the system could be cooled to its ground state.





Students to work to invent the future

EQuS PhD student Xanthe Croot recently took part in the inaugural, cross-disciplinary Inventing the Future program.

Xanthe Croot is in the final stages of her PhD on experimental quantum computing. She studies in the Quantum Nanoscience Lab in the Sydney Nanoscience Hub, but recently took part in the inaugural Inventing the Future program, for which her team's 'FluroSat' project won first prize.

This unique, cross-disciplinary program involved postgraduate and research students from the University's Faculties of Science, Architecture, Design and Planning, Engineering and IT and the Sydney Business School. Over 11 weeks, the students took part in the complete process of innovation, from ideation to prototyping to a funding pitch to industry, enabled by interdisciplinary collaboration and cross-faculty teaching.

"Our FluroSat project aims to use satellite imaging to monitor crop health, providing pre-visual detection and identification of crop stress" Xanthe said.

"The benefits of this technology are twofold: first, the early identification of crop stress, and subsequent rectification of any issues, can increase overall crop yields. Second, this technology can inform decisions about resource management – for example, imagery can identify which regions of crops are experiencing higher levels of stress, and can inform variable rate fertiliser/chemical/water distribution."

Rolling out this technology would mean farmers could make data-driven decisions about their use of chemicals, water and fertiliser, meaning they would use less and save costs. Similarly, the environmental impact of the farming would be reduced.

"The most enjoyable thing about the Inventing the Future program was working such a driven and motivated team. By working with other students from across the university, I developed my understanding of the business components of the project and got to delve into a different scientific field beyond my own."

Xanthe believes that cross-disciplinary project work encourages students to look at the same problem through completely different lenses.

"Having multiple people working on different aspects of the same project enables each person to have a much deeper appreciation for the multifaceted nature of achieving the project's goals. Learning to draw on each other's strengths to get the most out of the team is very rewarding."

"I think it really helped me to see where my skill sets can be used outside of the research contexts I am familiar with, took me out of my comfort zone on numerous occasions, and connected our team with academics and industry experts across a broad range of fields."

Xanthe will soon have another opportunity to engage with industry experts. She has just been awarded a Startup Catalyst scholarship, which took on her on a 10 day immersive mission to Silicon Valley later this month. This scholarship aims to expose future and current entrepreneurs to fast paced, startup rich environments with the goal of transforming the startup and innovation landscape in Australia.

"The most enjoyable thing about the Inventing the Future program was working such a driven and motivated team."

Profile

Faces of EQuS - Dr Sarah Kaiser

Why did you choose quantum physics?

I became interested in quantum physics when I was doing an undergraduate research fellowship and I learned about single photon detectors. It was possible to say you detected just 3 photons!? This got me excited by quantum optics. I started wondering, what could one do that's useful with these devices? I got really interested in how to do useful things with these neat photon detectors, sources, and wave guides.

What are you working on?

As a new postdoc at EQuS, I am excited to be looking at different colour centres in diamonds. There has been lots of investigation of colour centres in bulk diamond samples, but when the diamond crystals are only about 100 nm in diameter their properties change. The smaller nanodiamonds have really interesting applications as biological sensors and imaging tools because they can fit in cells or be attached to other chemicals. I am also interested in improving programming literacy and helped design and delivered a workshop on scientific computing, aimed to help our attendees get their science done more efficiently.

What are you looking forward to in 2017

I'm excited for things to get cold next year. Our lab has being running a lot of experiments at room temperature with nanodiamonds. We are now working on the capability to do these experiments (and more) in a wider temperature range. I'm working to set up a cryostat so we can lower the temperature and see what else we can learn about these interesting systems.

What would you like to see in the next few years in terms of equity in physics?

I think I would really like to see a mentoring program for early career researchers and students. I think that it is really important to have someone who is external from your research group who can help you with career planning. It would great to have a program to help you outline a path for where you want to be, not just scraping for the next 6-month contract.

Partnership

Microsoft partners with EQuS researchers

A select collection of labs worldwide are collaborating with Microsoft on quantum computing by doing revolutionary engineering and physics, including the Quantum Nanoscience Laboratory headed by CI David Reilly - whose group is world-leading in understanding the interface between quantum physics and the grand engineering challenges of building reliable quantum machine.

Microsoft Research is the research division of Microsoft and is one of the world's largest software research centres. Through Station Q Microsoft has developed a research group of world-class physicists, mathematics and engineers.

At the launch of the Sydney Nanoscience Hub, Microsoft head of research Professor Norman Whitaker said the research was similar to other "moonshot" ideas, such as the Manhattan Project or the moon landing which stimulated great breakthroughs in science and technology.

Activity Plan 2017: Quantum-Enabled Sensors and Metrology

CI Bowen's team will develop silicon carbide nanomechanical devices that reach the quantum coherent oscillation regime, for the first time for silicon carbide at room temperature. Silicon carbide has highly attractive material properties, when compared to the current state of the art in nanomechanics, and has only previously been constrained by the lack of effective fabrication techniques. CI Bowen's team have recently overcome this limitation. Demonstrating quantum coherent oscillation at room temperature will represent a significant step towards the practical realization of room temperature quantum devices and sensors, which was one of the grand challenges of this program.

CI Fedorov's group are also going to finish an experiment on the first experimental realization of a microwave diode implemented with superconducting qubits. They will also work towards the realization of a random number generator with a superconducting qutrit with randomness certified by Kochen-Specker theorem.

CI Reilly will oversee the completion of the nanodiamond magnetic resonance imaging (MRI) project. This experimental project has been highly successful, having established a means of detecting hyperpolarized nanodiamond using dynamic nuclear polarization.

CI Twamley, will focus on developing novel types of quantum sensors. He will work on developing novel devices to sense translational momentum directly. Most measurements of momentum are indirect, for example one senses position and time, and from these estimate the body's momentum. There are very few techniques that can sense mechanical momentum directly with the notable exception of the Doppler effect. In 2017, CI Twamley will work on designs of systems to measure/sense the mechanical momentum of moving systems directly using optical methods. This will help with inertial navigation as estimating accelerations and positions from velocity data is more accurate than using position data alone.

In 2017, a number of projects in the nanodiamond lab of **CI Volz** will see their completion. We will characterize the 'quantum trapping' of nanodiamonds with high concentration of SiV centres as an immediate follow-up on our recently published trapping paper in Nature Physics. In parallel, we will characterize the material and its superradiance properties over a wide temperature range. In addition, we plan to complete the joint EQuS project on nanohole sensing that we started in 2016 with **CI Molina-Terriza** and his group.

CI White will pursue a research direction unanticipated in the original EQuS application: developing a method for generating mechanical fringes using photon counting. In effect, this scheme applies the ideas of linear-optical quantum computing to generate new sensors. This new scheme is capable of generating non-classical mechanical states without the need for strong single photon coupling, and is resilient against optical loss and initial mechanical thermal occupation. Additionally, this approach provides a route to generate larger mechanical superposition states using effective interactions with multi-photon quantum states. This is a collaboration between CI White's lab and former group members Dr Vanner, now at Oxford University, and Dr Ringbauer, now at Heriot-Watt University.

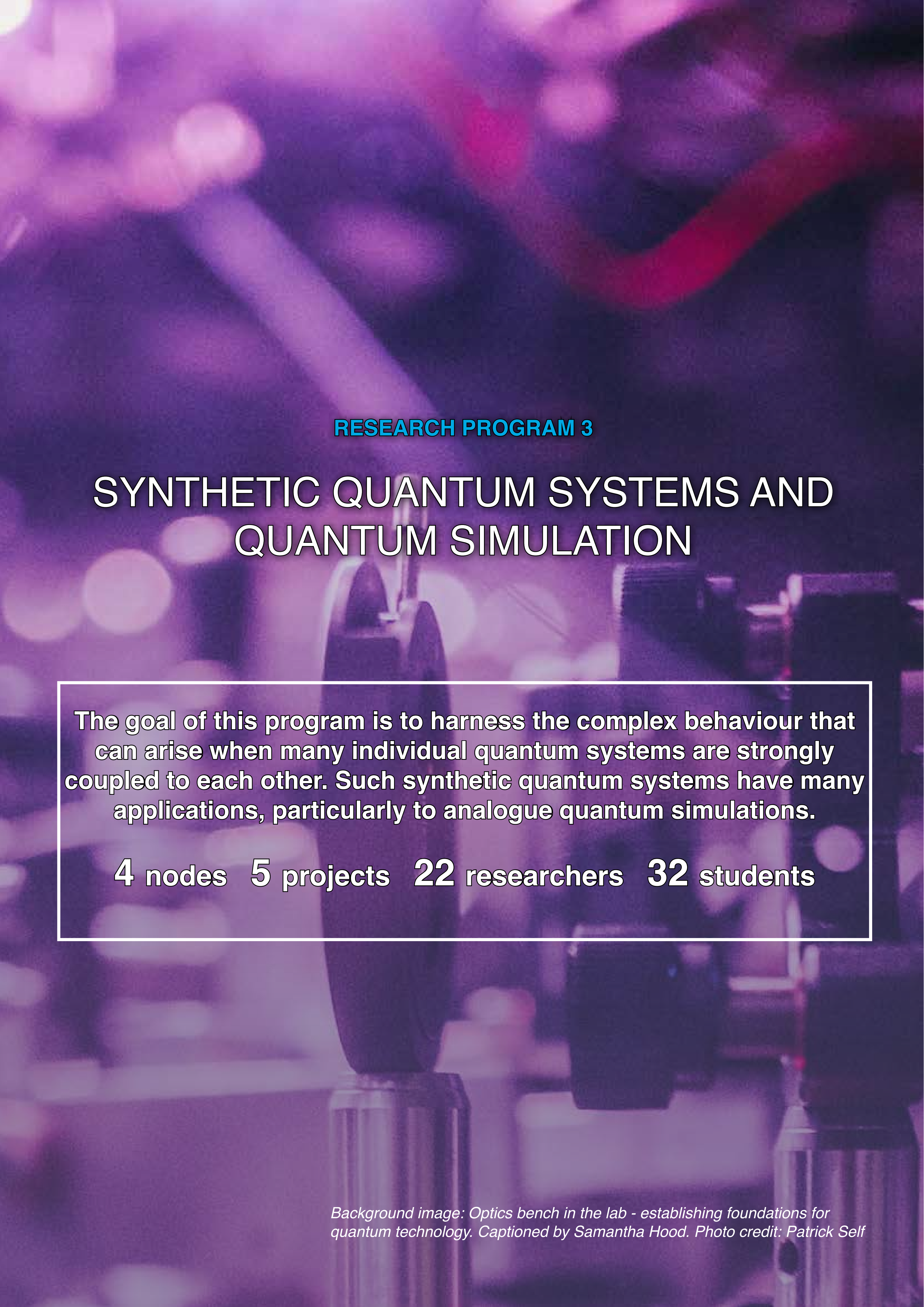
Above image: Calcite crystal splitting up light according to its polarization. Photo credit: Markus Rambach

RESEARCH PROGRAM 3

SYNTHETIC QUANTUM SYSTEMS AND QUANTUM SIMULATION

The goal of this program is to harness the complex behaviour that can arise when many individual quantum systems are strongly coupled to each other. Such synthetic quantum systems have many applications, particularly to analogue quantum simulations.

4 nodes 5 projects 22 researchers 32 students

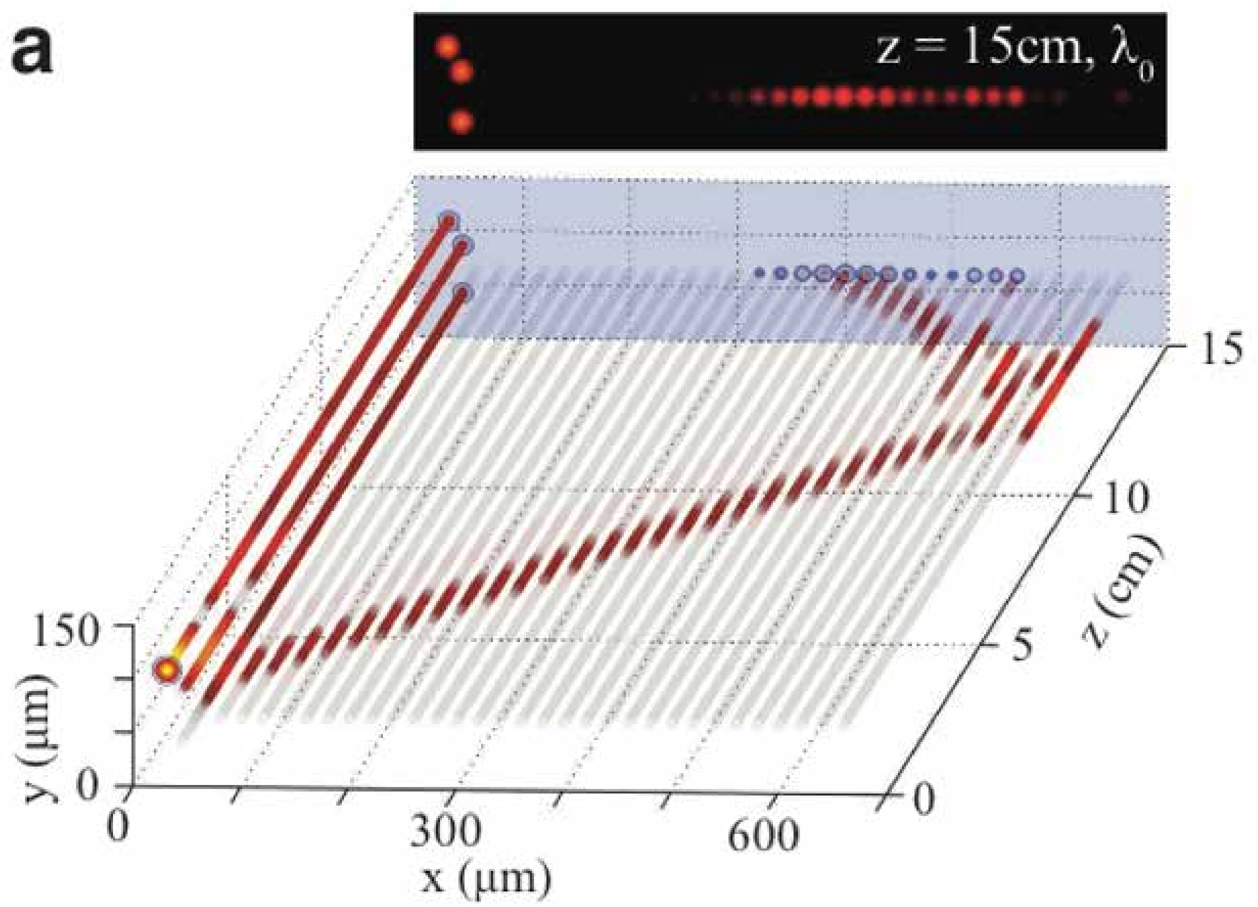


Background image: Optics bench in the lab - establishing foundations for quantum technology. Captioned by Samantha Hood. Photo credit: Patrick Self

Enhancing coherent transport in a photonic network using controllable decoherence

CI White
Nature Communications 7 11282 (2016)

Transport phenomena on a quantum scale appear in a variety of systems, ranging from photosynthetic complexes to engineered quantum devices. It has been predicted that the efficiency of quantum transport can enhanced through dynamic interaction between the system and a noisy environment. We report the first experimental demonstration of such environment- assisted quantum transport, using an engineered network of laser-written waveguides, with relative energies and inter-waveguide couplings tailored to yield the desired Hamiltonian (Figure below). Controllable decoherence is simulated via broadening the bandwidth of the input illumination, yielding a significant increase in transport efficiency relative to the narrowband case. We show integrated optics to be suitable for simulating specific target Hamiltonians as well as open quantum systems with controllable loss and decoherence.



Configurable microscopic optical potentials for Bose-Einstein condensates

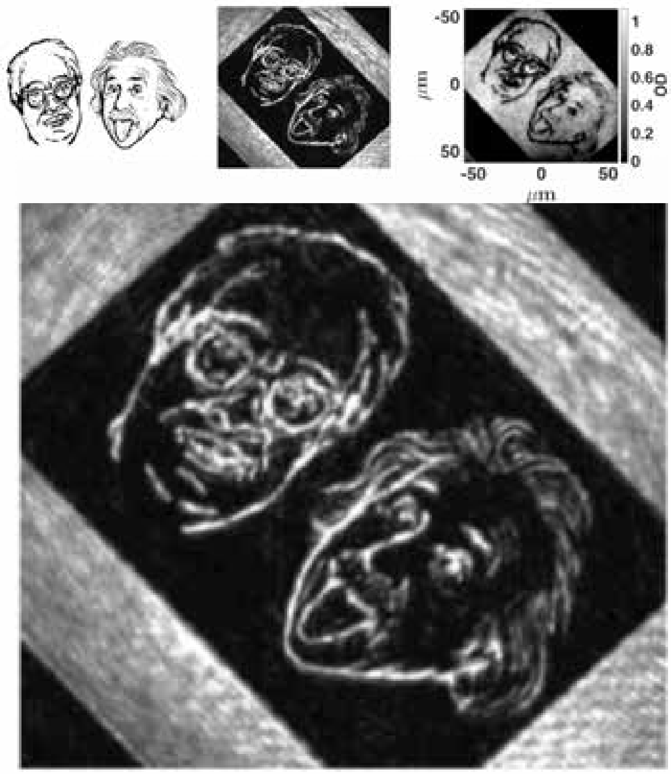
CI Rubinsztein-Dunlop
Optica 3, 1136 (2016)

Our experiment established a new technique for highly configurable 2D trapping of BECs (Figure below). The figure illustrates both high resolution potentials (650 nm FWHM at 532 nm illumination, within 5% of the diffraction limit) and high resolution imaging (960 nm FWHM, within 8% of the diffraction limit).

This has resulted in powerful capabilities of our experiment, namely:

1. Sculpting almost arbitrary, time dependent 2D potentials.
2. High-resolution in situ imaging.
3. The ability to levitate our atoms for resolving momentum spectrum in long time of flight.

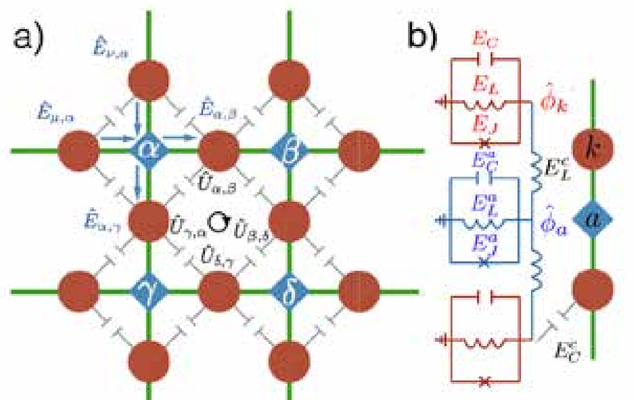
This capability enables our ongoing work on quantum simulations using this unique system where we trap a mixture of two atomic species. We have been investigating coupling BECs at different temperatures (for future studies of quantum thermos- dynamics), Josephson oscillations of the BEC and vortex turbulence and superfluid turbulence.



Loops and strings in a superconducting lattice gauge simulator

CIs Stace and Brennen
Physical Review Letters, 117, 240504 (2016)

Gauge theories play a fundamental role in modern physics, with examples ranging from quantum electrodynamics to the standard model of elementary particle physics. From the breakthrough contribution by Wilson in 1974, lattice gauge theories represent a cornerstone in our understanding of the physical world and lie at the heart of theories dealing with such diverse systems as quantum spin liquids and the quark-gluon plasma. Furthermore, there is good reason to believe that certain types of gauge structures could open up new possibilities for quantum computation. As such, these systems are a prime target for future experiments in quantum simulation. In this theoretical work, we propose a quantum simulation of electromagnetism 2 + 1 dimensions using an array of superconducting fluxonium devices (Figure below). We show how to engineer the Gauss constraint via an ancilla-mediated gadget construction and how to tune between the strongly coupled and intermediately coupled regimes. We demonstrate how to measure the observables that will distinguish the various phases of this system and allow the study of phase transitions.



EQuS researcher receives Westpac Research Fellowship

EQuS researcher Dr Ivan Kassal received funding to further his research in solar-energy harvesting using quantum effects following the announcement of the Westpac Bicentennial Foundation's inaugural Westpac Research Fellowships.

Since 2008, Dr Kassal has worked at the forefront research on quantum effects in photosynthesis, deciphering the factors that contribute to the efficiency of solar-energy harvesting.

Dr Kassal said, "The Westpac Research Fellowship means I can focus on my goal of translating fundamental scientific breakthroughs into advances in clean-energy technology."

"My project focuses on the design of better organic solar cells by examining the role of quantum coherence."

"Quantum coherence, which describes the wave-like properties of particles, is expected to play a fundamental role in the design of efficient, flexible and cheap renewable-energy devices," Dr Kassal said.

The co-funded Fellowship program is the first of its kind in Australia. The Westpac Bicentennial Foundation has collaborated with Australia's leading research universities - The Australian National University, The University of Melbourne, The University of Queensland and The University of Sydney - to offer a holistic package of support for early career researchers.

Susan Bannigan, CEO of the Westpac Bicentennial Foundation, said that the impact of this joint investment goes well beyond the lives of these four individuals.
"These early career researchers have the potential to shape our nation's future," Ms Bannigan said.

"The Westpac Research Fellowships aim to give them – some of our country's best and brightest – the chance to shine and explore their potential. In doing so, we are creating pathways for the innovators and true pioneers amongst us to really make their mark and shape history."
"The co-creation of this Fellowship with our University partners is a great example of industry and education working together towards addressing the opportunities and challenging facing Australia."

During 2016, Dr Kassal and a colleague from Sharif University of Technology found that purple bacteria use quantum coherence to harvest light during photosynthesis

READ MORE ONLINE

Faces of EQuS - Samantha Hood

Why did you choose quantum physics?

I started quantum physics during undergraduate because I did some research projects in atom inferometry. I chose those projects because I really liked theory and I liked the maths behind it. It was really fun. This field allowed me to play with a lot of different operations that you wouldn't get in other kinds of physics. From there, I got into theory and quantum mechanics, because it is a fun way for me to do theory.

What are you researching?

I'm currently looking at how electrons are transported in disordered systems. These systems are not like the nice crystalline systems that we understand well. In disordered systems, we really don't know how electrons behave. I'm using an open quantum systems approach to look at these. One example of these materials are organic solar cells, which are solar cells made out of plastics. I'm trying to optimise their performance so we can make better, more efficient technology.

What were your highlights for 2016?

Definitely overseas travel. I was very lucky to be able to go to New Zealand to present my work. I also attended a summer school in Colorado. I met some cool people and I learnt a lot. The school focused on alternative energy so it wasn't just my field, which made it very exciting. I have also been involved with programs looking at encouraging women in science. A group from EQuS went to Melbourne to attend a symposium on women in science and we also went to the National Press Club lunch which focused on women in science. That was really fun.

What are you looking forward to in 2017?

I'm really excited for next year even though my supervisor will be at a different university. I've been set up with a lot of independence and I'm looking forward to collaborating with different people and moving towards to a more open quantum systems approach to things. I'm hoping to follow up on a proposal that my group wrote for the Idea Factory workshop, which would mean a lot of collaboration. It is also the last year of my PhD so I have to get a lot done - It's going to be a big year!

For more on the EQuS Idea Factory, see page 48

Activity Plan 2017: Synthetic Quantum Systems and Quantum Simulations

Throughout 2017, the Sydney quantum theory **team of CIs Bartlett, Doherty and Flammia** will undertake research in the Synthetic Quantum Systems & Simulation program, completing a milestone project in the verification of quantum simulations. Specifically we will build on our earlier algorithm for efficient classical estimation of quantum events to quantify the resource cost in efficient simulation of general quantum processes. An exponential blowout in simulation cost, such as occurs in boson sampling, will be an indicator of nontrivial quantum behaviour.

CI Brennen's group will work on the topic of characterisation of finite squeezed continuous variable states and their preparation via reservoir engineering with applications to quantum communication protocols and many body simulations. Additionally, we will work on quantum simulations of symmetry protected topological phases using superconducting arrays or trapped atoms.

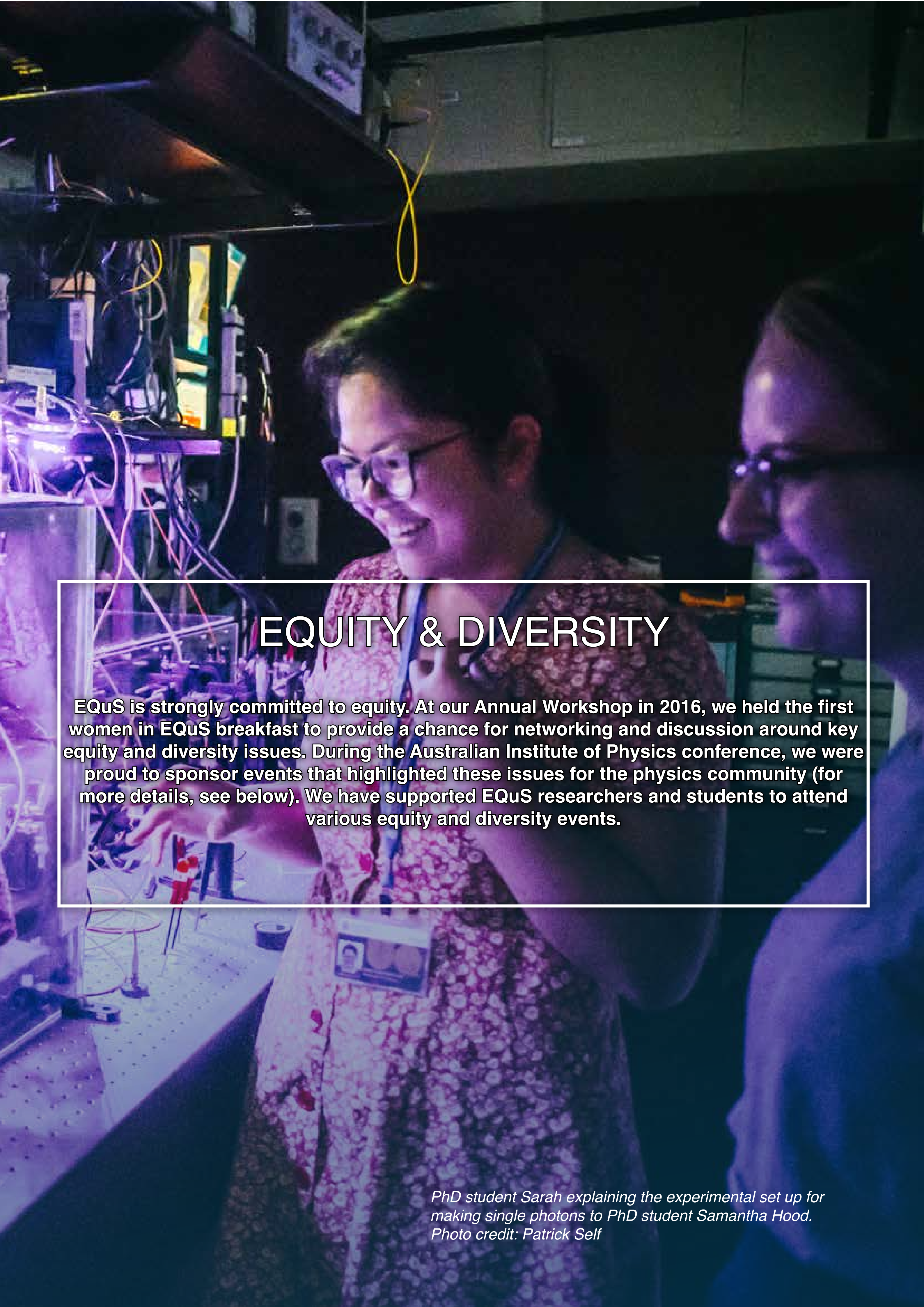
The **group of CI McCulloch** works on simulations of interacting quantum many-body systems. In 2017, his group is completing a range of studies including an investigation of symmetry fractionalization and topological order in frustrated magnets and of non-equilibrium steady states that could be used to engineer topological states of cold atoms in optical lattices.

During 2015–2016 experiments in the **group of CI Duty** robustly established Bose glass behaviour in nanoscale Josephson-junction chains. Progress in using such systems as controllable, synthetic many-body quantum systems—an EQuS grand challenge—crucially depends on our ability to move beyond the Bose glass phase to achieve Mott insulating behaviour. We have determined that the ubiquity of the Bose glass phase hinges on the presence of random offset charges in the device oxide. Building on our investment during 2014–2016 into building our own junction fabrication system, our main aim during the remainder of EQuS, is to solve the problem of random offset charges in order to reach the Mott insulator, using a variety of fabrication techniques.

The **group of CI Rubinsztein-Dunlop** has been working to develop highly configurable potentials for cold atoms in a two-species Bose Einstein condensate experiment that will enable detailed quantum simulations of a wide range of quantum many-body systems. The focus of 2017 activity will be to use this platform on which to demonstrate programmable quantum simulators, which are a grand challenge of the Centre. We will use this new capability to study transport of atoms, and the superfluid insulator transition in ring lattices and ring traps. These ring systems feature continuous boundaries along the ring circumference, so are applicable to the simulation of theoretical models with periodic boundary conditions. We plan to investigate the transition between insulating and superconducting states of these lattices.

In 2017, **CI Volz and his team** will finalize and complete an experiment aimed at demonstrating the polariton blockade effect. Ultimately, the idea is to construct a single-photon nonlinear hybrid light-matter interface.

In 2017, **CI White and his team** will continue to develop scalable photon sources for use in quantum simulators. They expect to publish several experimental papers on this topic in 2017, including active demultiplexing of quantum dot photon sources, achieving single photon nonlinearities using micropillars, and applying these sources in a BosonSampling demonstration. All projects are in collaboration with Professor Pascale Senellart, France; the first is also with Dr Mirko Lobino and his team at Griffith University.



EQUITY & DIVERSITY

EQuS is strongly committed to equity. At our Annual Workshop in 2016, we held the first women in EQuS breakfast to provide a chance for networking and discussion around key equity and diversity issues. During the Australian Institute of Physics conference, we were proud to sponsor events that highlighted these issues for the physics community (for more details, see below). We have supported EQuS researchers and students to attend various equity and diversity events.

PhD student Sarah explaining the experimental set up for making single photons to PhD student Samantha Hood. Photo credit: Patrick Self

Faces of EQuS - Dr Jacqui Romero

Why did you choose quantum physics?

I was interested in physics from a very young age. At my high school, we had physics for all four years. My teacher told me that quantum mechanics was really hard, so I just googled my way through it. All the articles were really interesting – it's strange, what you can do, especially quantum computation. I started with quantum computation, but it turned out that I'm more interested in the foundational implications of all these weird things. And that's what got me hooked.

What are you working on?

This year I was really focusing on setting up a quantum switch experiment, which is this superposition of orders in which you can do two operations. This leads to some computational advantage. My experiment is also interesting to philosophers and broader science. Causality is at the heart of what science does. If quantum mechanics has something strange to say about that, then let's hear it!

What are you looking forward to in 2017?

I want my experiment to work next year! The other thing is that in our lab, we will have superconducting number resolving single photon detectors – excited to see them in an actual experiment. (What can we do?) We can extend the range of experiments that we can do in our lab.

What would you like to see in the next few years in terms of equity in physics?

I'm excited about the SAGE initiative. I volunteered for the self-assessment team in my university. Good shift. Personally I would like to see more women with kids back at the university, there are a lot of women not continuing. If we can do something to make life easier for them so they can come back, then we should. Because right now it's so hard!

Women in STEM

February 11 was the inaugural United Nations Day for Women and Girls in Science. EQuS PhD students Natasha Taylor and Samantha Hood from The University of Queensland node shared why they love science with UQ news.

WATCH THE VIDEO ONLINE.

Samantha also joined Dr Maggie Hardy and Caitlin Syme (PhD candidate) on 612 ABC Brisbane.

EQuS supports events to promote equity in physics

In December 2016, EQuS was a Gold sponsor of the joint 13th Asia Pacific Physics Conference and 22nd Australian Institute of Physics Congress held in Brisbane during December 2016.

The Centre sponsored the Women in Physics Breakfast (December 6) and LGBTIQ Breakfast (December 7). EQuS CI Doherty also chaired the LGBTIQ breakfast while CI Stace organised the Aboriginal and Torres Strait Island Breakfast (December 8).

These events were a vital opportunity to highlight the current state of equity in physics and identify more opportunities for action. Keynote speakers, Professor Nalini Joshi co-founder of the SAGE initiative in Australia and Dr Lisa Harvey-Smith (LGBTIQ) an award-winning astronomer, acclaimed science writer and speaker, both gave interesting and insightful presentations on how we can make physics working environments better for all.

CI Stace convenes the inaugural AIP Congress Aboriginal and Torres Strait Islander Breakfast.

Aboriginal and Torres Strait Islander (ATSI) representation in universities is low, and this is even more pronounced in STEM subjects. On the final day of the 2016 AIP Congress, a topical breakfast was held to discuss indigenous representation in the Australian physics community.

Speakers included:

- Dr Christine Williams (Assistant Director-General, Science Division, Queensland Government Department of Science, Information Technology and Innovation) who discussed the initiatives that the Queensland Government has taken to fund indigenous researchers including several scholarships and fellowship schemes
- Dr Chris Matthews (Griffith University and Chair of the Aboriginal and Torres Strait Islander Mathematics Alliance) who described his “Goompee model” of teaching mathematics to kids – the “Goompee model” takes the notion of abstraction inherent in mathematics and trains kids to develop their own symbolic representations
- A/Prof Jon Willis (The University of Queensland Poche Centre for Indigenous Health) who ran through statistics of ATSI students enrolled in UQ physics courses and postulate that at least part of the reason was the that imagery showing people doing physics suffers from the “old, white, male” stereotype

Connecting women in STEMM

Women in Science Australia ran the first National Symposium: Connecting Women in STEMM in Melbourne during 2016. The event aimed to connect women in science, technology, engineering, mathematics and medicine (STEMM) regardless of their discipline or profession.

Image credit: Patrick Self

After attending the inaugural Connecting Women in STEM Symposium in September 2016, PhD student Samantha Hood returned to Brisbane and was inspired to create a networking opportunity for female researchers in Queensland.

In November 2016, Samantha organised a lunch to facilitate networking opportunities between Brisbane women in academia and industry.

Samantha said, “Brisbane has some amazing, talented women in STEMM - and we want to create opportunities for them to network and support each other,” she said.

“Creating networks between different levels in academia, between academic institutions and between academia and industry is very important.

“These connections improve job and collaboration prospects, professional support and mentoring opportunities.”

EQuS was proud to support the event held at Mu’Ooz in West End, a non-profit restaurant that supports training for refugee women. The lunch was a sell-out event with more than 30+ women from varying fields of STEM taking up the opportunity to networks with other like-minded individuals, with plans for future events already underway.

> “One of the best things to come out of this Symposium was the emphasis on developing professional networks so that we can learn from one another to implement best-practices.”
>
> READ MORE ONLINE about PhD students Samantha Hood and Sarah Lau’s experience at the inaugural Connecting Women in STEMM symposium.

National press club

EQuS PhD students Caxtere Casacio, Sarah Lau, Samantha Hood and Claire Edmunds attended the National Press Club’s Women of Science panel on March 30. The panel featured Professor Emma Johnston of The University of New South Wales and Sydney Institute of Marine Science, Professor Nalini Joshi of The University of Sydney and Professor Tanya Monro who is Deputy Vice Chancellor Research and Innovation at The University of South Australia.

“I found the speakers incredibly empowering and immediately knew that they were role models I could look up to. A lot of the things they said resonated with me.”

“One of the messages that stuck with me was that we need to work hard to fix this problem and compensate for the unconscious gender bias that occurs in society.”

COMMUNICATION & OUTREACH

The ARC Centre of Excellence for Engineered Quantum Systems aims to stimulate both Australian and international scientific and engineered interest in quantum technologies. As part of this effort, the Centre works to reach a diverse audience through online and traditional media. Centre research and researchers are promoted through media releases, social media, public lectures and the Centre website, as well as through joint initiatives such as Quantum Shorts with the Singapore Centre for Quantum Technologies.

Centre members are actively engaged in sharing their research with a variety of audiences. In 2016, our Chief Investigators took part in multiple briefings to government and industry while each node hosted school visits for secondary school students. This year saw the launch of a $150 million nanoscience hub at our University of Sydney node that resulted in wide press coverage. Meanwhile at The University of Queensland, the Quantum Technology lab supported the Big Bell Test initiative run by the Institute of Photonic Sciences, which attracted over 100,000 participants from across the world.

Big Bell Test

On November 30, people from across the world had the opportunity to participate in and contribute to the Big Bell Test - a unique worldwide experiment that aimed to test the laws of quantum physics.

More than 100,000 people participated in the Big Bell Test. Participants were able to complete more than half a million levels of the video game that generated more than 90 million bits, a number that tripled the initial expectations of the scientific team leading the project.

The project, coordinated by the Institute of Photonic Sciences (ICPO), consisted of twelve laboratories from around the world including our Quantum Technology lab at The University of Queensland.

Each lab ran quantum experiments powered by human randomness, with the aim of demonstrating experimentally that the microscopic world is in fact as strange as quantum physics predicts.

Participants across the world contributed to the initiative by generating sequences of zeros and ones through a video game in order to create sequences of numbers that were as random as possible. Each of these bits were used to control in experiments in real time. They moved mirrors, polarizing filters, waveplates - elements located on optical tables and that affect the type of measurements that are made on the different quantum systems in each lab.

Our team at the Quantum Technology lab used the human-generated random numbers to test quantum entanglement in time.

TOTAL NUMBER OF USERS
109,000+

TOTAL NUMBER OF BITS GENERATED

95,419,936

A night of nanotainment

Presented as part of the Sydney Science Festival, this free public event was an entertaining night of nanoscience brought to life through song, dance and performance by CIs Reilly and Biercuk as well as Professor Zdenka Kuncic from the Australian Institute for Nanoscience and Technology at the University of Sydney.

EQuS students and postdocs take quantum snaps

The Centre ran an image competition on Instagram during November 2016, which asked for quantum-themed photos. The competition attracted over thirty entries.

International judges Rainer Blatt and Ania Bles announced the winner (PhD student Ewa Rej and team) and runner-up (PhD student Christina Giarmatzi) during the EQuS Annual Workshop. Entries can be viewed online by the #quantumsnaps hashtag.


Image credit: Patrick Self

International film "Quantum Shorts" competition launches

In 2016, EQuS supported Quantum Shorts, an international festival for short films that draws inspiration from quantum physics.

"We think that filmmakers are like quantum physicists: driven by curiosity, creativity and passion. Please take our big ideas, strange theories and invisible effects and make them yours," said quantum physicist Artur Ekert, who will be a judge for the festival's top prizes and Director of the Centre for Quantum Technologies at the National University of Singapore, the organiser of Quantum Shorts.

The Australian premiere of the short-listed entries will be held at the Queensland Gallery for Modern Art during the World Science Festival Brisbane in March 2017. A panel discussion, moderated by EQuS Centre Director Andrew White will follow the screening.

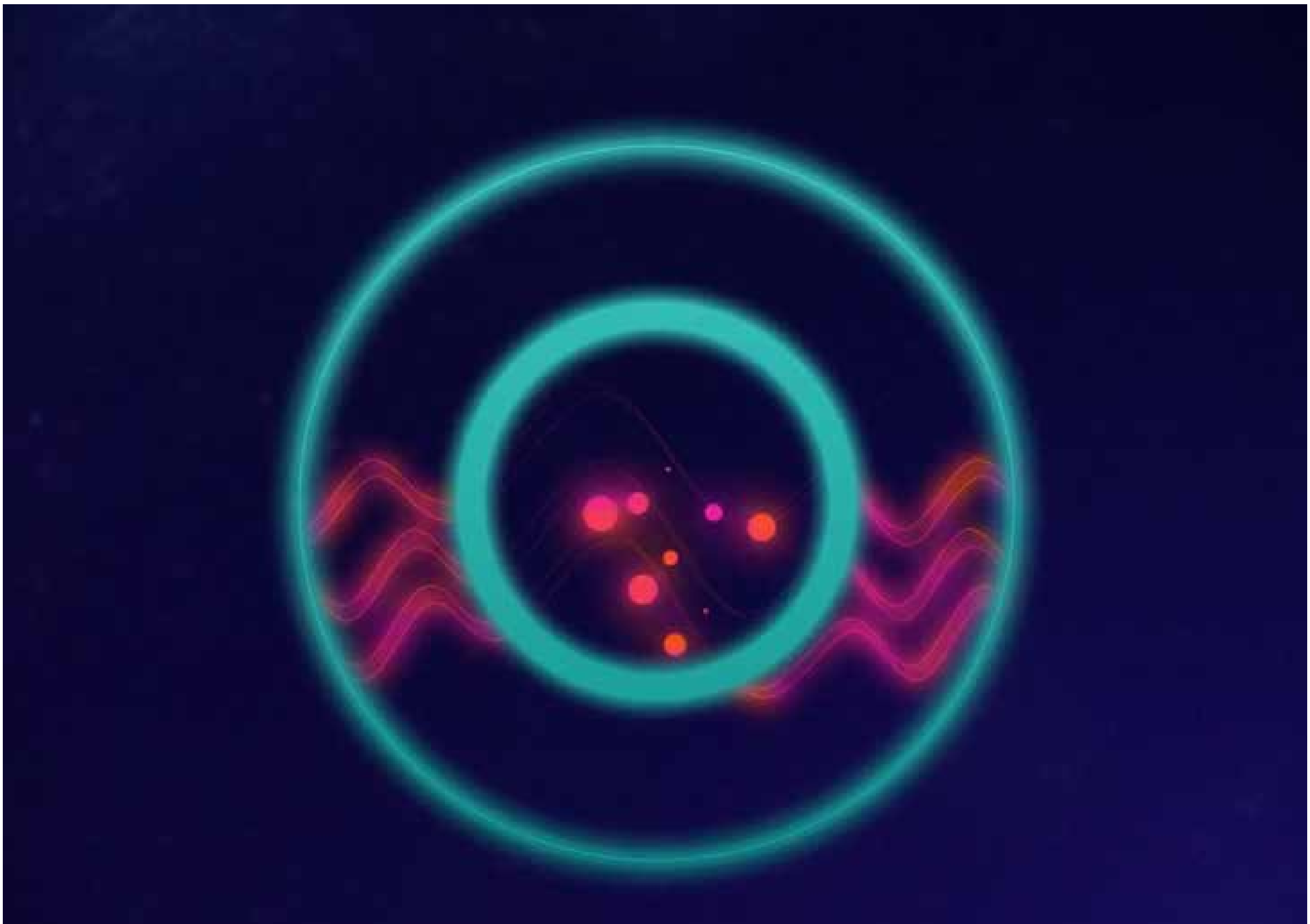
The other judges for Quantum Shorts are:

Physicist Brian Greene, Professor at Columbia University, who is a best-selling author and co-founder of the World Science Festival

Writer and filmmaker Alex Winter, whose most recent film, the award-winning documentary Deep Web, had its world premiere at the SXSW film festival in 2015

Charlotte Stoddart and Eliene Augenbraun from Nature Publishing Group's multimedia team, who create engaging video and audio stories for Nature and Scientific American, and

Curator Honor Harger, Executive Director for the ArtScience Museum, Marina Bay Sands, Singapore.



Still from film Ampersand enterted into Quantum Shorts by Erin Shea

Science teachers go to Canberra for STEM X Academy

The STEM X Academy is a five-day residential teacher professional learning program open to Australian teachers across all sectors and levels of experience. STEM X Academy is run in partnership with the Australian Science Teachers Association (ASTA), Questacon and CSIRO who worked together, to create a program that was both inspirational and practical.

The program was designed to encourage participants to work with research scientists and science educators, and also to work with fellow teachers. In 2016, EQuS awarded two scholarships and supported Kasey West (Meridan State College) and Rob Hilford (Grace Lutheran College Caboolture Campus) to attend the academy.

FEEDBACK

"*I have no doubt that this STEMX Academy has given me just this opportunity so that I can adapt my own pedagogical approaches enabling me to come into line with helping to ready young people to cope with meeting the progressive changes within Science, Technology, Engineering and Maths Curriculum as these important areas of education evolve.*" Rob Hilford

"*Every workshop, tour and conversation that I have experienced during the STEM X Academy has given me possibilities and ideas that I can implement in my teaching in the future. I can also see how I can lead other teachers in my region to see the potential that STEM has for students. Thank you again for enabling me to graduate from the STEM X Academy in 2017, I know that my STEM journey is just beginning but it is going to be an exciting ride.*" Kasey West

RESEARCH EDUCATION & TRAINING EVENTS

EQuS is committed to developing, training and mentoring researchers and students. This year we held a range of research education and training events to cover developments in Centre research and professional development, including science communication and proposal writing.

Image credit: Christina Giarmatzi

6th Annual EQuS Workshop

We held another very successful Annual Workshop in Noosa following the Australian Institute of Physics conference. Over 140 delegates from Centre nodes and collaborators, as well as members of our Advisory Board and Scientific Advisory Committee, attended. The Annual EQuS Workshop provides a forum for researchers and students to present and share their research findings for the year, provides valuable conference presentation training in a conducive environment, and facilitates serendipitous linkages between research programs, researchers and students within the Centre. Invited international and national speakers also provides valuable research training and linkages outside of the Centre.

Highlights:

- CI Tom Stace introduced a new "Quantum games" session, which called for game design submissions inspired by quantum physics
- International speakers, including: Prof. Daniel Shaddock ANU, Prof. Pascale Senellart CNRS, Dr. Jia Du CSIRO, Prof. Tilman Pfau Universität Stuttgart, Ass. Prof. Peter Rabl TU Wien, and Assoc. Prof. Ania Bleszynski UCSB
- The Poster night saw Rochelle Martin and Raphael Abrahao (PhD students) each win a travel voucher. Dr Jacqui Romero took home the postdoc poster prize

Highlights from Quantum Games entries

- A walk in their quantum world: Players take on the role of a scientist as they explore an unfamiliar environment
- Quantum derby: Imagine yourself as smaller, faster, hotter, more coherent and being able to influence your peers over unlimited distance. That's the world of quantum racing
- Life of a scientist: Live out the life of a scientist reenacting experiments throughout history
- Quantum tricks: A card game based on quantum states. In the genre of Euchre/500, players have a hand of cards and compete to win tricks

Sydney Quantum Information Theory Workshop

The workshop organised by CIs Bartlett, Brennan, Doherty, Flammia and Stace brings together leading and up-and-coming international and Australian researchers and research students in quantum information theory. The aim of this workshop is to present new results (or even new research directions without results yet).

An exciting array of national and international speakers was put together by the organising committee including Fields medallist, Professor Vaughan Jones (Vanderbilt, USA), Professor Terry Rudolph (Imperial College, UK) and Parsa Bonderson (Microsoft Station Q, USA)

In 2016, the workshop had a special focus on the connections between topology, quantum many-body physics, and quantum information, as well as selected topics from quantum computation and quantum information theory.

Building collaborative research and communication skills at the EQuS Idea Factory

EQuS Young Researcher Idea Factory was a three-day workshop that aimed to bring young researchers from all the different EQuS nodes together. The focus was on collaboration and research communication.

The Idea Factory included a science communication workshop, delivered by Director of the Centre for Public Awareness of Science Professor Joan Leach, with an improvisation warm-up and tips for selling research.

The workshop was organised and led by EQuS postdoctoral researchers Clemens Mueller (CI Stace) and Karin Cedergren (CI Duty) and aimed to create a stronger personal network among the young EQuS generation and to challenge people to think in new ways. Coming up with an idea, writing a proposal and presenting it, all in three days, was an ambitious task - yet every single group delivered!

FEEDBACK

"I think I got very good training in presenting an idea, working out the strong points of a proposal and presenting as a team."

"I enjoyed working as a team with specialists from different areas. The lecture on science communication was brilliant and… it will definitely improve my work."

"I really enjoyed the 3 minute presentations at the start - it was a great way to get to know people in terms of interest, experience and area of work. I liked being able to engage with a lot of areas outside my own and having to learn more about them."

Image credit: Samantha Hood

EQuS Winter School and Professional Development Day

During July 2016, the EQuS Winter School brought together PhD and Masters students from all EQuS nodes. The Winter School was an exciting opportunity to learn about core Centre research and develop professional and personal skills. The first day at The University of Sydney focused on professional development with sessions on build technical presentations and academic vs non-academic careers.

The next three days in the Blue Mountains focused on science with full days sessions, including interactive tutorials on majorana modes and other topologically interesting systems, quantum trajectories in the laboratory and Bayesian Inference.

Python for Quantum Information Science

A two-day workshop on Python for Quantum Information Science was conducted on November 17 and 18 in New South Wales at our Macquarie University node. The workshop provided interactive tutorials in: Version control with Git, Python for general and scientific use, and Libraries for QIP theory and experiments.

The workshop was organised by EQuS postdoctoral researchers Ben Baragiola, Chris Granade, Sarah Kaiser, as well as Yuval Sanders.

A calendar of EQuS research at UQ

The EQuS Q&A series at The University of Queensland node showcased current research in quantum physics taking place in our Centre throughout 2016. Each month was organised by a different research group as led by EQuS Chief Investigators.

We plan to roll the Q&A series across all five nodes.

Science communication training from the Australian Science Media Centre (AusSMC)

Dr Susannah Eliott and Lyndal Byford, from the Australian Science Media Centre, visited our University of Queensland node to deliver a three-hour session for early career researchers and PhD students.

Our speakers took attendees through an entertaining review of the current media landscape and discussed how building a profile online can help researchers interact better with those outside their field and help their career.

EQuS students in the UQ Demo Troupe participate in the World Science Festival 2016

PhD student Catxere is making a microscope that will use squeezed light. Captioned by Samantha Hood. Photo credit: Patrick Self

Life after EQuS

Faces of EQuS - Dr Martin Ringbauer

Why did you choose quantum physics?

I first got interested in quantum physics essentially in high school when I started reading popular science books that talked about quantum entanglement and wave-particle duality. And I was fortunate to grow up in Vienna which was the birth place of quantum information essentially, and many of the first experiments were done in Vienna. So I got into quantum things like simulation and computation very early on, and that's what I did in undergraduate. But what really got me hooked are these fundamental questions like what can q p tell us about how the world is, that's what got me here for my PhD.

What are you researching?

During my PhD, I've been part of the Quantum Technology lab. I did quantum photonics mostly, in particular high-precision quantum photonics. We actually built the highest quality four-level quantum systems in any architecture, which was quite amazing. And we used that to test things like the reality of the wave function and quantum causality.

What were your highlights for 2016?

Everything was a highlight for me! I particularly like that the public is really interested in what we're doing and that we can get the information out there. One example for 2016 was the Big Bell Test which got over 100,000 people involved. By playing a video game, they helped us with our quantum experiments and they got really excited about it.

What are you looking forward to in 2017?

I just finished my PhD a few weeks ago and it is time for me to move on. One place to go is Europe because they really appreciate the importance of quantum technology. Both the European Union and the United Kingdom are investing heavily into quantum and they have attracted a lot of talent.

In terms of research, I think what we'll probably see a lot more in the future is cooperation between different architectures like hybrid quantum systems, which is something I'm really interested in.

EQuS EA retires after 50 years of service to UQ

A huge congratulations to Ruth Forrest who retired at the end of 2016 after nearly 50 years at the University of Queensland.

Ruth has worked with EQuS researchers since the establishment of the Centre in 2011. Since 2011, she has worked closely with Centre Director Professor Gerard Milburn as his executive assistant and a node administrator.

Thank you, Ruth. Enjoy your well-deserved break!

EQuS alumni Dr Juan Loredo and Dr Matthew Broome were both awarded a Marie Sklowdowska-Curie Fellowship in 2016 to work with research groups in France and Denmark.

Congratulations, Juan and Matthew!

EQuS graduates 2016

PhD

Babatunde Ayeni
Ayeni Babatunde Jeremy
Bourhill Alexander Buese
Todd Green
Clara Javaherian
Juan Loredo
Keith Motes
Ewa Rej
Martin Ringbauer Hossein
Tavakoli-Dinani Nora
Tischler

Masters by research

Jake Glidden
Rochelle Martin
Nick McKay-Perry Sarath
Raan-Nair Alexander
Soare
Dean Southwood

Honours

Roger Ackroyd
Alex Hung
Justin Kruger
Kehuan Shi
Thomas Smith
Paul Webster

Life after EQuS

Stephen Parker
MRX Technologies

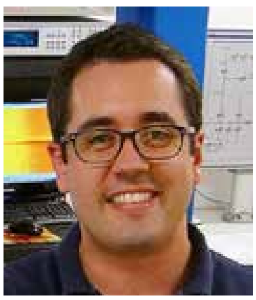
After working at UWA and in EQuS as a postdoctoral researcher, Dr Stephen Parker is moving on to be a technical specialist. He will work on software and algorithm development at an engineering firm that produces automated measurement systems for the rail industry.

Ivan Kassal
University of Sydney

After 6 years at UQ and in EQuS as a postdoctoral researcher, Dr Ivan Kassal has assumed a position as a Senior Lecturer and Westpac Research Fellow in Chemical Physics at The University of Sydney.

Courtney Brell
Perimeter Institute for Theoretical Physics

After studying at USYD and in EQuS as a PhD student, Dr Courtney Brell has moved to Canada to assume a postdoctoral position at the Perimeter Institute for Theoretical Physics.



Daniel Creedon
University of Melbourne

After working at UWA and in EQuS as a postdoctoral researcher, Dr Daniel Creedon has moved across Australia to assume a postdoctoral position at Melbourne University.

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Key performance overview

INVITED TALKS & KEYNOTE	STUDENTS MENTORED	PUBLIC LECTURES
47	106	31

PUBLICATIONS	MEDIA COVERAGE	WORKSHOPS ORGANISED
86	75	7

Key performance overview

INTERNATIONAL VISITORS

53

SOCIAL MEDIA FOLLOWERS

1200+

BRIEFINGS TO
GOVERNMENT & INDUSTRY

31

COURSES ATTENDED BY
STAFF & STUDENTS

103

WEBSITE SESSIONS

23126

SCHOOL VISITS

15

Key performance areas

Research findings

Performance measure	Target	Outcome
Journal articles	85	86
Quality of research outputs	77	80
Number of invited talks etc	20-30	47
Number of commentaries (media)	10	75

Research training and professional education

Performance measure	Target	Outcome
Attended courses for staff and postgrads	10	103
Number of Centre attendees at courses	35	732
Number of new PhD and Masters	17	15
Number of new postdocs	1	12
Number of new Hons	10 to 15	6
Completions PhD	14	12
Completions Masters	3	6
Number of ECRs	19	25
Number of students mentored	71	106
Number of mentoring programs	2	5

International, national and regional links

Performance measure	Target	Outcome
Number of international visitors	34	53
Number of national and international workshops by Centre	2	7
Number of lab and facilities/collaborative visits	50	58

Centre specific KPIs

Performance measure	Target	Outcome
Media releases	10	20

Key performance areas

End-user links

Performance measure	Target	Outcome
Number of government, industry and business briefings	11	31
School visits	12	15
Science teacher PD	3	2
Number of website revisions	12	12+
Number of sessions on website	1,300	23126
Number of public talks given by centre staff	10	12

Organisational support

Performance measure	Target	Outcome
Annual Cash contributions from Collaborating Organisations	University of Queensland $600,000; Macquarie University $250,000; University of Sydney $200,000; University of Western Australia $87,500; University of New South Wales $50,000	University of Queensland $600,000; Macquarie University $250,000; University of Sydney $200,000; University of Western Australia $93,625 University of New South Wales $50,000
Annual In-kind contributions from Collaborating Organisations	University of Queensland $1,783,476; Macquarie University $323,343; University of Sydney $4,744,379; University of Western Australia $1,225,178; University of New South Wales $141,525	University of Queensland $2,370,313; Macquarie University $900,264; The University of Sydney $4,709,974; University of Western Australia $5,322,673; University of New South Wales $2,058,005
Annual Cash contributions from Partner Organisations	University of Innsbruck $5,057; University of Ulm $4,506; Imperial College $5,000	University of Innsbruck $5,057; University of Ulm $4,506; Imperial College $5,000
Annual In-kind contributions from Partner Organisations	University of Vienna $10,000; Imperial College $9,119; University of Ulm $12,392; University of Innsbruck $21,609; Perimeter Institute for Theoretical Physics $30,000; University of Copenhagen $65,000	University of Vienna $10,000; Imperial College $9,119; University of Ulm $22,500; University of Innsbruck $21,609; Perimeter Institute for Theoretical Physics $30,000; University of Copenhagen $65,000
Other research income secured by Centre staff	$500,000	$10,747,708
Number of new orgs collaborating with Centre	2	3

National benefits

Performance measure	Target	Outcome
Contribution to National Research Priorities and National Innovation Priorities (% of papers)	85	85

2016 Statement of Income and Expenditure

	2015 Actuals $	2016 Actuals $	2017 Forecasts [1] $
INCOME			
ARC Centre of Excellence Grant			
Base Income	3,500,000	3,500,000	3,500,000
Indexation on Base Income	520,557	588,906	650,240
Administering and Collaborating Organisation Contributions			
The University of Queensland	600,000	600,000	600,000
Macquarie University [2]	249,462	250,000	250,000
The University of Sydney	200,000	200,000	200,000
The University of Western Australia			
UWA cash contribution as per agreement	87,500	87,500	87,500
UWA additional cash contribution	6,125	6,125	6,125
The University of New South Wales	50,000	50,000	50,000
Partner Organisation Contributions			
The University of Innsbruck	5,000	5,000	5,000
University of Ulm	4,506	4,506	4,506
Imperial College of Science and Technology	5,057	5,057	5,057
Overseas Government Organisations and Other Grants			
New South Wales State Leveraging Fund (SLF) [3]	-250,000		
Intelligence Advanced Research Projects Activity (IARPA) [4]	349,151	-221,266	
TOTAL INCOME	**5,327,358**	**5,075,828**	**5,358,428**
EXPENDITURE			
Salaries	2,596,793	2,738,576	3,844,514
Scholarships	295,462	269,853	422,428
Equipment and Maintenance	1,088,714	1,453,999	935,422
Travel	583,473	564,898	554,851
Other Expenditure	309,061	361,905	420,072
Intelligence Advanced Research Projects Activity (IARPA)	264,424		-
Partner Organisations	14,563	14,563	14,563
TOTAL EXPENDITURE	**5,152,490**	**5,403,795**	**6,191,850**
ANNUAL SURPLUS/(DEFICIT)	**174,868**	**-327,967**	**-833,422**
ADD: ADJUSTMENTS FOR PRIOR YEARS INCOME & EXPENDITURE [5]		**70,784**	
BALANCE BROUGHT FORWARD FROM PREVIOUS YEAR	**1,094,004**	**1,268,872**	**1,011,689**
TOTAL CARRYFORWARD TO NEXT YEAR [6]	**1,268,872**	**1,011,689**	**178,267**

Notes:

(1) 2017 Forecasts are projected expenditure and actuals in 2017 is subjected to change.

(2) Macquarie University 2016 co-contribution of $249,462 is $538 short of its $250,000 co-contribution due to an additional amount of the same value already contributed in 2011.

(3) In 2015, income of $250,000 has been reversed out to exclude New South Wales State Leveraging Fund (SLF) recorded in 2014. The SLF income is not part of EQuS Centre Agreement. No expenses in previous years have been recorded, therefore no reversal of expenditure is required.

(4) In 2016, the remaining balance for this Intelligence Advanced Research Projects Activity (IARPA) project is reflected as a reversal in income. This IAPRA project is not part of the Centre Agreement and thus have any carryforward funding rom 2015 into 2016 is to be excluded.

(5) In 2016, The University of Sydney made prior years adjustments to its income and expenditure. The $70,784 amount ($144,753 less $73,969) is a net adjustment figure for the $144,753 over-stated carry-forward surplus from from 2014 to 2015 (due mainly to under-reporting of 2014 salary costs), less the $73,969 understated deficit for 2015.

(6) The 2017 Forecast is a forecast and is subject to change. The forecast 2017 carryforward consists of only university co-contributions.

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Cover image: The winning image from our Quantum Snaps competition: A cryogenic switch matrix for steering pulses in quantum computation from the Quantum Nanoscience Laboratory.