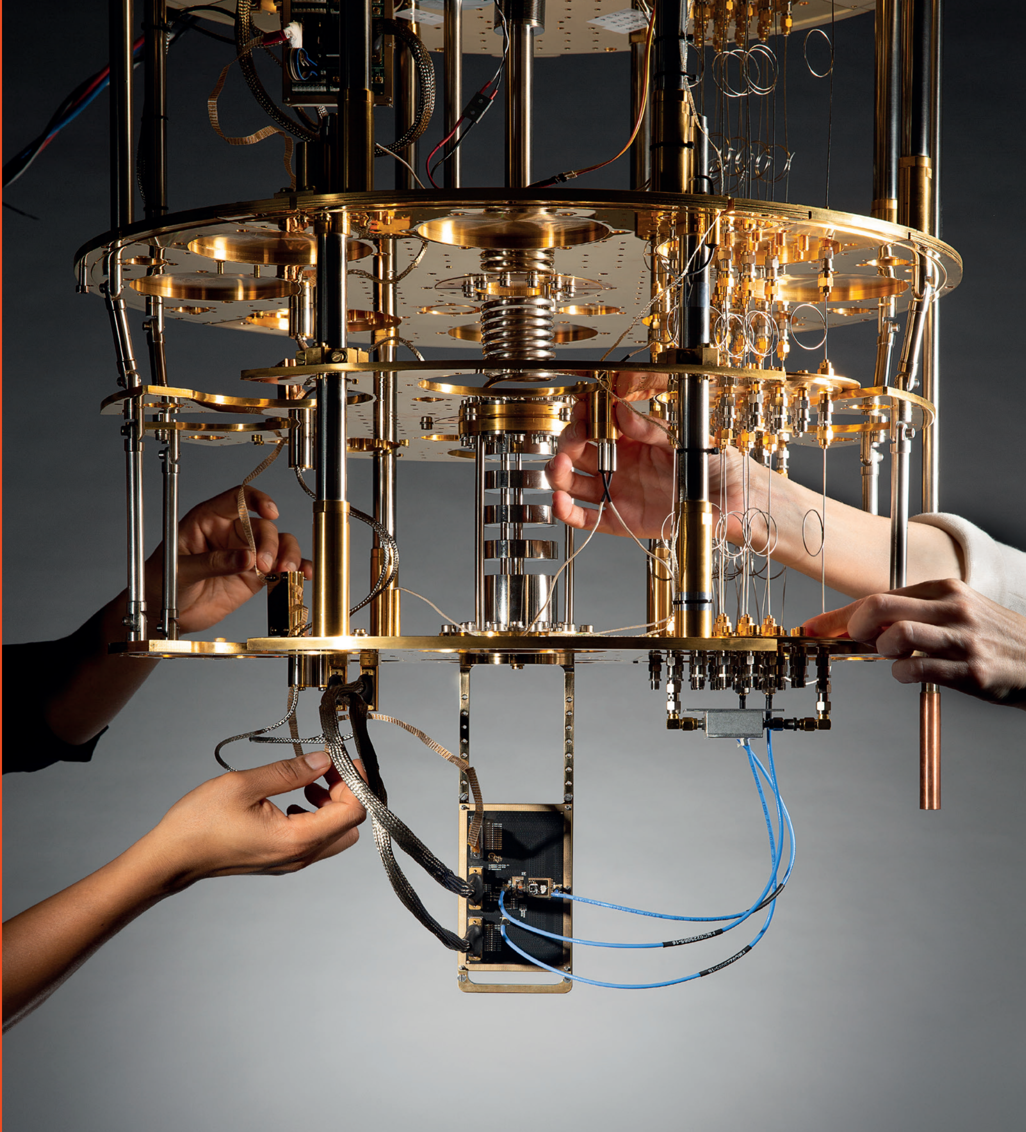
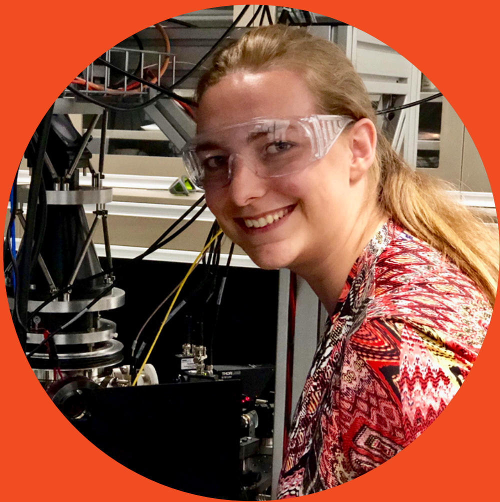


Quantum Physics at The University of Sydney

THE UNIVERSITY OF SYDNEY



“Quantum mechanics is an utterly incredible and bizarre area of physics; I cannot believe that I’m able to witness and exploit these remarkable phenomena everyday in our lab using individual trapped ions.”

Claire Edmunds
2021 / PhD, U Sydney
2021 / ESQ Fellow - University of Innsbruck

WHAT IS QUANTUM INFORMATION SCIENCE?

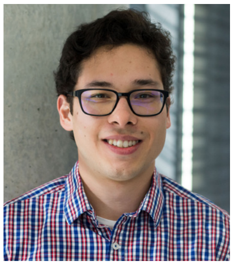
Quantum science is the study of quantum mechanics and how to translate knowledge about quantum systems into powerful new technologies. At the University of Sydney we have research programs that delve into both the understanding and application of quantum mechanics. We undertake theoretical and experimental research, which allows our researchers to engineer and manipulate complex quantum systems and create innovative hardware and software solutions. We tackle big questions. How does complex behaviour emerge from simple quantum systems? Can we control quantum systems to make a quantum computer? How do you correct errors in complex quantum calculations? What happens if we connect quantum systems together in a quantum internet?

What question are you interested in?

Ben Macintosh

2019 / Bachelor of Science (Honours), U Sydney

"In quantum mechanics, knowing everything about a system still leaves probability in the outcomes of measurement. We get to think about how fundamental uncertainties like this may be useful for computation."



Sebastian Pauka

2019 / PhD, U Sydney

"Researching quantum at the University of Sydney has given me the opportunity to meet international researchers around the world and work on some of the most dynamic and exciting problems in science today."

OUR RESEARCH

The **Quantum Control Laboratory (QCL)** explores new ways to control quantum systems for use in quantum computing, simulation and sensing. The group works with arrays of trapped ions, which are confined in ultra-high vacuum chambers and manipulated with laser and microwave radiation. Experiments are carried out in three quantum computer and quantum simulator prototypes hosted in two specialised, high-stability laboratories at the Sydney Nanoscience Hub.

Prof Michael J. Biercuk is QCL's director and founder & CEO of start-up Q-CTRL. His interests range from experimental quantum computation and simulation with trapped ions to quantum control engineering.

michael.biercuk@sydney.edu.au

Dr Ting Rei Tan leads the experiments with ytterbium ions in Paul traps and specialises in quantum computing, quantum simulation, and precision metrology.

tingrei.tan@sydney.edu.au

Dr Robert Wolf has a background in precision pectroscopy and leads the experimental efforts in quantum simulation using beryllium ions in a Penning trap.

robert.wolf@sydney.edu.au

In the **Superconducting Quantum Circuits Laboratory (SQCL)**, the excitations of superconducting circuits are used to explore fundamental physics and build hardware for high-performance quantum technologies. We design, fabricate and measure superconducting circuits with excitations and interactions that are optimal for quantum information processing, and engineer coherent interfaces between superconductors and other quantum platforms (e.g. semiconductors) to develop hybrid quantum technologies.

Dr Xanthe Croot is the director of the SQCL. Xanthe works with superconducting technology to build next-generation circuits for quantum computing and to explore fundamental physics.

xanthe.croot@sydney.edu.au

The **Quantum Integration Laboratory (QIL)** probes the quantum interactions between light, electronics, and atoms embedded in crystals. Understanding and engineering these interactions at the atomic scale promotes new technologies for connecting quantum systems through optical networks: a quantum internet.

Dr John Bartholomew is the director of the QIL and wants to use optically addressable spin technologies to transform lab-scale experiments to global-scale quantum science.

john.bartholomew@sydney.edu.au

The **Quantum Nanoscience Laboratory (QNL)** bridges the gap between fundamental quantum physics and the engineering approaches needed to scale quantum devices into quantum machines. The team focuses on the quantum-classical interface and the scale-up of quantum technology. The QNL also applies quantum technology in biomedicine by pioneering new approaches to magnetic resonance imaging using nanodiamonds.

Prof David J. Reilly is QNL's director and holds a joint position with Microsoft Corporation and the University of Sydney, as the Principal Researcher and Director of Microsoft Station Q, Sydney.

david.reilly@sydney.edu.au

The **Quantum Theory Group** explores a wide range of fundamental and applied questions ranging from the foundations of quantum mechanics to how to build practical quantum technology. What exotic properties of quantum mechanics give quantum computers their power? How do we scaleup 'quantum weirdness' from the size of an atom to the size of a mainframe? Can we debug quantum hardware and software, and reduce quantum errors through coding and fault tolerance?

Prof Stephen Bartlett is exploring the foundations of quantum mechanics, and then applies these ideas to the study of quantum computers. He also enjoys working with experimental teams to design better quantum technologies.

stephen.bartlett@sydney.edu.au

Dr Arne Grimsmo is interested in the theory of solid state quantum devices, designing quantum systems that can be used for information processing, and figuring out ways to manipulate quantum information in a noisy environment.

arne.grimsmo@sydney.edu.au

Prof Andrew Doherty is a theoretical quantum physicist. He works on methods for controlling quantum systems to produce qubits for quantum computing.

andrew.doherty@sydney.edu.au

HOW CAN I GET INVOLVED IN QUANTUM RESEARCH AT USYD?

There are many opportunities during your time at the University of Sydney to join the research teams that are driving discovery and innovation in quantum science. Everyone within a Physics Major can choose to complete a quantum research project in their 4th year. If you are a Dalyell Scholar or in the Special Studies Program you also have opportunities earlier in your degree. Contact the Unit of Study coordinator to find out more about project requirements.

First Year Physics

PHYS1904 Physics 1B (SSP)

The lab component of this unit features a group research project that can be performed with researchers from quantum science.

SCDL3991 Science Dalyell Individual Research Project

In this unit you will get a first-hand experience of cutting-edge research. Working in a quantum research group you will contribute to answering a novel research question. This could involve answering open theoretical questions or performing new quantum experiments. At the end you will present your results in a scientific seminar and report. This unit can be done in any year.

Second Year Physics

PHYS2921 Physics 2A (SSP)
PHYS2922 Physics 2B (SSP)
PHYS2923 (SSP)

You will work on an individual research project, mentored by one or more of the quantum science research staff. This replaces work in the laboratory, and the time commitment is 3 hours per week across the semester. At the end of the project you will give a presentation and write a report on your research.

"Quantum information science is an incredibly exciting and beautiful field, studying it within the Sydney group has been one of my most enjoyable experiences."

Sam Roberts
2019 / Phd, U Sydney
2019 / Quantum computing startup PsiQuantum, Palo Alto

“Quantum technology is believed to be the future of next-generation information processing. The wonderful experience working with the great scientists in the Sydney group has helped my research in this field to thrive.”

Wei-Wei Zhang
2017 - 2019 / Post Doc Research Fellow, U Sydney
2022 / Gusu Lab of Materials, Suzhou

Science Summer Research Program

There is also the opportunity to get research experience over the summer break with a summer vacation scholarship aimed at high performing students in the second and third year. You will work for 6 weeks (full time) with one of our research groups over the December to February break. This is a great way to get a taste of what it's like to work in a research group.

Third Year Physics

PHYS3888 Physics Interdisciplinary Project

In this project you will work in groups to tackle an interdisciplinary problem. For example, you could use machine learning to help understand the weird behaviour of quantum systems, or apply quantum control principles to investigate chemical reactions. This consists of 4 hours per week project work and at the end you will give a presentation and report describing your results.

Honours

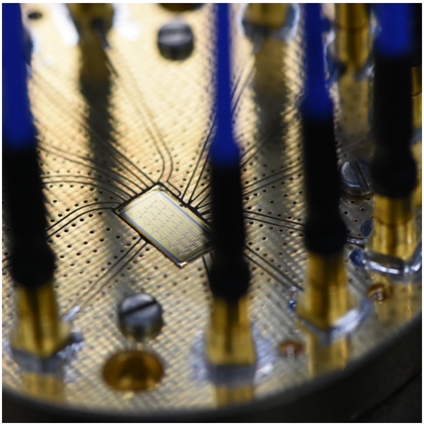
Physics honours is your chance to tackle a substantial year-long research project in quantum science. This can be a first step towards a research career, or excellent training in the problem-solving, information handling and programming skills that are highly sought-after in industry. Honours research tackles unsolved problems, and many students end up publishing scientific papers based on their honours thesis work. To enter honours you usually need a credit (65) average across Senior Physics, as well as a SciWAM of at least 65 or above. However you should contact the honours coordinator to discuss alternative paths.

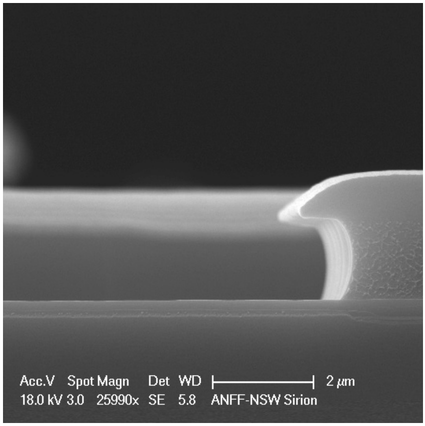
PhD

Doing a PhD will allow you to do a true deep-dive into quantum science, and become a world-leading expert on your chosen topic. PhDs in Physics typically take 3.5-4 years, and can be funded by a scholarship such as the Australian government Research Training Program (RTP) scholarship. The quantum science groups at the University of Sydney are also integrated with the new Sydney Quantum Academy, which provides both scholarships and a PhD Experience Program with a complementary course work stream in quantum science and technology.

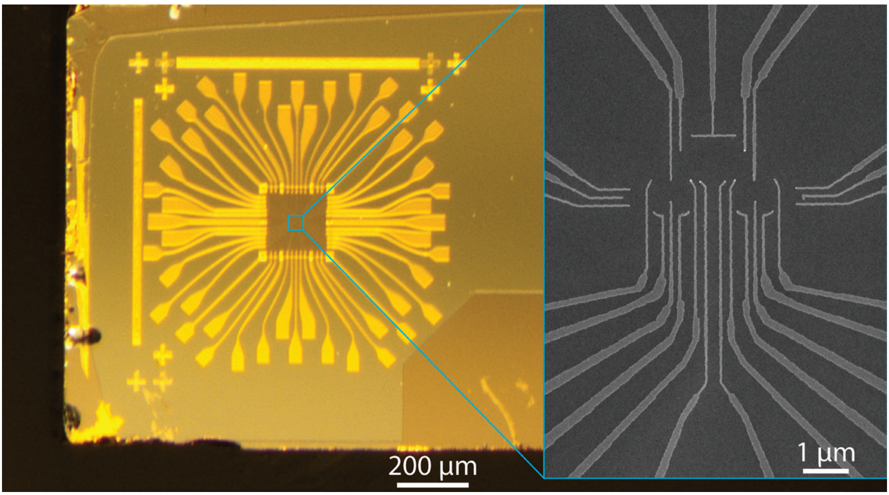
Left: Testing setup for a cryogenic high-speed multiplexer to reduce the number of control lines coming into a cryostat and control multiple qubits using low temperature signal distribution. Credit: John Hornibrook (QNL)

Right: Electron micrograph of a bilayer photoresist forming a sub-micron overhang. Credit: Sebastian Pauka (QNL)

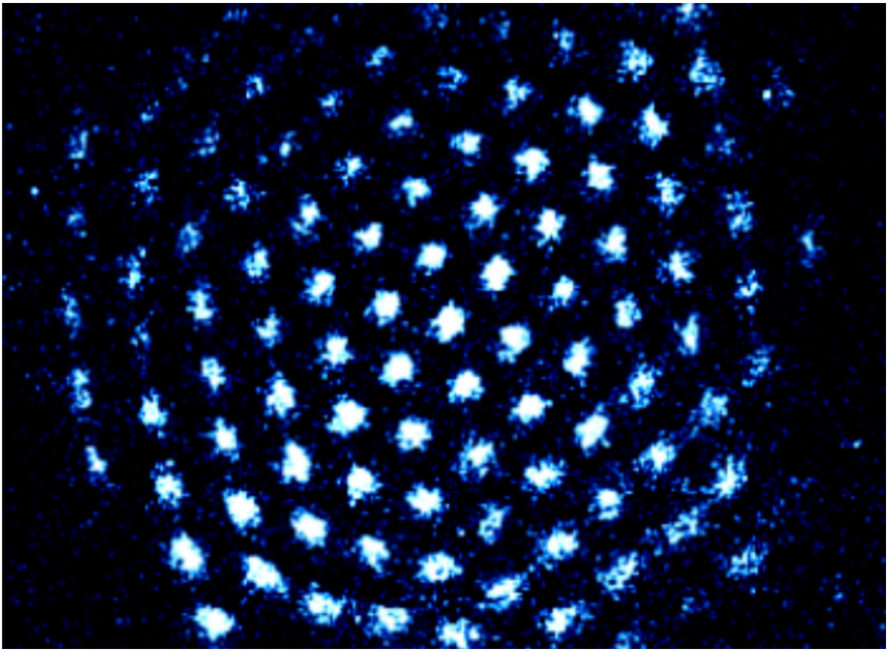




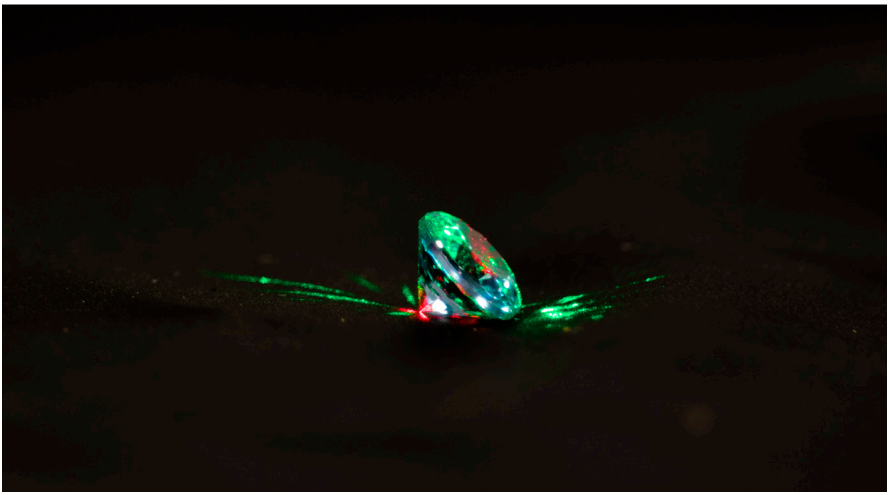
Wiring (left) and gate detail (right) of a quantum dot device. Two double-quantum dots are coupled via an additional quantum state, with electrons isolated by negative voltages on surface gates.
Credit: Sebastian Pauka (QNL)



Triangular lattice of a planar crystal of beryllium ions trapped in a Penning trap. Credit: Robert Wolf (QCL)



Atoms that interact with light and microwave fields can be embedded in transparent crystals to offer news ways to store and process quantum information. Credit: John Bartholomew (QIL) and Cornelius Hempel (QCL)



Maria Djuric

2019 / Bachelor of Advanced Studies (Dalyell Scholars)

"I am grateful for the opportunity to engage in current research in the field of quantum information theory at such an early stage in my degree. It has provided me with an idea of theoretical research as a career."

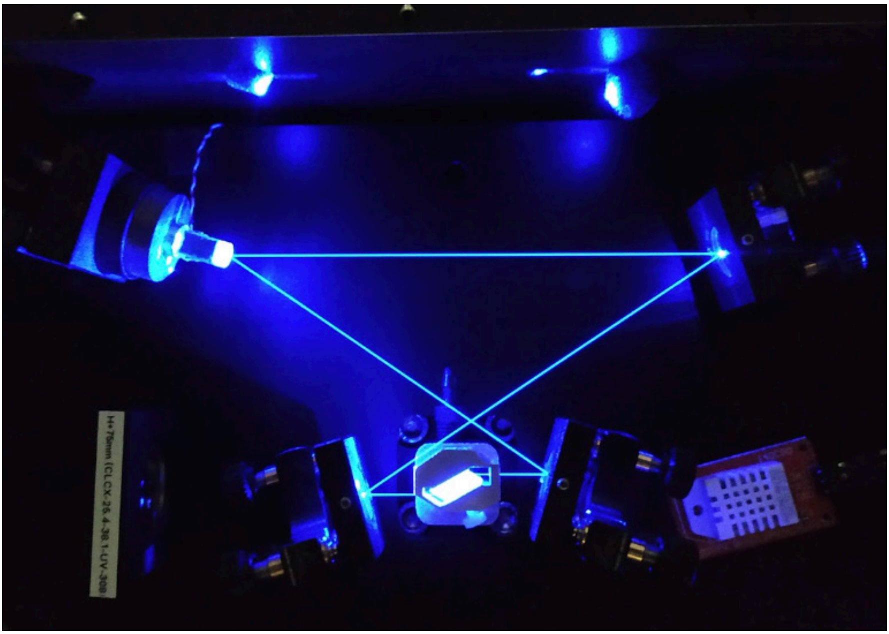
Alistair Milne

2021 / PhD, U Sydney

2021 / Senior Scientist at quantum technology startup Q-CTRL, designing and building quantum hardware

"Undertaking a PhD in the Quantum Control Laboratory enabled me to perform high impact experimental research in world class facilities. I developed the skills necessary to launch a career in the rapidly growing field of quantum technology."

High-power laser system to ionise beryllium atoms for quantum simulation experiments. Credit: Quantum Control Laboratory



“My quantum research at the University of Sydney provided me with the tools, ideas, and contacts I needed to become a professor at the Institute for Quantum Computing and co-found a quantum computing company.”

Joel Wallman
2013 / PhD, U Sydney
2019 / Assistant Professor, Institute for Quantum Computing & Department of Applied Mathematics, University of Waterloo

SYDNEY'S QUANTUM ECOSYSTEM

The research at The University of Sydney pushes the boundaries of quantum science. Joining our research team connects you to so much more than just great science.

Our researchers are based in the Sydney Nanoscience Hub, which was purpose-built to enable world class research into nano- and quantum science. This state-of-the-art research facility allows us to achieve impact beyond our individual laboratories.

We host a global research node of the Microsoft Station Q network (led by Prof. Reilly) focused on engineering interfaces between classical and quantum systems for more powerful quantum machines.

View to clean rooms in the Sydney Nanoscience Hub. Precision air conditioning supplies highly filtered air to the cleanroom that maintains the particulate level to levels 100 times cleaner than the air in a modern operating theatre.

As well as attracting partnerships with established tech companies like Microsoft, our innovative research is creating new companies that are helping build the international quantum technology sector. Q-CTRL (led by CEO Prof. Biercuk) is Australia's first venture-capital backed quantum technology company and their focus is developing software to reduce errors in quantum systems.

Our research also creates strong partnerships with other research institutions, both nationally and internationally. The University of Sydney is a node within the ARC Centre of Excellence for Engineered Quantum Systems, which links us to research and industry organisations across Australia and in more than twenty countries worldwide. Locally, we are a founding member of the Sydney Quantum Academy, together with UNSW, UTS and Macquarie University. The academy is a NSW government sponsored initiative to nurture education, engagement and innovation in quantum science.

Microsoft

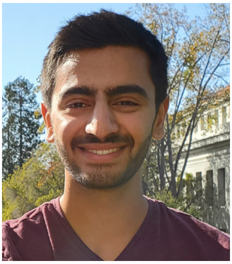
Q-CTRL

EQUS

SYDNEY QUANTUM ACADEMY

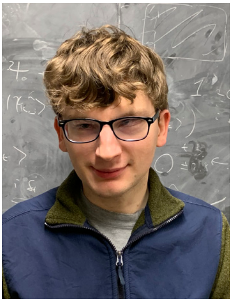
At the University of Sydney you will work with leaders in the field of quantum science to make new discoveries and engineer new technologies. And, in doing so, you will have developed key skills in automation, innovative design, and quantitative analysis that will enable you to launch your career in research, industry, or business.

Get in touch with us to start your contribution.



Ashwin Singh, 2018 / Bachelor of Science (Honours), U Sydney | 2019 / PhD candidate at the University of California, Berkeley

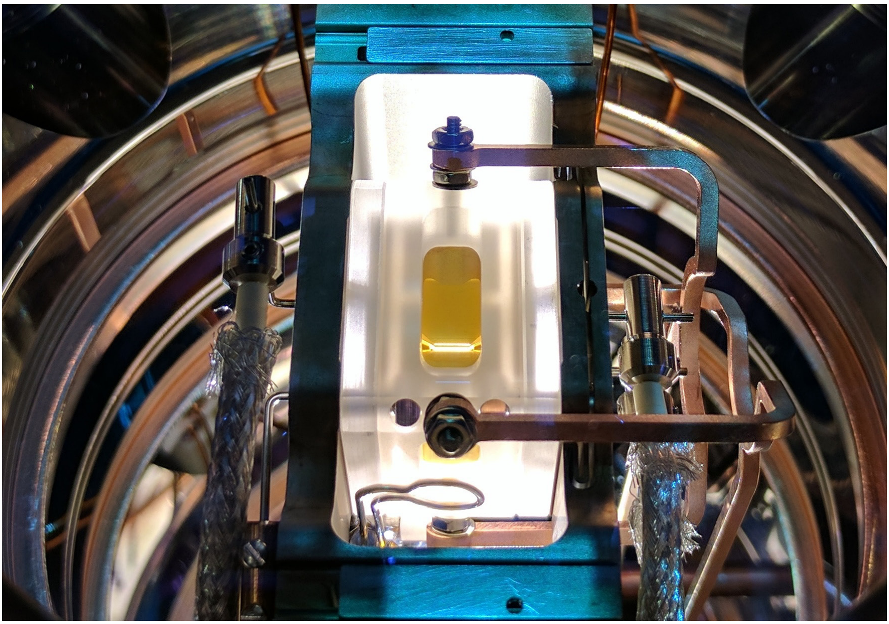
" Working on cutting edge projects with University of Sydney physicists who truly do understand quantum mechanics opened my mind and shaped the scientist I aspire to be today."

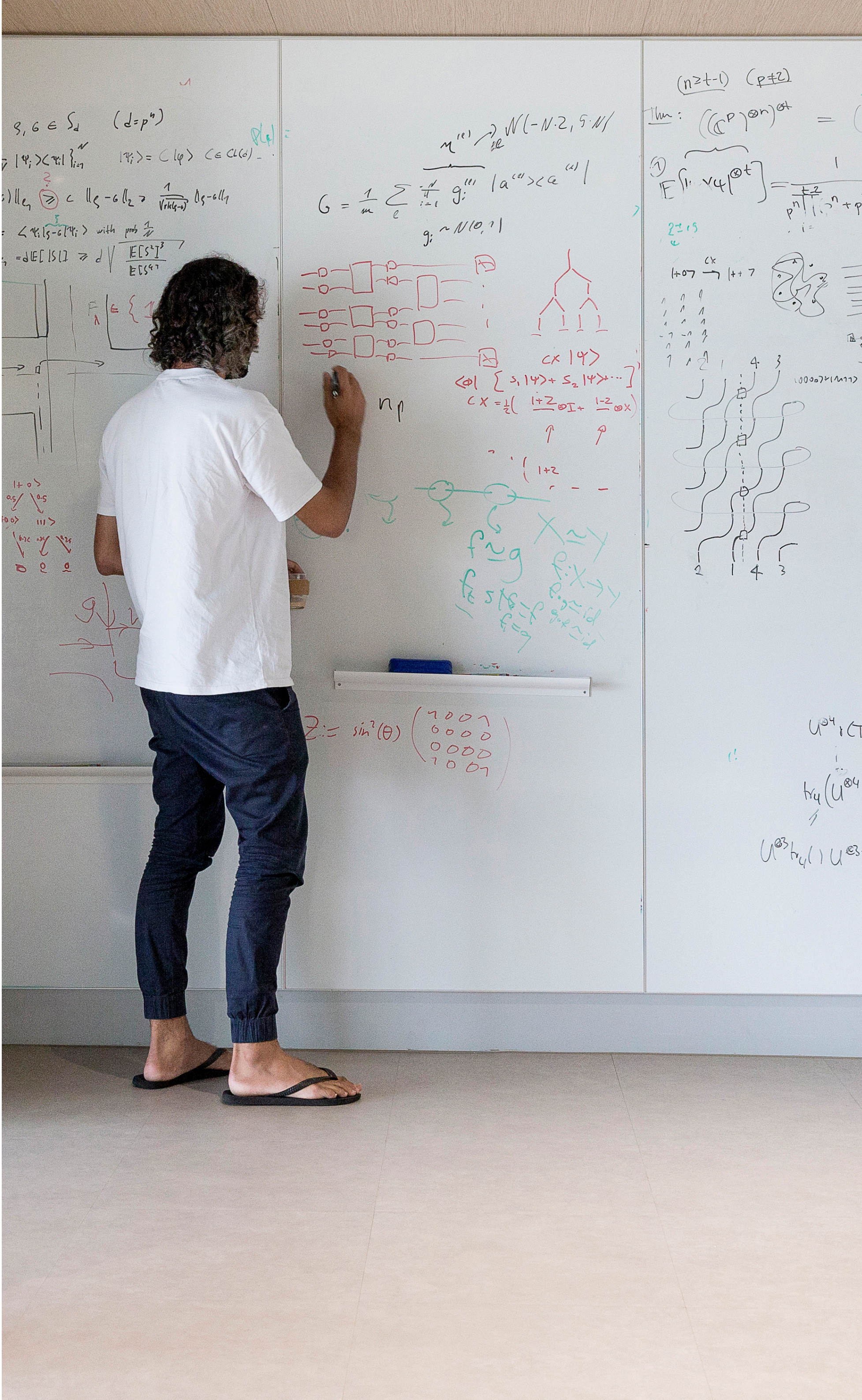


Dominic Else, 2011 / Bachelor of Science (Honours), U Sydney | 2022 / Breakthrough New Horizons Prize Winner, Harvard University

"Working in the quantum information group at Sydney was my initiation into the fascinating forms that quantum entanglement can take in quantum many-body systems, which I continue to explore in my research to this day"

Pg 19: PhD student Tim Evans working on a quantum algorithm.
Below: Linear Paul trap for quantum computing and quantum simulation with $^{171}Yb^{+}$ ions. Credit: Michael Biercuk (QCL)





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