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## Charting the Australian quantum landscape

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# Quantum Science and Technology



## PERSPECTIVE

### Charting the Australian quantum landscape

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#### Abstract

Australia has world-class research in quantum technology, and has been a significant presence since the earliest days of the field. There has been sustained and substantial support from all levels of government, and an industrial base that has grown from a single quantum-technology company to a spectrum of businesses covering both software and hardware. Here, we discuss the Australian approach to quantum technology, briefly outlining the research and funding, discussing the current environment, and looking forward to the future.

The future of quantum technologies looks bright with a multitude of announcements over the past few years regarding new research, applications, and investments in the field. It is no wonder that such substantial investment has occurred given the compelling capabilities enabled by the properties of quantum mechanics, which range from imaging and sensing through to computing and communication. All this makes the call for articles from the editors of this journal particularly timely. We were asked: where does Australia sit in the global quantum landscape? In attempting to answer this question, we delved into the history of quantum science in the nation, we reviewed the significant rounds of investment that made it all possible, and considered what makes the Australian approach to quantum technology unique.

## 1. The Australian approach

It is a good time for Australia in the burgeoning field of quantum technology. More than two decades of support for quantum engineering, science, and technology has paved the way for significant scientific outputs and exciting translation efforts. The Australian Research Council is currently supporting four national Centres of Excellence in this space—the Centres for *Engineered Quantum Science* (EQUS) [1], *Exciton Science* [2], *Future Low-Energy Electronics Technologies* (FLEET) [3], and *Quantum Computation and Communication Technology* (CQC2T) [4]—employing more than 500 scientists and running variously until 2023 and 2024. A research program in a fifth Centre, the *Centre for Gravitational Wave Astronomy* (OzGrav) [5], is utilising squeezing in gravity-wave astronomy: a superb example of quantum metrology. Defence has also established a Next Generation Technology fund with quantum technologies as one of the seven priority areas [6]; the first round of successful grants for this fund were announced in late October 2018.

The Australian approach to quantum technology can be summarised by the phrase ‘alloys make the strongest metals.’ Our research community is made up of competing, interweaving, and mutually supportive groups with leading researchers in every mainland capital city. The Australian funding system backs multiple scientific and technological approaches, guided always by scientific outcomes in determining what goes forward. Our research environment has reflected—and indeed at times led—the global shift from fundamental science to applications and outcomes for quantum science. At the time our two oldest Centres were formed their names were controversial, with comments that the terms ‘technology’ (CQC2T) and ‘engineered’ (EQUS) did not belong to science centres. These concerns seem quaint now, as in the next stage of research we look to the potential applications and benefits of quantum technology—benefits so compelling that they have inspired governments and the world’s largest private-sector organisations to invest heavily in the space.

In Australia, quantum is now supported to the tune of over AUD\$130 million through the federal government alone. State-level governments have also provided continued investment this century, most

recently through the New South Wales state government supporting four Sydney universities to establish an academy to train the next generation of quantum engineers [7], and prior to that with significant funding from the Queensland and Victorian state governments. In parallel with this activity, quantum-based Australian companies have begun to emerge, such as *Quintessence* [8], *QCtrl* [9], and *Silicon Quantum Computing* [10]. Indeed, the public profile of quantum technology has never been higher, with CQC2T Director Professor Michelle Simmons named as Australian of the Year for 2018, and high-profile researchers such as Professor Robert Clark and Professor Halina Rubinsztein-Dunlop each being named Officers of the Order of Australia.

## 2. The backstory

How did we get to this point? Arguably, quantum science in Australia was shaped by two fields of research in the 1980s and 1990s. The first was quantum optics with experimental and theoretical research efforts led by Professor Hans Bachor (the Australian National University, ANU, 1982) and Professor Gerard Milburn (ANU, 1985; the University of Queensland, UQ, 1988): the students and postdocs from these groups are now leading research around the world, with both Bachor and Milburn authoring and co-authoring significant textbooks that shaped the fields [11–15]. The second field was condensed matter physics, with Professor Robert Clark (the University of New South Wales, UNSW, 1990), establishing new research teams and pivotal pieces of research infrastructure, notably the *National Pulsed Magnetic Laboratory* [16]. Historically, the fields of quantum optics and condensed matter physics were quite disjointed, with the scientists from each rarely overlapping professionally other than in physics tea rooms or at national congresses.

This changed with several notable events at the turn of the century. In 1998, a postdoc at UNSW, Dr Bruce Kane, published a theoretical proposal to realise quantum computing with silicon technology [17]. At the same time, Gerard Milburn and colleagues in the United States were working on a theoretical proposal to achieve photonic quantum computing using linear optics [18]. This work laid the foundations for the first large-scale effort in quantum technology: the *Special Research Centre for Quantum Computer Technology* (CQCT) [19], led by Clark and Milburn as Director and Deputy-Director. The 1990s also saw groups at ANU and UQ, respectively led by Bachor and Rubinsztein-Dunlop (UQ, 1989), establish cold-atom systems that led to major quantum initiatives (discussed further below).

The problem of how to scale up scientific research efforts in Australia was addressed in 2003 when Professor Vicki Sara—then Chief Executive Officer of the Australian Research Council—established the *Centres of Excellence* program with the aim of undertaking innovative, cutting-edge research, while enhancing Australia's future economic, social, and cultural wellbeing [20]. Centres typically contain 100 to 150 scientists all working on an ambitious scientific challenge and are often virtual centres—technically unincorporated joint ventures—that typically span the continent. When the program was launched, the perceived wisdom was that—due to the small size of Australia and notwithstanding its large and active community of quantum scientists—at most, one quantum-focused centre might be funded. To the delight of the physics community, two quantum Centres of Excellence were supported. The first, built on the existing Special Research Centre became the *Centre of Excellence for Quantum Computer Technology* (CQCT). Led by Clark and Milburn, CQCT aimed to enhance Australia's momentum in this race, build a stronger research team, and coordinate projects with the goal of achieving silicon-based and photonic quantum computers. The second centre, the *Centre of Excellence for Quantum-Atom Optics* (ACQAO) [21], led by Bachor and Professor Ken Baldwin (ANU), combined quantum theorists and experimentalists to produce squeezed states of light and Bose–Einstein Condensates. At the same time as these large-scale grants—worth over \$24 million during the first four years of funding—the Australian funding landscape allowed a broader investment in other vital and often complimentary projects to happen alongside of the Centres, e.g. with Rubinsztein-Dunlop leading a five-year Discovery Project on Quantum Atom Optics with Micro Bose–Einstein Condensates (2003–2008, \$1.4M).

## 3. Current research landscape

Since 2003 there have been three significant rounds for quantum-focused Centres of Excellence. The second round was in 2011. As this year approached, the quantum science landscape of Australia began to share characteristics with today. Following applications during the Australian Research Council Centre of Excellence round, the *Centre of Excellence for Quantum Computation and Communication Technology* (CQC2T)—led by Simmons and Professor Lloyd Hollenberg (University of Melbourne)—was formed from the legacy of CQCT (2003–2010). In the same year, Milburn and Professor Andrew White (UQ) led the new *Centre of Excellence for Engineered Quantum Systems* (EQuS), with a research team eager to follow promising new research into broader quantum technologies. In addition, a third quantum optics-related Centre, the *Centre of Excellence for Ultrahigh Bandwidth Devices for Optical Systems* (CUDOS) [22], was also funded and led by Professor Ben Eggleton

(University of Sydney) and Professor Yuri Kivshar (ANU). Emphasis on the technological applications for quantum science began to increase as the scale of research and investment internationally increased dramatically. New quantum technologies were now expected to have a considerable impact on many of the world's biggest markets in a broad range of areas, stretching from communication and sensing through to measurement and computation.

One of the features of the Australian research landscape is that quantum technology has been supported at all levels with significant research programs outside the Centres. A notable example is the project led by Professor Andre Luiten (University of Adelaide) on Sapphire Clocks—clocks so precise that they gain or lose just one second over 40 million years—which is being rolled out into our national defence systems [23]. The oldest quantum company in Australia, *Quintessence Labs*, has become a global supplier of solutions for quantum random number generation and quantum key distribution. Elsewhere, the University of Technology Sydney has established the *Centre for Quantum Software and Information* through ARC and university funding [24]. This centre will contribute to the development of powerful tools for when large-scale quantum information processing becomes a reality.

In 2017 two new quantum-focused Centres of Excellence were established, running from 2017 to 2023: FLEET, led by Professor Michael Fuhrer (Monash University) and Professor Alex Hamilton (UNSW); and Exciton Science, led by Professor Paul Mulvaney (University of Melbourne) and Professor Udo Bach (Monash); as well as two Centres transformed, EQUUS and CQC2T, running from 2018 to 2024. In August 2018 four quantum Centres—EQUUS, Exciton, FLEET, and ACQAO—organised a conference on Magnetic Island in the Great Barrier Reef that drew together researchers, government, and industry to debate the future of quantum industry in Australia. Our researchers hold advisory roles in government and industry around the world, a striking recent example being Professor Gavin Brennen (MQ, EQUUS) as Chief Community Officer, and Professor Ping Koy Lam (ANU, CQC2T) as Expert Panel Chair, of *Qubit Protocol*, a platform that helps guide strategic investments in quantum technologies [25].

In addition to grants through federal and state government, large technology companies have also come to call. This has included one of the world's largest—*Microsoft*—which invested many scores of millions in the quantum engineering research of Professor David Reilly (University of Sydney, EQUUS). Meanwhile, Australian banks and telecommunications companies are supporting *Silicon Quantum Computing*, which is working to create and commercialise a quantum computer. Investment in this space is booming—not just from government and large companies, but also from venture capitalists looking for the next quantum start-up. With high levels of both investment and attention, we are arguably in a quantum bubble: there are currently over 70 spin-off and start-up quantum-related companies worldwide, with five of these based in Australia.

As a result of the immense support for this field in Australia, there is a clear scientific legacy. Equally important, although less well documented, is the generation of high-quality Australian-trained postgraduates who are placed domestically and internationally within research institutions, industry, and policy. Notable Australian alumni who have founded quantum companies globally include: Professor Jeremy O'Brien (University of Bristol; PhD UNSW; Postdoc UQ and CQC2T), founder of PsiQuantum in the United States [26]; and Dr Christian Weedbrook (University of Toronto; PhD UQ and CQC2T), founder of Xanadu in Canada [27]. The training of our people is the most significant legacy to come from the first 30-plus years of quantum science in Australia. With the scientific and human legacy of Australian investment in this space already assured, what remains to be seen is to how this translates into societal benefit in terms of prosperity and security.

## 4. Conclusion

While we were writing this article, Australia's quantum community took its first collective steps into the political arena. Last November, at a breakfast in Australia's capital, Canberra, politicians, advisers, policymakers, and senior members of the STEM sector met to discuss quantum technologies and considered the need for a national plan for the sector. In February, Dr Cathy Foley, Chief Scientist of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), led a follow-up meeting on developing quantum industry, bringing together stakeholders from every national sector. It is early days for this potential Australian strategy for quantum technology, but we hope it will be informed by the distinctly Australian approach to research—which is characterised by multiple efforts in quantum research and translation being supported over extended periods of time by government, both federal and state, as well as individual universities, and, increasingly, industry partners. Our research community and partners are producing significant research results and innovative spin-offs, and a national strategy might just be the right place to start capitalising on those strengths as we move into the second quantum revolution.

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## Author contribution statement

TMR and AGW contributed to the content and writing of this manuscript; TMR took the lead in writing the manuscript.

## Author backgrounds

TMR is the Communication Officer in EQUS and is currently undertaking a PhD in Science Communication at Australia's Centre for Public Awareness of Science. AGW is Director of EQUS (2018–2024) and was a member of the SRC for CQCT (2000–2002), and the COEs EQuS (2011–2017) and CQC2T (2003–2010 and 2011–2017).

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