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The 1st Australian Quantum Communication Forum

Thursday 21st March 2024
Canberra, Australian Capital Territory

#AuQComForum

The Australian Academy of Science's Shine Dome
15 Gordon Street, Canberra, ACT 2601

Acknowledgement of Country

We acknowledge the Traditional Owners of Country throughout Australia. We pay our respects to Elders past and present.

Forum Program

Forum Program

8.00	Registrations Tea and coffee on arrival
8.25	MC Scott Martin CSIRO
8.35	Enrico Palermo Head of Australian Space Agency, Australian Government
8.50	Michele Graham Science and Technology Group – Technology and Digital - Quantum Department of Industry Science and Resources, Australian Government
9.05	Colonel Clifford White, Director – Space Service SATCOM, Space Capability Branch, Joint Capabilities Division, Australian Defence Force
9.20	Angelo Bassi Professor of Physics, University of Trieste
9.40	Nasser Barghouty Chief Scientist of the Space Communications and Navigation (SCaN), NASA
10.00	Morning Tea
10.30	Q&A Expert Panel: Quantum Communication Infrastructure Keynote Speaker: Tanvirul Islam, Centre for Quantum Technologies National University of Singapore *A series of secured network nodes linked by quantum-secured data channels would provide the basis for an experimental quantum communications network. There are two media used to propagate quantum communication signals: within optical fibres; and through free space. Quantum communications at scale will require the combination of these technologies – satellite links to ensure long haul communication links, with fibre networks to connect local users. The group of experts will present some national and international activities highlighting the technical challenges and state of the art in quantum communications capability. What could we build now, with the technology we have already developed?*
10.45	Technical Section Facilitator: Sarah Lau, CSIRO Speakers: Kate Ferguson, ANU Daniel Floreani, Cyber Ops Matthew Sellars, ANU Ramana Kompella, Cisco Research for Emerging Technology and Incubation
11.35	Panel and Public Discussion
12.00	Lunch

13.30 Q&A Expert Panel: Quantum Assured PNT

Keynote Speaker:
Susannah Jones, DSTL - UK

Quantum communications links through free space provide a highly secure method for positioning and navigation by allowing the users to be sure that no attacker can spoof the true positioning signal. The group of experts will present some national and international activities highlighting new methods of time transfer over optical fibre and optical free-space links utilising both conventional and quantum techniques.

13.45 Technical Section

Facilitator: Stephen Gensemer, CSIRO

Speakers:
Giuseppina Dell'Armi-Stoks, DST
Sascha Schediwy, UWA
Fred Baynes, Quantx
Stuart Szigeti, Q-Ctrl

15.35 Panel and Public Discussion

15.00 Afternoon Tea

15.30 Q&A Expert Panel: Quantum Information Networking

Keynote Speaker:
Paolo Bianco, Quantum Computing Systems Integration and Analysis Group Leader, Forschungszentrum Jülich Germany

In the longer term, Quantum information networks could provide substantial enhancements to the Quantum Communication Infrastructure using a combination of quantum memories and quantum repeaters to distribute entanglement across multiple network nodes. The technology to develop the QIN is under development and not commercially available at present. The group of experts will present some national and international activities highlighting the state of research as well as opportunities and challenges.

15.45 Technical Section

Facilitator: Chris Vale, CSIRO

Speakers:
Sophi Zhao, ANU
Linh Nguyen, DST
Rose Ahlefeldt, ANU
Robert Bedington, SpeQtral Singapore

16.35 Panel and Public Discussion

17.00 Conclusion
Chris Vale, CSIRO
Nicola Sasanelli AM, Agora High-Tech

17.05 Networking

About

The 1st Australian Quantum Communication Forum has been developed as part of the CSIRO Quantum Technologies Future Science Platform with support of Agora High-Tech. This milestone as well as the QComm Narrative and QComm Capability directory are a result of the collective efforts and invaluable contributions from government, universities, private enterprises, start-ups, and consultants.

Australian Quantum Communication Narrative

Please scan QR Code to dowload the document.

Australian Quantum Communication Capability Directory

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Forum Registration

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Speakers

Dr. Rose Ahlefeldt

Senior Research Fellow
Australian National University (ANU)

Rose is a Senior Research Fellow in the Research School of Physics at the Australian National University (ANU). She completed her PhD at ANU in 2013, and then worked at Laboratoire Aimé Cotton, France as well as at Montana State University, USA on a Fulbright Scholarship, before returning to ANU in 2016 as an Australian Research Council DECRA fellow. In 2018 she was named Australian Capital Territory Scientist of the Year for her research. Dr Ahlefeldt's research expertise is in quantum information applications of rare earth crystals, including quantum memories, quantum processors, and optical quantum interconnects for various quantum computing technologies. Her primary research interests lie in optimising rare earth materials to improve quantum device performance, and she has a leading expertise in the experimental and theoretical study of strongly interacting rare earth systems.

Dr. Nasser Barghouty

Chief Scientist of the Space Communications and Navigation (SCaN)
NASA

Dr. Barghouty joined NASA SCaN (Space Communications and Navigation) in 2019 as its chief scientist, with the primary goal to build up SCaN's quantum communications and networking strategic capabilities. Before joining SCaN he served as the technology lead for the Astrophysics Division of the Science Mission Directorate at NASA Headquarters. Dr. Barghouty joined NASA in 2004 from academia to start a space radiation and shielding program at NASA's Marshall Space Flight Center, where he also served as chief of the Astrophysics Branch, 2012-2017. His academic career includes appointments at Caltech, the University of Arizona, Tennessee Technological University, and Roanoke College in Salem, VA, where he was named Brian H. Thornhill Professor of Physics in 1998. His awards and recognitions include Marshall's Software-of-the-Year award in 2016, and a Fulbright Fellowship in 1998. Dr. Barghouty holds a doctorate in theoretical nuclear physics and a masters in physics from Kent State University in Kent, OH, and a bachelors in electrical engineering from San Jose State University, in San Jose, CA.

Professor Angelo Bassi

Professor of Physics
University of Trieste

Angelo Bassi, with a PhD in Physics from the University of Trieste (2001), was postdoc at ICTP inTrieste, and Marie-Curie Fellow at the LMU in Munich. As a full professor at the University of Trieste, he works on quantum mechanics. His contributions include over 150 publications and presentations at more than 70 international conferences, along with organizing over 30 events. His work has been recognized internationally, leading to presentations at prestigious institutions like MIT, Harvard and Princeton. Bassi has successfully led numerous research projects, raising over 7 million euros. Featured in New York Time Magazine (June 2020) and other journals, he writes for La Repubblica on Quantum Physics and Technologies. He coordinates the Quantum Communication program in Friuli Venezia Giulia (Italy), launched in 2020. This includes the "Quantum FVG" and "QuFree" projects, a Quantum Communication Lab at the University of Trieste, and the development of a regional QKD network.

Dr. Fred Baynes

Research Group Leader
QuantX Labs

Fred Baynes began his career with a passion for fundamental science and has transitioned to delivering cutting edge solutions for Industry and Defence. He obtained a PhD in Physics from the University of Western Australia in 2013 for an optical test of special relativity and undertook post-doctoral positions in the Time and Frequency divisions of both the National Institute of Standards and Technology in the USA and the National Physical Laboratory in the UK. Since returning to Australia in 2016 he worked at the University of Adelaide on precision oscillators for Defence and is now the research group leader at QuantX Labs overseeing projects in cryogenic sapphire oscillators, magnetometers and time transfer.

Dr. Robert Bedington

Co-founder and CTO
SpeQtral

Dr Robert Bedington is co-founder and CTO of SpeQtral Pte Ltd, a Quantum Communications company based in Singapore and specialising in satellite quantum key distribution. SpeQtral is a spin-out company from the Centre for Quantum Technologies at the National University of Singapore where Robert was previously a senior research fellow and satellite team lead for the SpooQy-1 CubeSat mission. SpooQy-1 launched in 2019 and is currently the only quantum CubeSat in orbit. In the same year Robert was recognised by MIT as one of ten Innovators under 35 for the Asia Pacific region. Previously he worked as a JSPS fellow researching the miniaturisation of satellite instrumentation for plasma analysis at the Japan Aerospace Exploration Agency (JAXA) and for his PhD at University College London he developed a miniature plasma analyser that was launched on the PoleCATS sounding rocket mission. He has a Physics degree from the University of Durham.

Paolo Bianco

Quantum Computing Systems Integration and Analysis Group Leader
Forschungszentrum Jülich Germany

Paolo Bianco graduated in Mechanical Engineering at Cranfield University (UK) and in Aeronautical Engineering in Turin (Italy). Paolo started his career in space at CGS (OHB), Milan, Italy, then he joined Astrium, now Airbus, in Portsmouth (UK). As a space system engineer, Paolo has designed systems for Earth orbit and for currently flying interplanetary missions. In parallel, as technologist, Paolo has developed a wide range of technologies for space and aerospace applications. This became his job as Global R&T Cooperation Manager for Airbus Defence and Space, for UK and Asia-Pacific. In 2015 he got involved in Quantum Technologies (QTs), investigating and assessing on how to use them in Airbus operations and products. He provided his views on QTs application to the European Parliament, the House of Parliament and to the European Commission, for the deployment of the QT Flagship. In June 2023 he stepped up his QTs involvement by moving to his current job as team leader of the Quantum Computing Systems Integration and Analysis Group of PGI-12 at Forschungszentrum Jülich (Germany).

Dr. Giuseppina (Pina) Dall'Armi

Research Leader,
Electronic Warfare Operations Defence Science and Technology Group

Pina obtained her PhD degree in Physics in 1996 from Flinders University. She worked in private industry before joining Defence Science Technology Group in 2000. As a research scientist and then as a senior research scientist Pina has worked on assessing the impact of electromagnetic interference and compatibility of systems for maritime, land, space and air domains. Pina was awarded a Defence Science Fellowship placement at the Naval Postgraduate School, USA. In 2018 she was promoted to Group Leader of the Electromagnetic Characterisation and Effects group, and then Directed Energy and Technologies and Effects Group. In 2021, Pina took on the role as Research Leader of Electronic Warfare Operations oversighting all Radiofrequency and Electro Optics Electronic Warfare and Quantum Technologies Science and Technology (S&T). Her current role is Research Leader Electro Optics Sensors and Electromagnetic Warfare. Pina has published numerous technical reports and papers in her research field and is an advocate of STEM outreach.

Dr. Kate Ferguson

Associate Director Strategic Projects
Australian National University for Space

Dr Kate Ferguson is the Associate Director Strategic Projects at the Australian National University for Space. As part of this role, she has managed the industry engagement and translation of the ANU Quantum Optical Ground Station. She was awarded her PhD in 2016 on developing quantum communication hardware, in particular quantum memories and entangled light sources for long range quantum networking.

Dr. Daniel Floreani

Principal Consultant and Director,
CyberOps

Daniel is a consultant with over 25 years' experience in communication networks connecting diverse things to the Internet. Daniel has worked in many local and global roles during his career including R&D, systems engineering, sales, technical leadership, enterprise architecture, business development and market creation. He has developed a specialisation in Defence, Satellite, Cybersecurity and Public Sector ICT architectures and putting Internet based systems into Space.

Dr. Stephen Gensemer

Team Leader, Optical Systems Industrial Innovation Program
Manufacturing CSIRO

Dr Gensemer earned his Ph.D. in Physics from University of Connecticut in 2000, studying light-matter interactions in atoms and molecules. He worked at the National Institute of Standards and Technology (U.S.), University of Amsterdam, Penn State University and Sydney University before joining CSIRO in 2013. At CSIRO he has developed a range of sensor technologies for environmental and agricultural uses, and manufactured precision optical components that are used for gravitational wave detection and in the ESA's Solar Orbiter. He leads the CSIRO Laboratory for Satellite Optics at the University of Adelaide, where CSIRO is building custom spectral imaging instruments for cubesats, drones, and high altitude pseudosatellite missions. The team is also building instruments for remote and in situ water quality sensing (part of CSIRO's Aquawatch effort), agricultural monitoring, and quantum communications.

Michele Graham

General Manager, Quantum Branch,
Australian Government Department of Industry, Science and Resources

Michele Graham is General Manager, Quantum Branch at the Australian Government Department of Industry, Science and Resources (DISR). Michele has worked at DISR since 2019, including leading Science Policy & Governance Branch. Before this she supported 5 Australian Prime Ministers in a range of roles at the Department of the Prime Minister and Cabinet, culminating in leading the Cabinet Secretariat. Prior to her public sector roles, Michele developed business strategies for major Australian and multi-national companies in the financial services, manufacturing, information technology, energy and telecommunications sectors. Michele holds a Master of Business Administration (Executive) from Australian Graduate School of Management, a MPhil in Educational Research from Cambridge University and a Bachelor of Engineering (Civil) with 1st Class Honours and the University Medal from University of Sydney.

Dr. Tanvirul Islam

Senior Research Fellow
Centre for Quantum Technologies National University of Singapore

Tanvirul Islam completed his PhD on quantum networks from School of Computing, National University of Singapore. Currently he is a Senior Research Fellow at the Centre for Quantum Technologies, NUS. His research area includes satellite based quantum communication and quantum random number generation.

Dr. Susannah Jones

Principal Quantum Research Scientist
DSTL UK

Susannah Jones is a Principal Quantum Research Scientist at the Ministry of Defence (MoD), Defence Science Technology Laboratory (Dstl). Her current role at Dstl is the joint Technical Strategy Lead for Quantum Technology and Project Technical lead for the Quantum Sensing and Timing research. Susannah joined Dstl as a graduate researcher in 2012. Since joining the organisation her research has included developing active and passive armour for the mounted and dismounted soldier, creation of a novel maturity tool to support the development of novel technology and development of quantum technology for defence applications.

Dr. Scott Martin

Senior Manager, Strategic Relationships, Quantum Industry and Technology, CSIRO

Scott is the Senior Manager, Strategic Relationships, Quantum Industry and Technology within CSIRO's Strategic Partnerships Group. The focus of his role is to address the immediate and expanding needs of quantum technologies across CSIRO and to position CSIRO as a key innovator and advocate to Australia's emerging quantum industry. Working closely with CSIRO's Quantum Technologies Future Science Platform (FSP), of which he was Acting Director from March to September 2023, his role is to liaise with industry, academic and government partners to identify research-led projects that enable CSIRO to develop and deploy capability, provide advice on quantum strategy and develop unique research collaborations with universities.

Ramana Kompella

Head of Research in the Emerging Tech and Incubation Group
CISCO

Ramana Kompella is currently a Distinguished Engineer, and the Head of Research in the Emerging Tech and Incubation group at Cisco, where he leads university research collaborations. In his prior role within Cisco, he was a founding member, Head of Engineering, and the CTO of the Candid alpha project that built the Network Assurance Engine for providing continuous formal verification of intent for Cisco's ACI data center networks. Prior to Cisco, he was a Staff Network Architect in the Network Operations team (NetOps) at Google, where he led several network measurement initiatives for the next-generation Google Data Center Networks. He also was the co-founder, and CTO of Appformix and led the engineering effort to build the first generation application optimization platform for virtual environments. Until 2013, he served as an Associate Professor at Purdue University where he led the Systems and Networking Research funded by grants over 2M$s from NSF and other Industrial Sources, and served as the thesis advisor for several Ph.D. and Masters Students. He holds a B.Tech degree from IIT Bombay, M.S. from Stanford University and a Ph.D. from UCSD, all in Computer Science.

Dr. W. Y. Sarah Lau

Research Scientist, Manufacturing
CSIRO

W. Y. Sarah Lau completed her doctorate in physics at the University of Queensland. She focused on integrating a narrow bandwidth single photon source with an atomic ensemble-based quantum memory with collaborators at the Australian National University. Sarah has since worked as an R&D Optics Engineer at Finisar Australia (Coherent Corporation) gaining experience in advanced manufacturing and delivery of a first-to-market product to customers. Sarah is currently at CSIRO with ambitions to combine her passion of translating research out of the lab with frontier quantum technologies research for meaningful impact, and to support and expand Australia's capabilities. Previously she also trained and worked as a high school teacher, valuing the engagement of underrepresented groups in STEM, especially early in their education.

Dr. Linh Nguyen

Defence Science and Technology Group
DSTG

Dr Linh Nguyen has been with DSTG for over 20 years. He has worked across the TRL spectrum from long-range research to capability acquisition projects. He is currently the acting Group Leader Quantum Technologies in the Sensors and Effectors Division.

Nicola Sasanelli AM

Chairman and Founder
Agora High-Tech

Nicola graduated from the University of Bari, Italy with a degree in Electronic Engineering. He started his career as a researcher in microelectronics high-reliability components before being appointed as Scientific Attaché at the Embassy of Italy in Canberra from 2001 to 2008. In 2009, Nicola joined the South Australian Government as a Special Envoy for higher education research and technology transfer to Europe and later became Director for International R&D Collaborations. In September 2017 the South Australian Space Industry Centre was established with Nicola as Director. In 2019 he was instrumental in establishing the SmartSat Cooperative Research Centre and in 2020 he founded, and for about three years was the CEO of the Andy Thomas Space Foundation. In January 2023 he established the 'Agora High-Tech' and is now the current Chairman. 'Agora High-Tech' is a private consultancy company focused on enhancing collaborations and encouraging networking which aim to bring a significant advantage to the innovation processes.

Enrico Palermo

Head of the Australian Space Agency

Enrico has led the Australian Space Agency since January 2021. Under his leadership, the Agency has reached an agreement with NASA for an Australian designed, built and operated rover to be included in a future mission to the Moon, issued the first launch permits and launch facility licenses under the Australian Space (Launches and Returns) Act, and seen the first commercial spaceflights from Australia. Before joining the Agency, Enrico spent 14 years in various roles at Virgin Galactic. This included establishing and leading a vertically integrated aerospace manufacturing and testing operation for Mach 3 crewed commercial spaceships. From there Enrico was part of the team that launched the New York Stock Exchange listed public company and was appointed Chief Operating Officer. A Perth native, Enrico graduated from the University of Western Australia with a Bachelor of Engineering in Mechanical Engineering and Bachelor of Science in Physics and Applied Mathematics. He also studied at the International Space University in Strasbourg.

Associate Professor Matthew Sellars

Associate Professor of Physics and Engineering
Australian National University

A. Prof Sellars' main research expertise is in the spectroscopy of solid-state optical centres and their application to quantum information processing. Matthew manages Quantum Network work package in the ARC Centre of Excellence for Quantum Computing and Communication Technology, which aims to develop quantum memories, sources and detectors utilising rare-earth doped crystals for quantum communication applications. His group specialises in studying quantum coherent interactions between solid-state systems and light, applying the results of these studies to develop quantum information processing devices. The group combines precision spectroscopy, advance material development with quantum optics and quantum information processing.

Associate Professor Sascha Schediwy

Principal Research Fellow
University of Western Australia

Associate Professor Sascha Schediwy is an internationally recognised research leader in the fields of high-precision space and astronomy instrumentation. He was named the 2021 Australian Space Awards Academic of the Year and won the Excellence Award (the highest individual award). He leads the Astrophotonics research group at the University of Western Australia, the Australian Space Agency TeraNet optical ground station network project, and a SmartSat research project on coherent free-space optical communications.Associate Professor Schediwy is the lead designer of the Square Kilometre Array radio telescope's photonic Frequency Distribution System, and he has previously worked on radio-frequency phased arrays for the SKA telescope, laser technologies for advanced gravitational wave detectors, and the analysis of Apollo rock samples to learn about the early evolution of the solar system. He has authored 71 peer-reviewed publications across space and astronomy, including 15 as first author and 31 as group leader.

COL Clifford White

Director – Space Service SATCOM, Space Capability Branch
Joint Capabilities Division

COL White is a senior satellite and telecommunications engineer serving with the Australia Military for over 20 years and Commercial Satellite Industry. He has deployed on several operations and was on of the last Australian contingent in Afghanistan. COL White recently joined the newly formed Defence Space Command being selected to lead the Australian Defence Force SATCOM capabilities. COL White is a soldier at heart and understands the war fighter. His passion is to reshape the Australia Defence Force with the most modern telecommunications systems to increases the already effective Australian war fighter. He has successfully delivered several major telecommunications projects including Joint Project 2072 2B, ahead of schedule and budget delivering a fully integrated software defined network for the tactical environment. He has also delivered Australia's first satellite on move capability integrated with the Bushmaster PMV. He is avid surfer and basketball nut.

Dr. Stuart Szigeti

Head of Quantum Sensing Capability
Q-CTRL

Dr Stuart Szigeti is the Head of Quantum Sensing Capability at Q-CTRL, where he leads the development of novel quantum control solutions for next-generation quantum sensors. His team experimentally validates core concepts in software-defined quantum sensing and assesses, through simulation and modelling, the improvement offered by Q-CTRL's quantum sensors to navigation, mineral exploration, and hydrology. Stuart has a PhD in quantum physics from the Australian National University and has worked as a researcher for more than a decade, contributing to advances in quantum cold-atom sensor design and performance, including under realistic fielded conditions and in sensor-fusion architectures.

Professor Chris Vale

Professor of Physics and Director
Quantum Technologies Future Science Platform, CSIRO

Chris Vale is Professor of Physics and Director of the Quantum Technologies Future Science Platform at CSIRO aimed at developing the capabilities and expertise to support Australia's emerging quantum industry. Prior to joining CSIRO he led an experimental research program at Swinburne University of Technology using gases of atoms cooled to nanoKelvin temperatures to study complex behaviours found in quantum materials, such as superfluids and superconductors, and to harness these for use in quantum technologies. Prof Vale has been a Chief Investigator in two ARC Centres of Excellence in Future Low-Energy Electronics Technologies (FLEET) and Quantum Atom Optics (ACQAO) and previously held an ARC Future Fellowship. He has also worked at the University of Queensland, the University of Sussex and Imperial College (UK) studying Bose-Einstein condensates on atom chips. Chris has been actively engaged in the promotion of physics and quantum science through the Australian Institute of Physics, conference organisation and public outreach.

www.

Dr. Jie (Sophie) Zhao

Research Fellow, Australian National University Quantum Repeater Technology Program Manager, CQC2T

Dr. Jie (Sophie) Zhao received her PhD from ANU with her work on enhancing quantum information using post-selections. She was awarded as the first prize winner in a global competition “Rising Star of Light” organized by Nature Light Science and Applications. She was a permanent employee at Xanadu Quantum Technology, developing large-scale quantum entanglement using time-domain multiplexing, offering a pathway towards the demonstration of quantum supremacy. After Xanadu, she joined the group led by Dr. Paul Lett and Nobel Laureate William Phillips at the Joint Quantum Institute, NIST & UMD. She worked on quantum information and phase-locked lasing using four-wave-mixing from Rb vapors. Dr. Zhao has expertise in photonics quantum communication and photonic computation. She has a proven track record in innovative research developed from working at three world-distinguished institutes in Australia, Canada, and the US, with high-impact publications in Nature Photonics, Nature Communications, Optica, Optica Quantum, and Chemical Reviews.

Australia's National
Science Agency

Australian Quantum Communications Narrative

Prepared by:

Dr Stephen Gensemer
CSIRO Manufacturing

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3 January 2024

Important disclaimer

Acknowledgements

The authors acknowledge substantial contributions to this document by

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Professor Bronwyn Fox, CSIRO Chief Scientist
Professor Chris Vale, CSIRO Quantum Technologies Future Science Platform
Dr Scott Martin, CSIRO Manufacturing
Dr Marcel Bick, CSIRO Manufacturing
Dr Seyit Camtempe, CSIRO Data61
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Nicola Sasanelli AM

Chairman & Founder
Agora High-Tech

Welcome Message

Around the world, the overhaul of communication security technologies is already underway, augmenting our traditional or "classical" communications with ultra-secure "quantum" communications. It is estimated that this combined market will reach US$10 billion by 2030. It is estimated that the potential communications security technology market size by 2040 will be US$106 billion, which will include an estimated quantum communication market size of US$1-US$7 billion (BCG 2023 and Mckinsey & Company QTM 2023).

It is an important challenge for researchers and tech developers around the world to take advantage of this growing market. We need to better understand the many functions and uses of quantum communications and the key factors that will drive the adoption of these technologies in the global economy.

The 'National Quantum Strategy – Building a thriving future with Australia's quantum advance', launched last year by the Minister Hon Ed Husic MP and Dr Cathy Foley AO PSM, provides a clear policy for all the national stakeholders involved in quantum technology. In this framework, quantum communication has an important role. In response to the rapid increase in interest in the technology and to the National Quantum Strategy, the CSIRO Quantum FSP, assisted by Agora High-Tech Pty Ltd, has developed a program aiming at cultivating the quantum communications ecosystem in Australia.

This national program started in April 2023 and led to a survey among key stakeholders on quantum communication: universities, private companies, governmental agency, start-ups and consultants. This national consultation phase led to the development of a series of activities such as this Australian Quantum Communications Narrative, the first edition of an Australian Quantum Communications Capability Directory, and the establishment of the first Australian Quantum Communication Forum, to be held on 21 March, 2024 in Canberra.

Australia already has key advantages in the field of quantum communications: a university sector with many world-class physicists who have been pioneers in quantum communications and other quantum technologies, and several companies already selling products and services in the quantum communications market. In addition, Australia has a rapidly growing capability in ground-to-satellite optical communications, set to support NASA's Artemis Moon mission with high bandwidth data links, which also takes us one step closer to operating quantum communications ground stations and becoming a valued international partner.

In the coming decades, quantum communications presents an opportunity for national economic growth, improving productivity and national security, as well as creating new, highly skilled jobs. This national program and the consequent activities that have been established aim to develop a vibrant quantum communication ecosystem in Australia identifying and coordinating key actions to promote sustainable growth in this new and vital area.

We present the narrative and capability directory here as a contribution to this growing quantum communications ecosystem as a discussion paper.
The survey and many consultations we have had with various stakeholders in the past months have helped us to develop this first QComm Narrative and identify the critical issues surrounding quantum communications. Please continue to engage with us and we will endeavour to use further feedback on these documents to ensure that the upcoming forum focuses on the topics of interest and concern to both tech developers and to the industries they will impact.

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Executive Summary

Quantum technologies play a vital role in modern life, from the transistor to the atomic clocks that provide global positioning and timing.

A new phase of quantum technology is emerging, based on devices that take advantage of the properties of individual quantum particles, such as atoms or photons. What physicists of past generations viewed as "thought experiments" with individual atoms are now routinely performed in labs worldwide. The sensors and information processing that can be performed on quantum-scale systems exhibit exotic behaviour and opens up radical new opportunities for quantum-scale engineering.

CSIRO published Growing Australia's Quantum Technology Industry (CSIRO 2020, 2022), highlighting that by 2030 Australia's quantum technology industry could reach $2.2 billion, generating around 8,700 new jobs. With the right support and adoption, this has potential to contribute $5.9 billion and create 19,400 jobs to the Australian economy by 2045. Recently, the Department of Industry, Science and Resources has published the 'National Quantum Strategy - Building a thriving future with Australian's quantum advantage'. This strategy provides a clear policy for all the national stakeholders involved (entrepreneurs, students, academics, investors, government officials and end users) aiming to grow a vibrant quantum industry and research ecosystem. Furthermore, quantum technology capabilities and expertise are considered part of the 'asymmetric advantage' highlighted in the "National Defence Review: Defence Strategic Review 2023".

In this framework, quantum communication has an important role, and it could reach markets in the very near future, and potentially transform multiple industries concurrently.

Recently a dedicated national survey was conducted by CSIRO, assisted by Agora High-Tech, which obtained input on quantum communications from thirty-three Australian organisations and three international organisations. The main goal of this survey was to summarise the challenges and opportunities facing any coordinated, national effort at advancing quantum communications to provide tangible impacts on society. The results underpinned this Narrative, which outlines the opportunity. By sharing this narrative, we intend to support the sustainable growth of the Australian quantum communication ecosystem, in alignment with the National Quantum Strategy, Themes 1 and 2.

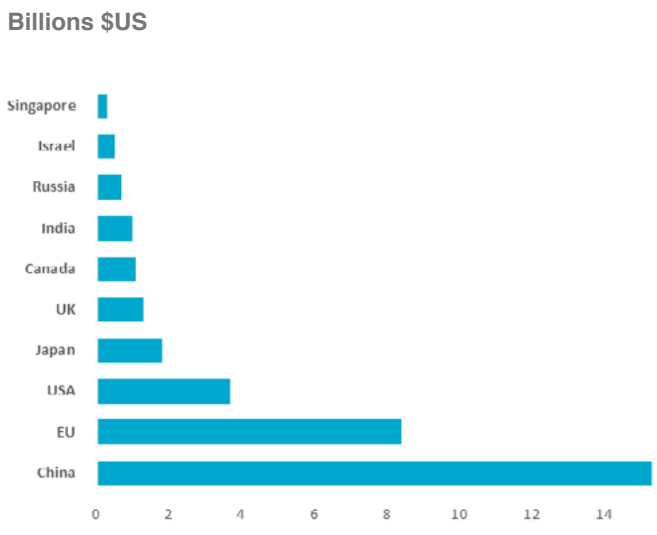
The survey results were also used to create the first **Australian Quantum Communication Capability Directory** and have helped guide the establishment of the **Australian Quantum Communication Forum (AQCF)**. This full-day event will connect private and public sectors, enabling new opportunities to advance quantum communication technologies and projects. The survey was the first in a series of initiatives CSIRO is undertaking to support the sustainable growth of the Australian quantum communication ecosystem.

01 Overview

Quantum technologies could become one of the core technical engines in the next step of our industrial development. According to the report Quantum Technology Monitor (McKinsey 2023); quantum technology start-up investment hit a new high (US$2.35 billion) in 2022, 70% more than in 2021 (which was more than double that of 2020).

McKinsey estimates that as of 2022, USA leads private sector investment with US$3.3 billion, followed by UK and Canada both at roughly US$1.1 billion and Chinese quantum startups received roughly US$482 million. But in terms of government spending, McKinsey reports that as of 2022, the Chinese government has announced a total $15.3 billion in funding, which is almost double that of the EU and triple of the US.

Announced Government Investment in Quantum Technologies through 2022



Source: Boston Consulting Group 2023 and CSIS China Power Project. McKinsey & Company.

The scope of quantum technologies includes three primary streams:

- Quantum computing
- Secure communication networks
- Precision sensors and measurements

Quantum computers are rapidly advancing with recent demonstrations of quantum advantage in specific computational tasks. The number of physical qubits in contemporary Noisy Intermediate Scale Quantum (NISQ era) quantum computers is experiencing an exponential trajectory. IBM anticipates a scale-up from 127 (physical) qubits in 2021, to 433 in 2022, aiming to 1386 qubits in 2024 and 4158 qubits in 2025 (The IBM Quantum Development Roadmap 2023). Meanwhile, significant investments are already being made in the software and algorithms that will run on future quantum computers. The entire computing community eagerly anticipates the advent of fully fault-tolerant, error corrected quantum computers. These systems will supersede today's NISQ-era systems and begin to realise the true power of quantum computing – potentially with hundreds of thousands or millions of logical qubits. The power of a quantum computer scales exponentially with the number of logical qubits – hinting that the development trajectory could be astounding. Quantum computing opens the possibility of solving problems of complexity and scale previously inconceivable.

The best known application of quantum computers is undoubtedly their ability to crack encryption. However, many other applications of computing could benefit from the speed advantages of QC. For example, Quantum Machine Learning algorithms are in their infancy and will not be as effective as "classical" Machine Learning for some time yet, though the potential is expected to become very significant. The recent announcement of quantum computational advantage from the Canadian company Xanadu (Madsen 2022) with a programmable photonic quantum computer has opened the door to a new era of computing possibilities.

While quantum computing is making headlines, **quantum sensing** and **quantum communication** is expected to reach the market sooner, and potentially transform multiple industries.

Quantum communication networks and cybersecurity technologies have potential application in diverse industries including telecommunications, finance, health, government, defence, infrastructure security and space. All these sectors have a pivotal role in modern Australia and our everyday lives.

Quantum-Enhanced Secure Communication

The phenomenon of quantum entanglement can be exploited in communications systems when the properties of two (co-generated) states (of, for example, photons) are intimately connected. Both exist in a state of superposition, meaning that their inherent properties are simultaneously two incompatible values. With entanglement, the nature of this superposition intrinsically links two fragile quantum systems, even if they are widely separated, and there is no direct influence between them. This strange property can be exploited in quantum communications systems, wherein any eavesdropper will reveal their presence by destroying the entanglement and introducing a large amount of noise into the signal.

Quantum communication technologies leverage the transfer of quantum information from one location to another. Quantum communication can be used to facilitate the transfer of complete quantum information between locations – for example from one 'quantum processor' to another, using quantum state teleportation – which could be a critical enabler for scaling the size of quantum computers.

At present, the world communications system is rapidly expanding into space-based infrastructure. With the advent of satellite constellations such as StarLink and OneWeb, worldwide coverage with high bandwidth is being provided from space, which adds a new dimension of concern for cybersecurity. This means, that instead of being buried underground (in optical fibres) and in secured data centres, the communications infrastructure on which our society relies will become increasingly exposed to interception.

Quantum communications technologies today provide quantum random-generated encryption that secures networks against any attempts to eavesdrop, spoof or fake verification. Quantum encryption takes advantage of the laws of physics which guarantee that no interception by any eavesdropper would be possible without being apparent to the sender and intended receiver.

They could also be used to provide secure position, navigation and timing services. Quantum communication networks may be utilised to network multiple quantum computers in data centres in the future, and could be used to test predictions in fundamental physics.

With data security a key issue of concern for businesses and government, it will be imperative to ensure widespread adoption of quantum-assured communication with a view toward long term security and resilience.

02 Communication Sovereignty

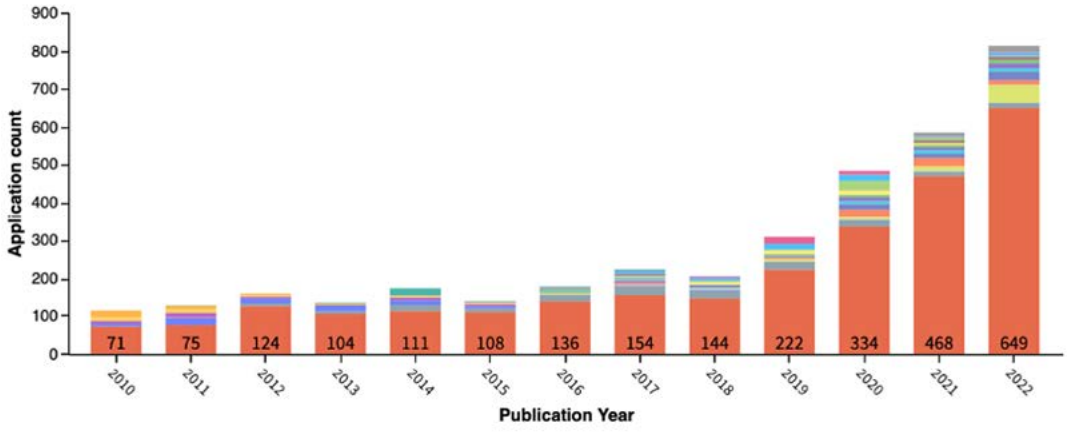
At present, the core enablers of the quantum communication ecosystem (hardware and software) are not yet widely available as commercial products. Revenue for suppliers is generated mainly through supply for research, and through joint research projects with publicly funded research organisations. As demand for secure free-space communications grows, many products will move from the prototype stage to commercialisation, which will likely lead to an increase in commercial sales and opportunities for growth.

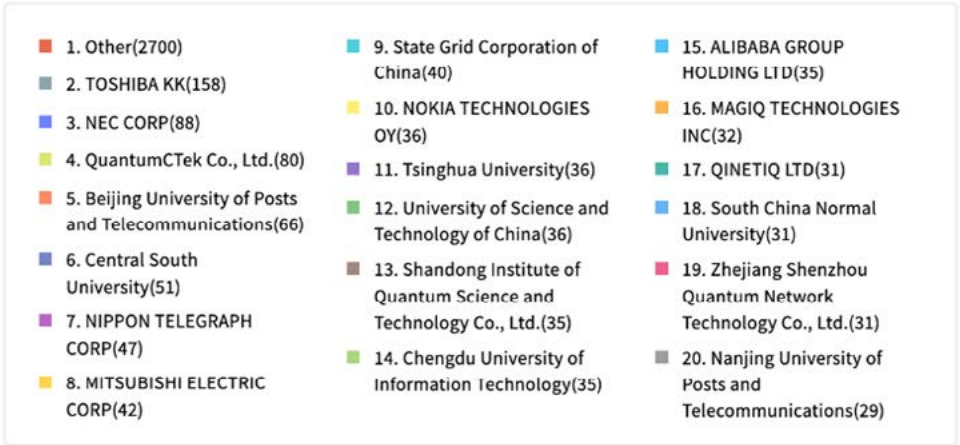
At this stage, R&D, scientific publications, and patent activity are critical to expand the IP base for the industry. Universities with quantum communication research and quantum technology degree programs are also crucial to growing our technology ecosystem, given the supply of engineers and computer scientists with a background in quantum mechanics is extremely limited at present.

During the period 1/1/2010 – 31/12/22 the number of patents in quantum communication has increased, especially in the last five years, quadrupling the overall number and demonstrating strong interest especially from Chinese organizations (Mason 2023).

Quantum Communications Patents - All

2010/01/01 - 2022/12/31

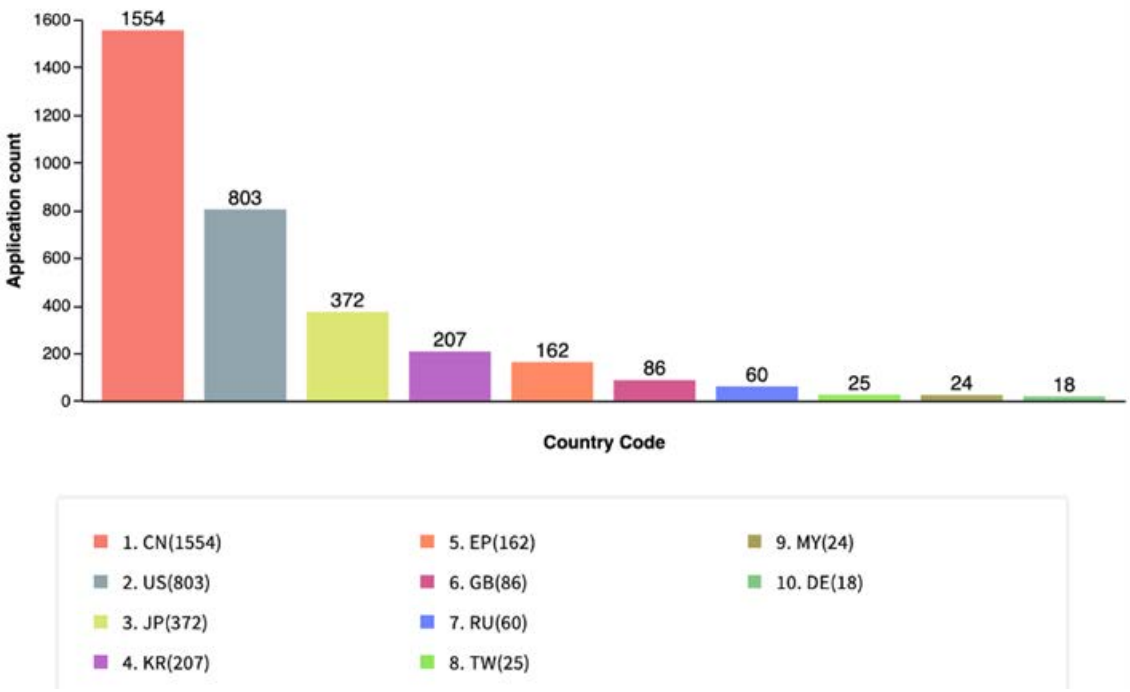




Source: QED-C 'Quantum patent trends updated:2022' Authored by Elliott Mason.

Quantum Communications Patents - Top 10 Offices

2010/01/01 - 2022/12/31



Source: QED·C 'Quantum patent trends updated:2022' Authored by Elliott Mason.

Quantum relevant publications % (share of articles and country's h-index [1])

(McKinsey 2022)

Countries	%
EU	23
China	21
US	11
UK	4
Japan	3
Australia	2

Number of Universities offering advanced degree programs in quantum technology

(McKinsey 2022)

Countries	Research Programs
US	64
EU	41
UK	14
China	11
Canada	9
Australia	8

03 Quantum Cryptography

Quantum cryptography is the most well-known application of quantum communications.

To understand the role quantum communications could play in securing future communications networks, we need to distinguish between two essentially different methods of securing messages.

- Any message might be sent from A to B using a secure channel - such as a trusted courier - allowing sender and receiver confidence that no other party could have seen or copied the message. Any method that relies on this approach must protect against attempts to eavesdrop, copy, tamper with or replace the message in transit.

- A message that one expects to be intercepted, copied, or altered can be *encrypted*. Typically encrpytion is done using a secret encryption key; decoding the message is simple if an eavesdropper can obtain the key. Encryption is vulnerable if 1) a copy of the key can be obtained, either locally stored on a computer or intercepted during distribution, or 2) the key can be inferred from the structure of the message, as has famously been proven in the cracking of RSA encryption by supercomputers, and is known to be substantially easier with quantum computers by way of Schor's algorithm. *Post-quantum cryptography* is a relatively new class of encryption methods that are believed to be resistant to cracking by future quantum computers.

Securing a communication channel and encrypting it are entirely different but complementary approaches to providing cyber security. Any secure communication channel might add encryption to ensure against some back-door an eavesdropper might obtain, and likewise any encrypted network might gain another layer of security by restricting access to the physical channels.

Widespread advice from government organisations holds that post-quantum cryptography is essential to implement now. Post-quantum encryption algorithms that have proven to withstand attacks (from classical computers) to date provide the best defence in the short term for securing of systems. Given that quantum computing is in its earliest infancy, we must consider the possibility that securing the channels themselves through quantum communications could add an additional layer of protection for our most critical infrastructure, on top of post-quantum cryptography.

The Australian Signals Directorate (ASD) is responsible for monitoring alternative methods of securing communications such as QKD.

Currently, due to the practical limitations of QKD, ASD does not support its use for secure communications.

However ASD encourages Australian industry to continue research and development of quantum technologies and explore other methods such as post-quantum cryptography (PQC) with research, testing and practical algorithm trials.

Develops and manufactures quantum resilient & quantum safe encryption technologies.

QuintessenceLabs (Qlabs), based in Canberra, is leader in quantum cybersecurity recognised for its advanced quantum-safe data protection capabilities offering a suite of unrivaled cybersecurity products. Solutions include the flagship Trusted Security Foundation (TSF) Key & Policy Manager. The TSF is crypto-agile and the industry's most secure key management platform, integrating the security of a FIPS 140-2 Level 3 hardware security module (HSM) with advanced encryption key and policy management (KMS), and qStream, the world's fastest quantum random number generator (QRNG), delivering the strongest foundation for encryption and data security.

04 Quantum Communications Infrastructure

The benefits to society of quantum-secured communications will rely on the development of a **Quantum Communication Infrastructure (QCI).** A QCI would consist of a series of secured network nodes linked by quantum-secured data channels would provide the basis for a quantum secured communications network. The technology to build the QCI exists, is well known in Australia, and this is currently being implemented in a number of other countries (WH 2022, Chen 2021).

Quantum signals, transmitted by laser, are usually visible-light or near-infrared signals. There are two media used to propagate quantum communication signals:

1. within optical fibres and;
2. through free space.

- Terrestrial quantum communication uses fibre-optic networks which present a limitation, as optical fibres typically absorb ~0.2dB/km; after 20-30 kilometres, the single-photon signals are degraded, requiring the addition of quantum repeaters (a separate, highly demanding scientific challenge in their own right).

- Through free space, it is possible to propagate a laser with much lower losses than fibre and, therefore, increased range is possible – enabling communication between satellites thousands of kilometres apart. Establishing quantum-assured intersatellite communication is critical to preserving information security across networks that necessarily span uncontrolled (unsecured) territory. Moreover, the communication between satellites and ground stations present additional challenges due to the interaction with the atmosphere.

Serving national needs for cyber security using quantum encryption will very likely require the combination of these technologies – satellite links to ensure long haul communications links, with fibre networks to connect local users. Past attempts to build a quantum assured fibre optic network have failed due to the high cost of the thousands of quantum repeaters that would be required, and interference between classical and quantum channels that share the same fibre.

Quantum Communication Infrastructure

Development of a basic quantum communications infrastructure could play a key role in future-proofing critical infrastructure against unforseen cyber security threats. The development of a QCI can be seen as a two-phase process:

First phase: Node-to-Node

The first phase of a QCI would be a series of "node-to-node" quantum encrypted links, with secured quantum channels alongside traditional classical channels. Each node could use the quantum channel to continuously verify the integrity and security of any quantum-secured links, using quantum-distributed encryption keys to encrypt the data passed along the classical channels. The uses of these links extend beyond QKD and could include time synchronisation and real-time sensor data such as time-critical supply/load monitoring in the energy grid. To achieve long distances across Australia or overseas, it would comprise both a terrestrial and a space component. It would support dedicated R&D studies and development in the context of the growth of a valuable secure communications service.

Second phase: End-to-End

The second phase is termed the "Quantum Information Network" (QIN), and provides higher security through distributed entanglement of quantum states between any two nodes of a network. By providing any pair of end users at distant parts of the network with entangled qbits, they would be able to verify the integrity of all of the network links between them without relying on any other trusted party, providing "end-to-end" quantum encryption. Quantum repeaters and quantum memory devices would be required to establish the distributed entanglement, and satellite constellations would be essential to connect distant regions across the world.

The creation of an experimental, research testbed precursor to a QCI, similar to that under construction in other countries (see sidebar “International Best Practices”), would open critical opportunities for progress in the Australian ecosystem. In particular, it would:

- Direct targeted R&D projects that will develop needed components for quantum communications infrastructure
- Grow the workforce of skilled workers in the quantum industry
- Provide test market opportunities for suppliers of quantum technology
- Allow development of novel secure networking combining QKD with post-quantum encryption
- Connect many sectors of the economy to the emerging quantum technologies
- Provide a path for national communications infrastructure to remain secured against eavesdropping or spoofing cyber attacks.

International Best Practices

According to the University of Science and Technology of China, China has established the world’s first integrated quantum communication network. It has developed 4,600 km of quantum network that combine over 700 optical fibres with two satellite-to-ground links to support quantum key distribution. (Chen 2021) China also aims to develop small-scale, cost-efficient QKD satellites and ground-based receivers, as well as medium and high orbit satellites to achieve persistent quantum networking across 10,000 km.

Europe’s Quantum Flagship initiative has launched in 2018 a dedicated program worth more than €1 billion over ten years, 25% of the overall budget is set aside for quantum communications (EC 2022). The main goal is to involve more than 2,000 European quantum experts in joint research projects with the long term vision to develop in Europe a quantum internet, where quantum computers, simulators and sensors are interconnected via quantum communication network.

In the US the Quantum Computing Cybersecurity Preparedness Act requires data to be quantum resistant by 2035 (WH 2022). Moreover, the US department of Energy (DOE) intends to develop a national quantum internet, bringing the United States to forefront of the global quantum race and ushering in a new era of communications (USDOE 2020).

05 Quantum-Assured Position, Navigation and Timing

Using precisely clocked terminals on both ends of a communications link, the exact distance between two nodes can be determined to very high precision. This is the principle behind the GNSS (Global navigation Satellite System) networks, which are well known to be subject to spoofing and jamming.

Quantum communications links through free space provide a highly secure method for positioning and navigation by allowing the users to be sure that no attacker can spoof the true positioning signal. This method of secure, local positioning adds extra value to an optical communications network through free space where positioning is critical and there is a threat of spoofing.

In addition, highly precise timing between remote clocks can be critical for some applications, especially where distributed communications or sensing require synchronisation. Quantum communications networks can provide absolutely secured timing information through free space, allowing an alternative, and much more secure, method for timing synchronisation, where again the traditionally used GNSS systems are subject to spoofing attacks that could be used to launch cyber attacks against infrastructure.

Secure time synchronisation between multiple sites

QuantX, in conjunction with the University of Adelaide, has made a breakthrough in which optical atomic clocks can provide enhanced performance over microwave clocks and do it in a much smaller package.

The South Australian company is developing methods of time transfer over optical fibre and optical free-space links utilising both conventional and quantum techniques. Compared to current techniques, these approaches have the potential for vastly improved performance and guaranteed security, acting as the building blocks towards a secure and flexible alternate architecture for a GPS-like timing and position system.

[1] The h-index is the number of articles (h) in a country that have been cited at least h times.

06 Quantum Information Networking

In the longer term, Quantum information networks (QIN) could emerge to provide more far-reaching applications. A QIN would use the quantum communications links to entangle qbits at distant locations.

The technology to develop the QIN is under development and not commercially available at present. Eventually, however, the QIN would provide much greater security than the basic node-to-node secured links that are readily available now. By providing any pair of end users at distant parts of the network with entangled qbits, they would be able to verify the integrity of all of the network links between them without relying on any other trusted party, providing “end-to-end” quantum encryption.

A QIN would provide substantial enhancements to the QCI using a combination of quantum memories, quantum repeaters and relatively small quantum computers to generate entangled qbits at very long distances, potentially separated by several intermediary nodes. This would allow end users separated arbitrarily across the network to establish a secure quantum encryption key that cannot be known by any untrusted actor.

The QIN could be used within a data centre that supports a number of quantum computers with limited computing power to pool their resources, similar to the way supercomputers support parallel processing across computer cores. However, with quantum computers, interconnections between them allow the computing power to scale much faster than with classical computers. This may become a critical component of the eventual realisation of high value quantum computing, and it could be facilitated by a much more mature quantum communications infrastructure.

A great many research concepts for new methods of sensing and measurements using QINs have been proposed (de Forges de Parny 2023), and would provide ample opportunities for new science and innovation to further grow the quantum industry.

The Australian Optical Ground Station Network (AOGSN)

ANU is working on establishing an Australian Optical Ground Station Networks (AOGSN). The optical ground station would play a key role in the advancement of the ‘quantum internet’, that is data transmission across the world using quantum-key distribution through optical links to quantum satellites.

New market opportunities from Quantum Networks

Source: Boston Consulting Group partners & Inside Quantum Technology (BCG 2023)

Technology at Experimental level	Network type	Transmission	Architecture	Key Limitations	Applications
Current	Trusted node	Satellite and metro/regional fiber	Point to point	- Trusted node must be secured; - Carrier can access keys	Simple QKD encryption
In three years	Simple repeater	- Satellite and metro/regional fiber; - Carries quantum states.	Point to point initially, then multipoint	QKD applications with keys that are genuinely secret; no carrier access	..
In four years	Quantum repeater; enables entanglement sharing	Satellite but trending toward fiber, including long-haul	Multipoint	No storage of quantum states	Advanced QKD, secure payment, quantum computer networks
In six to ten years	Quantum repeaters with memory	Predominantly Fiber	Multipoint	Unknown territory in terms of costs and demand	Quantum clouds for quantum computing and quantum IoT

07 Socio-Economic Impact

It is important to envisage the possible impacts of quantum technologies on science, industry and society, as well as on a framework of legislation needed to define the rules and operators. Particularly, using a quantum communication infrastructure at the national level will have a huge societal impact by delivering:

- A higher level of cyber security for government and critical infrastructure.
- Driving the growth of a quantum engineering workforce capable of supporting the expansion of many related quantum technologies that have longer time horizons such as quantum computing.

It is estimated that the communication security technology including the combined market for classical and quantum communications will reach US$10 billion by 2030, worldwide (BCG 2023). In the context of quantum industries, the advancement of quantum communications is attractive since it presents a very straightforward application of quantum engineering that has a clear market value in the near to mid-term, if one considers the current arms race around cyber security. Quantum secured communication networks shine as the gold standard for cyber security, providing a guarantee - based on the fundamental laws of quantum mechanics - that no future attacks could pose a cyber threat.

The Boston Consulting Group (BCG 2023) have identified three waves of quantum communication technologies:

- The first wave (2015-25) is related to applications in the government and defence sectors which include first adoption of Quantum Random Number Generation (QRNG) chips in smartphones, tablets, PCs, and data centres.
- The second wave (2025-30) is starting to develop an interest by private market with dedicated application of QRNG chips in IoT infrastructure and devices.
- The third wave (2030-beyond) will develop a broad network developing new technologies such as repeaters, memories and new better error-correction algorithms.

By providing opportunities for new companies to grow and hire quantum engineers, quantum communications can play a key role in kick-starting the field of quantum engineering and lay the groundwork for the eventual development of quantum computers, which are potentially have even farther reaching benefits to society.

Quantum drives quantum

It is perhaps ironic that the existence of quantum computers, and the possibility of further future breakthroughs in encryption cracking they could bring, may become one of the chief drivers of quantum communications. In fact, one of our colleagues remarked over 20 years ago, “you only need quantum encryption if somebody out there has a quantum computer,” since classical encryption was uncrackable using classical computers. Finally, the time has arrived when someone has a quantum computer, and cyber security experts are scrambling for solutions that will protect them against future QC-based attacks. Those solutions are loosely described as “post-quantum cryptography”, and it is indeed ironic that by far the most secure method of “post-quantum cryptography” is “quantum” itself - quantum communications.

08 Australia's Main Challenges

In the National Quantum Strategy (DISR 2023), the Minister Hon Ed Husic states 'We [Australians] have all the ingredients to sustain our existing leadership on quantum into the next decade.' The recent National Quantum Strategy (NQS), with its five central themes and 13 actions, provides a clear policy for all the national stakeholders involved (entrepreneurs, students, academics, investors, and government officials) aiming to grow a vibrant quantum industry and research ecosystem. In this framework, quantum communication has an important role, and could reach markets soon and potentially transform multiple industries concurrently.

In this context CSIRO intends to develop a series of initiatives for cultivating the quantum communications ecosystem in Australia. Among these initiatives, a national survey has been launched to develop a quantum communication ecosystem in Australia identifying and coordinating key actions to promote a sustainable growth.

The national survey, launched in July 2023 and concluded in August 2023 with the assistance of Agora High-Tech, has targeted more than 100 national and international stakeholders in the field of quantum communication including government entities, universities, national research organisations, private companies, associations, and start-ups.

The survey received 36 answers as listed below (among these organisations three are international):

- 10 representatives from six Government agencies (DSTG, ASA, Australian Army, the Office of the Chief Scientist, CSIRO and ACT Government),
- 12 representatives from eight universities (Swinburn Uni, UTS, three from ANU, UNSW, UQ, Uni Sydney, Uni Melbourne, WA University and Uni Canterbury (NZ))
- 14 representatives from 14 private organisations (Sydney Quantum Academy, EarthSpace, Penten, Agora HT, CyberOps, Franke Hyland, QUECWA, QuantX Labs, SmartSarCRC, Quintessence, Archer Materials, SkyKraft, Forschungszentrum Jülich (Germany) and Flawless Photonics (USA)).

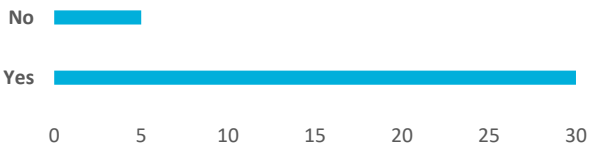
The first set of questions have been shared amongst the national Quantum Communication community to develop a National 'Capability Directory'. It is a document which includes the main expertise and capability in this sector highlighting who does what. This document is essential in developing the sense of national community as well as promoting our ecosystem abroad. The first 'Australian Quantum Communication Capability Directory October 2023' is attached to this Narrative and it is a document that will be updated periodically.

A second set of six questions has been shared with the national and international Quantum Communication community to receive useful information about the national expectations as well as identifying challenges and ambitions. The questions have provided inputs in the following areas:

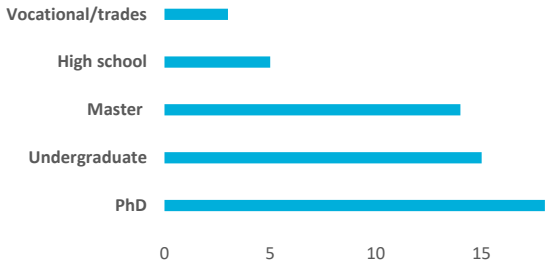
- Concrete national initiatives to improve awareness of this sector;
- Educational levels and relevant scientific and technological disciplines, essential to prepare a skilled workforce for the future;
- Relevant research and development programs capable of developing the maximum impact in the progress of the national industry;
- Significant initiatives to develop the Start-up culture and support Scale-ups;
- Relevant legislative measures to support the growth of a sustainable national industry;
- Major national projects that can unlock Australia's ambition in this area.

The answers of this second set have been integrated in this narrative and here below are some collegial feedbacks.

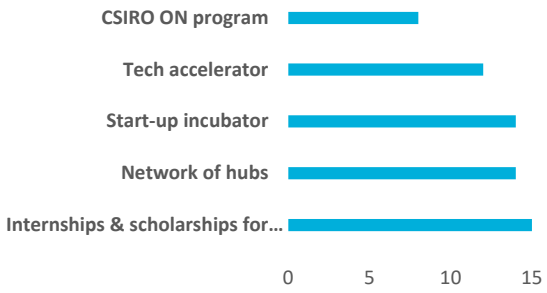
Question: In your opinion, do you believe that specialised training courses and post-bachelor's degree programs are essential for preparing a skilled workforce in the field of quantum communication?



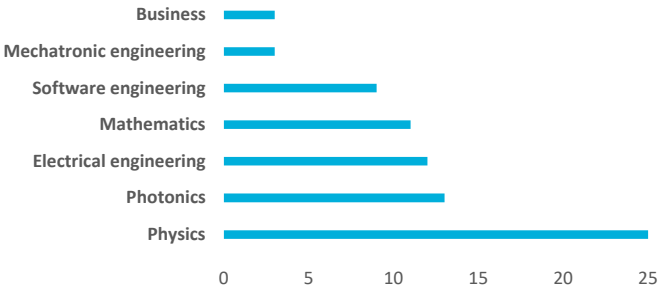
Question: Which educational levels do you believe should be prioritised to build a skilled quantum communication workforce?



Question: How can we stimulate the proliferation of new start-ups and support the scale-up of SMEs in the quantum communication area?



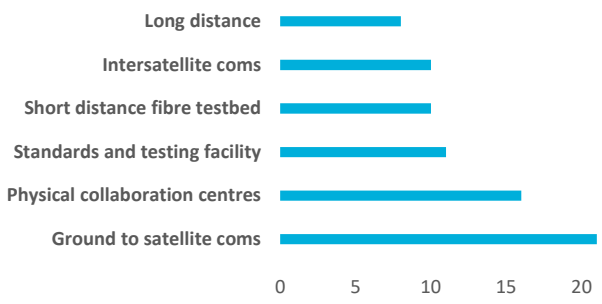
Question: Which educational topics do you believe should be prioritised and advocated for?



Other educational topics have been highlighted such as:

- Information theory and basic communications theory
- Material science
- Communications/Networking Engineering
- Post Quantum Cryptography
- Professional development/ microcredentials

Question: Which of the following research and development (R&D) programs or demonstrators do you believe would have the greatest impact in advancing Australia's quantum communication industry?



From the '2023's Australian QComm Survey' has also emerged the need to identify more opportunities for networking and interaction, to stimulate a rapid growth of the Quantum Communication ecosystem in Australia. As an action we have planned to organise one day event called 'Australian Quantum Communication Forum' (AQCF). Ths event aims to stimulate the Australian QComm ecosystem by:

1. Encouraging the exchange of information from local and international speakers,
2. Growing a local QComm capability,
3. Showcasing Australian capabilities to national and international audiences,
4. Assisting research organisations to identify industry needs and future areas of demand, particularly within STEM pathways,
5. Promoting commercial application of new research and technologies.

According to the inputs coming from this survey, the first AQCF could have the following three topics:

- Quantum Communication Infrastructure.
- Quantum Information Networking (particular emphasis on quantum enhanced secure Com for satellite and IoT).
- Quantum Assured PNT.

The AQCF is planned to be held in Canberra during the first quarter in 2024.

09 Conclusion

As summarised in this document, a dedicated survey obtained input on quantum communications from thirty-three Australian organisations and three international organisations. The results have helped us to generate this Narrative and to establish a systematic approach to supporting the sustainable growth of the Australian quantum communication ecosystem, in response to the National Quantum Strategy, Themes 1 and 2.

The national survey has also developed the first Australian Quantum Communication Capability Directory. The draft, attached to this narrative, is a dynamic document upgraded periodically (in response to the National Quantum Strategy Actions 1.2; 2.2 ; 3.4 and 4.2). It provides a snapshot of the Australian quantum communication industry, featuring key information from private enterprises, consultancies, associations, research organisations, educational institutions and government departments currently contributing to the nation's vibrant ecosystem.

Moreover, the survey has encouraged the establishment of the Australian Quantum Communication Forum (AQCF). This full-day event will connect private and public sectors, enabling new opportunities to advance quantum communication technologies and projects. The AQCF will be crucial in laying down the foundations of a thriving and innovative Australian quantum communications ecosystem. In response to National Quantum Strategy Actions 1.2; 2.2 and 5.1, the event will be a platform to amplify communication and outreach within the sector and could become a series of annual events.

In the coming decades, quantum communication presents an opportunity for national economic growth, improving productivity and national security, as well as creating new, highly skilled jobs.

Glossary of Terms

R&D	Research and development
NISQ	Noisy Intermediate Scale Quantum
QCI	Quantum Communication Infrastructure
QIN	National Quantum Information Network
QKD	Quantum Key Distribution
QC	Quantum computers
QComm	Quantum communication
QS	Quantum sensing
QRNG	Quantum Random Number Generation
Qubits	Quantum States of single photons
IoT	Internet of Things
PQC	Post-Quantum Cryptography

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Australia's National
Science Agency

Australian Quantum Communications Networks (QCN) Capability Directory

February 2024

Capability Matrix

		Quantum repeaters and quantum memories	Communications links	Space segment based on satellites	Quantum repeaters with cryptography and eavesdropping detection	Cyber security	Simulations	Sensing/metrology	Computing	Consultancy	Other	Page Number
Company	Archer Materials Limited					x					Qubit	38
	CyberOps Pty Ltd		x	x		x						39
	Franke Hyland Pty Ltd		x			x		x	x			40
	Penten		x			x			x			41
	QuantX Labs		x					x			Clocks and Imaging	42
	Quintessence Labs		x	x	x	x						43
	Skykraft		x	x					x			44
	SmartSat CRC	x	x	x		x		x			Precision timing and frequency	45
	Agora High Tech									x		46
	Earthspace			x						x		47
	Inovor Technologies		x	x					x			48
Research & Education	Australian National University Centre for Gravitational Astrophysics							x				50
	Australian National University Department of Fundamental & Theoretical Physics							x				51
	Australian National University Research School of Physics	x	x	x	x	x	x	x	x		Modelling to quantitatively assess end-use cases	52
	Swinburne University of Technology			x		x		x	x			53
	Sydney Quantum Academy	x	x	x	x	x		x	x			54
	The Quantum Education Centre of West Australia (QUECWA)										Education	55
	The University of Adelaide, Quantum Machine Learning Research Group								x		Machine Learning and Computer Vision	56
	The University of Melbourne						x	x	x			57
	University of Queensland - CQC2T	x	x	x	x	x		x	x			58
	University of Queensland, ARC Centre of Excellence for Quantum Computation and Communication Technology	x	x	x	x	x		x	x			59
	The University of Sydney	x	x	x	x	x	x	x	x	x		60
	University of Technology Sydney	x		x	x	x	x		x		Quantum Information Theory, Software Development	61
	University of New South Wales						x		x		Quantum materials, quantum electronics	62
	University of Western Australia		x			x	x	x	x			63
Government	Australian Army	x	x	x	x	x		x	x		Post quantum cryptography	65
	Chief Scientist, Australian Government		x					x				66
	Australian Space Agency	Provide strategic direction and support for industry via the Communications Technologies and Services Roadmap										67
	CSIRO					x		x	x			68
	Defence Science & Technology Group	x	x	x		x	x	x	x		Quantum time transfer	69
	Chief Minister, Treasury and Economic Development Directorate	x	x	x	x	x	x	x	x			70

Companies

Archer Materials Limited

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Overview

We're developing the next generation of advanced semiconductor devices and technologies that are a result of the creativity and pioneering scientific discoveries of our team. We're designing and integrating innovative materials for operating qubits in quantum technologies; we're building graphene transistors for enhanced biosensing; and we're developing semiconductors that push the boundaries of modern technology. Our development spans qubit processors for practical quantum computing technology, and lab-on-a-chip biosensors for integrated bioelectronics.

Capabilities & Expertise

Strong shareholder and investor engagement, creating value with focus, Archer is developing advanced semiconductors for commercialisation in global markets.

Unique Selling Points

Archer is at the forefront of nanotechnology, with our staff responsible for some of the most important advancements, from synthesising single atom graphene to fabricating the single atom transistor, we have pioneered solutions to seemingly intractable problems, and we continue our path in setting technology trends.

CyberOps

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Overview

CyberOps is a defence, space and cyber company based in the SpaceLab building within the innovation precinct of Lot Fourteen, offering a mix of bespoke services around security and space/ defence that are recognized globally. Participating in the global space domain awareness ecosystem with our SpaceIQ Passive RF sensor network and delivering space cyber testing, training and simulation environments as part of defence innovation initiatives places CyberOps in a good position to investigate and trial quantum communication techniques and detection processes.

Capabilities & Expertise

CyberOps delivers tailored services its customers in the areas of governance & business security advice, security strategy & architecture consulting, security design and investigation, review & assessment, space and ground solutions, and defence readiness and security consulting. Currently CyberOps is building a space cyber testbed and simulation environment that will be used for verification as well as workforce skills development in defence and other critical infrastructure ecosystems. With a high percentage of cleared workforce and a collection of cleared trusted partners, CyberOps can deliver from strategy to architecture and design, to install and monitoring for its customers. We pride ourselves on being customer centric in all we do, ensuring the best outcomes can be delivered for the best value.

Unique Selling Points

Archer is at the forefront of nanotechnology, with our staff responsible for some of the most important advancements, from synthesising single atom graphene to fabricating the single atom transistor, we have pioneered solutions to seemingly intractable problems, and we continue our path in setting technology trends.

Franke Hyland

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Overview

We provide IP strategy and IP attorney services to Australian technology developers, particularly those looking to project their technology internationally and built an international IP portfolio.

Capabilities & Expertise

We are able to assist with a wide variety of technologies and provide focused IP advice in all major jurisdictions.

Unique Selling Points

Strategy first approach to IP protection.

Penten

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Overview

Penten is an Australian owned, multi-award winning, cyber technology business. We offer unique, sovereign capability to deliver new defence and security technologies for the future fight. Our advanced hardware and software products and services support government and defence clients with Secure Mobility, Applied AI and Tactical Communications Security solutions.

Capabilities & Expertise

Cyber security, secure communications, cyber deception, AI, hardware and software development.

Unique Selling Points

Penten is an Australian-based cyber technology company focused on innovation in secure mobility, applied AI (artificial intelligence) and tactical communications security. We work with exclusive clients to solve the hardest cyber challenges of tomorrow and support complex transformations in the digital age.

QuantX Labs

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SA

quantxlabs.com

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Overview

The premier, sovereign provider of high precision timing and sensor products used in defence and space. QuantX has developed their own unique experience of driving all the way through the defence innovation pipeline, by developing one technology from a university research project through to in-service capability with defence. We are in the process of now applying this experience to a much wider range of devices. Our programs include the world's most precise clock (Cryoclock), ready for deployment into the ADF's JORN Defence Radar, a ground-breaking development of a next generation space atomic clock based on optical technology, and quantum magnetometers that sense extremely small changes in magnetic field due to ferrous material. These leading-edge technologies are just the beginning of the innovative solutions being designed for a range of sovereign and global applications including resilient position, navigation and timing services.

Capabilities & Expertise

Precision and Quantum Sensing and Timekeeping.

Unique Selling Points

Have taken one technology all the way from a university research project through to in-service capability with defence. This has given us near-unique experience of driving all the way through the defence innovation pipeline. We are in the process of now applying this experience to a much wider range of devices.

Quintessence Labs

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Overview

Australian-based QuintessenceLabs (Qlabs) is a global leader in quantum cybersecurity recognized for its advanced quantum-safe data protection capabilities, offering a suite of unrivaled cybersecurity products for today and tomorrow. The company has been widely recognized for its cybersecurity innovations around the world, most recently through its selection as a World Economic Forum Global Innovator. Solutions include the flagship Trusted Security Foundation (TSF) Key & Policy Manager. The TSF is crypto-agile and the industry's most secure key management platform, integrating the security of a FIPS 140-2 Level 3 hardware security module (HSM) with advanced encryption key and policy management (KMS), and qStream, the world's fastest quantum random number generator (QRNG), delivering the strongest foundation for encryption and data security. QuintessenceLabs continues in the advancement of quantum cyber security solutions with their latest quantum-safe offering, qOptica Quantum Key Distribution (QKD). Customers using these solutions include defence, government and private industry, the financial sector, cloud storage, aerospace, and defence supplier sectors, and those looking to enhance the protection of their sensitive data now and in the future.

Capabilities & Expertise

Qlabs develops and manufactures quantum resilient & quantum safe encryption technologies that allow and organisation to future proof their encryption environments. We provide this capability across 7 product sets: qStream - high spped Quantum random number generation, qRand - entropy service client, Trusted Security Foundation - KMS, policy management as a physical or virtual applianc, qClient - PKCS 11, KMIP SDK, Entropy as a Services - Random number as a service, qOptica - QKD and qProtect - data zerioisation.

Unique Selling Points

Qlabs products & services are designed to augment such that an organisation can transition into a quantum resilient or quantum safe state. All products are designed in Australia in Canberra. We are recognised as a globally leading Quantum encryption technology manufacture.

Skykraft

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Overview

Skykraft is an Australian space services company that specialises in the design, manufacture and operations of satellite constellations for the delivery of global services. Skykraft is developing a new space-based service to increase air safety and address gaps in surveillance and communications for aircraft travelling across oceanic or remote areas that are limited by ground-based communications infrastructure. Using supply chains from across Australia in a sustainable production process, we employ local engineers from electrical to mechanical to software who display globally leading skills in the aerospace sector.

Capabilities & Expertise

Skykraft has designed and manufactured over 70% of the mass of Australian built satellites in orbit. We produce globally competitive satellite constellations to deliver profitable services directly to customers. Our agile design and local manufacture allow rapid development of satellites on timescales of months rather than years.

Unique Selling Points

Being a leader in global constellations that are affordable at scale, Skykraft is uniquely placed to deliver services with very high densities. This improves coverage, reduces revisit rates and closes business cases that would be unviable with more dated constellation designs.

SmartSat CRC

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smartsatcrc.com

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Overview

The SmartSat CRC is a consortium of universities and other research organisations, partnered with industry that has been funded by the Australian Government to develop know-how and technologies in advanced telecommunications and IoT connectivity, intelligent satellite systems and Earth observation next generation data services.

Capabilities & Expertise

Space technology development through collaborative research.

Unique Selling Points

Not-for-profit company with expertise in identifying and creating research programs that drives Australian industry capabilities in delivering space technology to customers in government, civil and commercial markets.

Agora High Tech

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Overview

Agora High-Tech is an Australian company, working with clients from a wide range of industries, including aerospace and defence, IoT, quantum technology, cyber security, AI and engineering. Drawing on expertise from across the critical technologies, Agora High-Tech can respond to the latest advances in the technology revolution. The experience maturated by the team in the last decade is oriented in:

- Growing the high-tech and critical ecosystem.
- Promoting R&D cooperation among academia, research organisations, industries, and start-ups.
- Providing policy advice to government and not for profit sectors.
- Promoting STEM uptake to support the high-tech workforce of the future.

Capabilities & Expertise

Agora High-Tech works with customers to help them transform the ways we use technology and to communicate this in a meaningful way to achieve outcomes. The company provides services to maximise the use of new technological opportunities and to ensure the future local and global growth of organisations. Agora High Tech is a private consultancy company providing a wide range of services, including:

- Business development
- Technology innovation
- Strategy and planning
- Supply chain management and sustainability
- Networking with business-to-business engagement
- Marketing and communication

Unique Selling Points

Agora High-Tech believes high tech can positively impact the way business is done, from strategy through to delivery, acknowledging that the new technologies doesn't just give a competitive advantage, it can provide opportunities to increase success: productivity and efficiency positioning organisations to be a natural leader and adopter of technology.

Earthspace

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Overview

Space Systems Engineering Consultancy.

Capabilities & Expertise

Over 200 accumulative years of xperience in the international and Australian civilian and defence space industry.

Advising in Space engineering organisational structure, Mission development, Systems engineering, Project Management, Operations Management

Unique Selling Points

Industry Space veterans provide independent guidance and support without the fear of competition.

Inovor Technologies

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Overview

Inovor Technologies is a world-leading supplier of next generation small satellite technology and subsystems. Our unique low-cost, disaggregated technology has the flexibility to host an extensive range of technical applications including communications, remote sensing, imaging and scientific payloads. With our in-house developed technology, we provide turnkey solutions for commercial, government and research clients wanting missions flown in space. Inovor also provides specialist services to Defence in the Electronic Warfare and Space Situational Awareness areas. We are positioned at the centre of Australia's growing space hub, and are owned and operated in Adelaide, South Australia. Uniquely, all electronics, hardware and software are manufactured inhouse with a sovereign supply chain.

Capabilities & Expertise

We redefine the satellite industry with our unique vertical integration approach. We build every essential subsystem from the ground up. We provide turnkey mission solution services, from designing satellites, to manufacturing, integrating and testing, through to operations, and the launch. Our focus lies in incorporating quantum technologies to enhance satellite communication, navigation, and sensing capabilities. We also have expertise with power systems, batteries, solar chargers, management units, solar panels, attitude control system, controller units, reaction wheels, star trackers, earth sensors, command and data handling systems, mission computers, UHF satcomms radios, payload edge compute units, and much more.. By leveraging quantum communication principles, we strive to

Capabilities & Expertise Cont.

develop secure communication systems that are resistant and ensure the integrity of sensitive data transmissions in space.

Unique Selling Points

Inovor is geographically close to the booming Asia-Pacific region and has a less restrictive export control regime, allowing free access to this growing market. Inovor has developed significant intellectual property related to satellite platforms and SDA mission technology. We personally craft every line of code and select each component, providing unparalleled visibility into our systems. Why does this matter? Because owning all intellectual property empowers us to adapt systems for diverse missions on-demand, ensuring top-notch mission assurance. Inovor is a 100% owned and operated Australian commercial satellite manufacturer, and we contribute to Australia's national security program through the provision of electronic warfare expertise and our inhouse satellite production capabilities to defence.

Research & Education

Australian National University

Centre for Gravitational Astrophysics

Australian National University

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Distinguished Professor
David McClelland
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Overview

We are a research and research training centre at the Australian National University focused on gravitational wave astrophysics and spinoff technologies.

Capabilities & Expertise

Optical and quantum optical sensing; gram-scale cryogenic interferometry; ultra-low loss large area optical coatings; suspended mass interferometry; control systems; gravitational wave (GW) sources; electromagnetic follow-up of GW sources using Australian optical telescopes; data analysis using large data sets from the Laser Interferometer Gravitational-wave Observatory. Space interferometry for earth observation and GW detection.

Unique Selling Points

We are one of the world's leading laboratories for developing quantum optical methods to improve gravitational wave detectors. Our high bay laboratory and coating facility allow development of techniques applicable to long-baseline GW detectors. We combine experts from across precision sensing (ground and space), optical telescopes to astrophysics unique in Australia. We are a core member of the ARC Centre of Excellence for Gravitational wave Discovery. Out Applied Measure Laboratory has a focus on translating sensing techniques to industrial application.

Australian National University

Department of Fundamental & Theoretical Physics

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Overview

The purpose of the Department of Fundamental & Theoretical Physics is to provide a platform for theoretical and computational physicists across various disciplines to exchange about theoretical concepts and tools, while fostering deep connections with other Departments and Schools. The Department performs research at the highest international levels in theoretical and computational physics, pushing the boundaries of modern physics in areas such as quantum field theory, the quantum many-body problem, quantum communication, and nonlinear systems.

Capabilities & Expertise

Quantum communication, quantum information theory, quantum metrology, Bell inequalities, quantum many-body systems.

Unique Selling Points

Long experience, international theoretical and experimental collaborations, publications in high profile journals, e.g., Physical Review Letters, Physical Review X, Nature Communications.

Australian National University

Research School of Physics

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Overview

The Research School of Physics at The Australian National University is a leading institution dedicated to advancing the field of physics and its practical applications. With a rich history spanning over 75 years, the School has a distinguished record of scientific discoveries and translational successes.

Capabilities & Expertise

ANU has a long history of research in the fundamental quantum, optical and material physics that underpin advancement in quantum technologies. We have world-leading expertise in optics and light-matter interaction research, with applications to gravitation wave detection and gravimeters, as well as quantum technologies. We are the leading institution in Australia in the area of quantum communications networks. This work is enabled by world-leading capabilities in fundamental quantum science, optical design, optical material science, nanofabrication, and space technology. ANU has spun out more quantum-aligned companies (six to date) than any university. ANU trains the largest number of quantum graduates with graduates driving and contributing to many Australian quantum-aligned company.

Unique Selling Points

Comprehensive mechanical, electronic and nanofabrication facilities (ANFF). Diverse physics environment (materials, nuclear, quantum, optical, theoretical), encompassing the largest long-term investment in Physics in Australia. Recent, $220M investment in quantum-aligned facilities. Industry incubator, Momentum, with seven companies all with research/education alignment to the School. Expertise and active research programs in quantum memories, uantum repeaters, satellite optical communications, quantum communication protocol developments, and quantum sensors. Collectively, these components form the majority of parts for a future quantumm internet that would link quantum computers and distributed sensors exploiting the full suite of quantum technologies under development at ANU.

Swinburne University of Technology

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Overview

Swinburne is ranked among the top 300 research-intensive universities in the world. A dual-sector organisation, it delivers research that creates economic and social impact, and our researchers are producing innovative solutions to real-world problems across a range of disciplines and sectors. Our research degrees give students access to world-class researchers, first-rate facilities, training and support. Typically programs of research are weighted towards applied research and collaboration with industry.

Capabilities & Expertise

The research ecosystem has been focused on key areas: Space/ Aerospace, MedTech and Health Innovation, Advanced Manufacturing, Digital Platforms (specialising in cyber and AI for industry), as well as transformative technologies in renewable power/storage, quantum, and hydrogen. Swinburne has one of the largest astronomy groups in the world, with a range of capabilities across data analysis, space domain awareness, Earth Observation and next generation multifunctional materials.

Unique Selling Points

The university operates an Industry 4.0 research/training and uplift for industry partners at Factory of the Future. Houses the national supercomputer OzSTAR and Ngarrgu Tindebeek. First 2kW blue laser in the country Nano Lab ($8M facility with leading 10nm electron and ion beam lithography). Swinburne-CSIRO National Industry 4.0 TestLab (is the world's first industrial-scale, 3D printing multilayer approach to near net composite manufacture, twinned with Germany facilities in ARENA 2036). World-leading quantum cold atom lab, as well as quantum theory group.

Sydney Quantum Academy

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Overview

Sydney Quantum Academy (SQA) is a unique partnership between four world-leading universities: Macquarie University, UNSW, The University of Sydney and University of Technology Sydney. We are generously supported by the New South Wales Government in our vision to build Australia's quantum economy.

Capabilities & Expertise

Collaborating with academia, industry and government, SQA harnesses Sydney's collective quantum expertise to develop diverse talent and a globally recognised quantum ecosystem. Our training, education and scholarship programs are designed to create future quantum leaders, specialists and entrepreneurs. We partner with industry to better understand their evolving needs and to create awareness of the potential of quantum technologies and responsible development, through initiatives such as events, workshops, and internships. By promoting Sydney and Australia's world class quantum education and research expertise, we also work to attract global talent and investment.

Unique Selling Points

SQA represents over 100 quantum experts and 20 research groups active within our four partner universities, with expertise spanning quantum communications, computation, and sensing. Our partners also have a large emerging talent base, with over 150 PhD students specialising in quantum science and technology.

The Quantum Education Centre of West Australia (QUECWA)

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WA

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Overview

QUECWA was established in 2018 to provide quantum physics/computing education to the corporate sector and general public of West Australia.

Capabilities & Expertise

100 Educational Presentations on the QUECWA YouTube channel on Quantum Computing and Generative AI www.YouTube.com/c/quecwa.

Unique Selling Points

Academic knowledge and experience in Quantum Computing and Generative AI. A member of the Advisory Committee to the Quantum Girls project.

The University of Melbourne

Contact Details

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Overview

Research intensive comprehensive university with core interests in quantum technology since 2000.

Capabilities & Expertise

Nanofabrication toolkit for silicon and diamond-based quantum devices. (growth, processing, measurement, packaging, etc.) Quantum Biology, especially using colour centres in diamond. Single photon sources (especially for defense applications) Quantum algorithms and access to IBM quantum computing platforms Quantum based magnetometry for defense and health applications.

Unique Selling Points

Complete vertical for diamond-based quantum devices. Highly developed software team using IBM quantum hardware. World leading single ion implantation infrastructure.

University of Queensland

Australian Research Council (ARC) Centres of Excellence: of Engineered Quantum Systems of Future Low-Energy Electronics Technologies in Quantum Biotechnology for Quantum Computation and Communication Technology

CENTRE FOR
QUANTUM COMPUTATION &
COMMUNICATION TECHNOLOGY
AUSTRALIAN RESEARCH COUNCIL CENTRE OF EXCELLENCE

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Overview

The University of Queensland (UQ) is the home of Quantum Technology in Australia. It hosts four Quantum COEs: EQUS is engineering the quantum future by building quantum machines that harness the quantum world for practical applications; FLEET addresses the grand challenge of reducing the energy used in information technology; QUBIC aims to pioneer paradigm-shifting quantum technologies to observe biological processes and transform the understanding of life; CQC2T is focused on delivering world-leading quantum research to develop full-scale quantum systems, encompassing ultra-fast quantum computation, secure quantum communication and distributed quantum information processing.

Capabilities & Expertise

UQ studies a broad range of issues associated with quantum communication, quantum imaging and sensing, and quantum computation in several physical architectures, including atomic, neutral-atom, photonic, quantum-dot, solid-state, and superconductor. In sensing, imaging, and computing, coherent quantum communication enhances capability, performance, or both. There are both experimental and theoretical programs, ranging from foundations research in quantum communication, exploring the use of higher-dimensional systems or using indefinite causal order to achieve outcomes impossible in classical communications, through scaling of short to long range communication via the development of quantum repeaters, and small to medium scale processing through novel architectures and algorithms.

Unique Selling Points

UQ has a long record of proposing and developing key quantum technologies and information protocols, from the first proposal for a quantum-logic gate in 1989 (Physical Review Letters), through to the first demonstration of an entangling two-qubit logic gate in 2003 (Nature), through to the first quantum microscope in 2021 (Nature). Foundational texts in the field were all authored or co-authored at UQ: Quantum Optics, Walls and Milburn, Quantum Computation and Quantum Information, Nielsen & Chuang, Quantum Measurement and Control, Wiseman & Milburn, Quantum Optomechanics, Milburn & Bowen. Global Quantum Technology companies have been founded by UQ alumni, including PsiQuantum (USA), Universal Quantum (UK), and Xanadu (Canada), as well as Australian start-ups such as Analog Quantum Circuits, and quantum technology alumni include CTOs of companies including Quantum Valley Ideas Lab (Canada), and Quix (Netherlands). With respect to quantum communication protocols in particular, UQ has significant, continuing engagement with Defence both in Australia and with allies, and through international Defence Primes. UQ enjoys the highest-resolution, highest-throughput electron beam lithography in Australia, used for fabrication of nanophotonics and nanomechanics for use in quantum communication, quantum computation, quantum imaging, and quantum sensing.

University of Queensland

ARC Centre of Excellence for Quantum Computation and Communication Technology

CENTRE FOR QUANTUM COMPUTATION & COMMUNICATION TECHNOLOGY
AUSTRALIAN RESEARCH COUNCIL CENTRE OF EXCELLENCE

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Contact Details

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Overview

The Australian Research Council (ARC) Centre of Excellence for Quantum Computation and Communication Technology (CQC2T) is focused on delivering world-leading quantum research to develop full-scale quantum systems, encompassing ultra-fast quantum computation, secure quantum communication and distributed quantum information processing. CQC2T Nodes that are particularly focused on quantum communications research are the UQ, Griffith, ANU and RMIT Nodes.

Capabilities & Expertise

The UQ Node of CQC2T studies a broad range of theoretical issues associated with optical quantum computation and quantum communication. With respect to quantum communications we are particularly concerned with improving the performance of quantum secure communication systems and the scaling up to medium to long range quantum communications through the development of quantum repeaters, error correction and related technology. We collaborate with other Nodes, Partner Investigators and international groups on experimentally demonstrating key protocols and technologies.

Unique Selling Points

The UQ Node of CQC2T (and before it CQCT) has a long record of proposing and developing key quantum information protocols that are integral to current optical quantum technology. CEO's of international quantum start-ups Quintessence Labs, Psi-Quantum and Xanadu came out of or were co-supervised by the UQ-Node and the strong association continues through co-funding and consulting. With respect to quantum communication protocols in particular, the UQ Node has significant, continuing engagement with Defence through the NGTF and with Northrop-Grumman, USA through ARC Linkage. We work with: the Griffith Node in developing discrete variable technology based on photon counting; the ANU Node in developing continuous variable technology based on homodyne detection and quantum memory; and the RMIT Node in developing chip-based technology.

The University of Sydney

Contact Details

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Overview

The University of Sydney is a large and comprehensive research and education leader. Founded in 1850, it is the oldest university in Australia and is one of the country's six sandstone universities. It was one of the first universities in the world to admit students solely on academic merit and opened their doors to women on the same basis as men.

In quantum science, Sydney has made a significant investment over two decades in research, training and infrastructure and is recognised as a world leader.

Capabilities & Expertise

Leading expertise in theoretical quantum science and experimental programs in quantum dots, ion traps, spin qubit and photonics. Quantum computing, quantum/classical interface, quantum error correction, quantum interconnects, scale-up of quantum technologies.

Sydney Nanoscience Hub provides specialised labs with low vibration and EM shielding for precision measurements.

Core facilities including semiconductor fabrication clean room, advanced manufacturing and prototyping, microscopy.

Our multi-disciplinary approach fosters collaboration across disciplines.

Unique Selling Points

Comprehensive science and engineering capabilities with world leading research in quantum computing, photonics, nanotechnology, sensors and communications. Research spans quantum computing, sensing and communications with fundamental and applied research, including commercialisation success. Significant national and international partnerships especially with industry and defence.

University of Technology Sydney

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Overview

The University of Technology Sydney (UTS) has an extensive research program on quantum technologies, spread across the faculties of Science and Engineering and IT. Research expertise in nanofabrication and 2D materials, photonics, sensing, quantum communications, and quantum computing, among other areas of Quantum Technology. UTS also houses the Centre for Quantum Software and Information (QSI), the largest non-corporate effort in Australia focused on theoretical research into quantum information science and software. With 13 full time faculty and over 40 Postdoctoral researchers and PhD students, QSI is one of the leading institutions around the world for work in quantum computing, communications and information theory.

Capabilities & Expertise

Bachelor of Advanced Science (Quantum Technology) introduced in 2023. All physics staff members are involved in teaching subjects within this major. Strongly connected to Sydney Quantum Academy and Defence Innovation Network. We are a node for the ARC centre of excellence in Quantum Computing and Communications Technology, a subcontractor on three separate teams in the US Defence Advanced Research Project Agency (DARPA) Quantum Benchmarking program, the joint US AUS AUSMIRI program and the CSIRO Next Generation Emerging Technologies Graduates Program.

Unique Selling Points

UTS has the largest non-corporate or startup effort in quantum information theory and software in Australia and one of the largest in the world. UTS is a founding member of the Sydney Quantum Academy and the founder of the Australian Quantum Software Network. UTS has also seeded the spin-out of the first startup in Australia dedicated to building technology focused on quantum education and literacy, Eigensystems Pty Ltd, and UTS is currently engaged with multiple startups in the quantum ecosystem. Faculty at UTS have been at the forefront of research in Quantum communications. UTS is the only institution in Australia with two members appointed to Minister Husic's National Quantum Advisory Committee (Simon Devitt and Ed Santow), and UTS researchers collaborated closely with the drafting of the CSIRO reports into the national quantum program in 2020.

University of New South Wales

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Overview

Go8 university.

Capabilities & Expertise

World leaders in quantum research and teaching.

Unique Selling Points

World leaders in quantum technologies.

University of Western Australia

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Overview

Established as the State's first university in 1911 and founded with a mission to 'advance the prosperity and welfare of our communities', the University opened in 1913 to just 184 students. Today, more than 25,000 students are enrolled from 100 countries. Since our beginnings, UWA has blazed the trail in producing remarkable and life-changing contributions across learning, teaching and research. UWA is ranked in the world's top 100 universities and a member of the Group of Eight, which consists of the eight most research-intensive Australian universities.

- $243 million Research income (2021 data)
- 5,338 Research outputs
- 19,560 Students (Total equivalent full-time student load)
- 5,521 Postgraduates (By coursework)
- 1,478 Higher degree (By research)
- 12,561 Undergraduates

Capabilities & Expertise

Quantum Sensing. Capability and facilities include:

- ARC Centre of Excellence for Gravitational Wave Discovery (Oz Grav)
- ARC Centre of Excellence for Engineered Quantum Systems (EQUS)
- ARC Centre of Excellence for Dark Matter Particle Physics
- Quantum Clock flagship program
- Australian National Fabrication Facility (ANFF), WA node

Quantum communications. Capability and facilities include:

- UWA Astrophotonics Group (www.icrar.org/study-with-icrar/postgraduate-opportunities/postgraduate-research-projects/astrophotonics)
- International Center for Radio Astronomy Research (ICRAR), a UWA and Curtin University joint venture, co-funded by the State Government of Western Australia. (www.icrar.org)

Quantum computing and software. Capability and facilities include:

- QUISA Research group (Quantum Information, Simulation and Algorithms)
- UWA & Pawsey Quantum Computing Centre (UP-QCC)

Unique Selling Points

- Developed the lowest noise microwave measurement and oscillator technology in the world, necessary for application in high precision frequency systems, such as atomic clocks and atomic qubits, resulting in systems operating at the quantum projection noise limit.
- Development of practical outcomes to support the airborne exploration industry, including improvements in airborne gravity exploration, airborne electromagnetic exploration and seismic surveying technology.

The University of Adelaide

Quantum Machine Learning Research Group

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Overview

We are a research group at the University of Adelaide and at the Australian Institute for Machine Learning. We focus on cutting-edge techniques that bridge classical and quantum paradigms. The work combines quantum computing with machine learning and computer vision, resulting in novel approaches to robust regression, binary neural networks (BNNs), and Boltzmann machines.

Capabilities & Expertise

In the realm of robust fitting, the group pioneers the application of quantum algorithms. Quantum-enhanced regression models handle noisy data, outliers, and uncertainties more effectively than classical counterparts.

The team pioneered Quantum Boltzmann Machines (QBMs) for NN training, extending classical Boltzmann machine concepts to quantum systems. QBMs leverage quantum entanglement and superposition, potentially offering exponential speedup for specific learning tasks.

For binary neural networks (BNNs), the team explored encoding schemes for quantum annealers. Quantum states can represent binary information efficiently, leading to compact and expressive neural architectures. BNNs reduce memory and computational requirements during inference, making them suitable for resource-constrained environments.

Unique Selling Points

The group's strength lies in their ability to bridge classical and quantum machine learning. Investigating hybrid models that combine classical and quantum components, they achieve better performance than purely classical or purely quantum methods. Additionally, they explore using quantum annealing processors for QBM training and applications and trapped-ion quantum computers for running quantum algorithms, using the best available quantum hardware.

In summary, our group's pioneering work contributes significantly to advancing machine learning in the context of quantum computing.

Government

Australian Army

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Overview

The Australian Army aims to gain and retain an early quantum advantage through rapidly identifying and exploiting the most disruptive applications of quantum technology in the land domain. Army is approaching this through their Quantum Technology Roadmap.

Capabilities & Expertise

Rapid identification, experimentation and validation of use cases and their associated quantum technologies. Providing opportunities for the emerging quantum industry to demonstrate its capabilities and build connections.

Unique Selling Points

Australian Army is an engaged government organisation who is willing to contract demonstrations of technologies and tests of applications.

Chief Scientist

Australian Government

Australian Government

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Overview

Leading the development of the quantum strategy for the government and building the demand across different industry sectors.

Capabilities & Expertise

I have been working on the development of superconducting quantum devices for over 35 years. Also, their packaging, systems development and applications. I have successfully commercialised one sensor system.

Unique Selling Points

Muliti.

Australian Space Agency

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Overview

The Australian Space Agency (the Agency) is a division of the Department of Industry, Science and Resources established in July 2018. Its role is to transform and grow a globally respected space sector for the benefit of Australians. Its responsibilities include:

- Lead policy and coordination of civil space activities across government
- Shape and grow national space capability, including delivery of Agency programs
- Lead international civil space engagement to support Australian foreign policy objectives
- Promote a responsible space sector for current and future uses of space through education, technology and regulation
- Promote value and benefits of space to the community to inspire a highly skilled workforce, including through the Australian Space Discovery Centre in Adelaide.

Capabilities & Expertise

The Australian Space Agency does not undertake direct technology and scientific research. However, it maintains policy, science and engineering expertise in space technology with applications including Communications Technologies and Services, as outlined over a decadal roadmap (published Dec 2020).

The Agency run a national communications technical advisory group (TAG) to monitor developments across 6 satellite communications focus segments of which three applicable ones are Quantum-Enabled communications, Optical Ground Stations and Hybrid RF-Optical communications.

Other areas covered by the Agency are:

- Position, Navigation and Timing (PNT)
- Earth Observation (EO)
- Space situational awareness (SSA) and debris mitigation
- Robotics and Automation on Earth and in Space
- Applied Space Medicine and Life Sciences
- Access to space
- Space flight safety and regulation
- Space sustainability
- STEM workforce and skills policy development

Unique Selling Points

The Australian Space Agency is Government's lead agency for advice on civil space matters.

CSIRO

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Overview

As Australia's national science agency, CSIRO solves the greatest challenges through innovative science and technology. We are Australia's most trusted research institution and most connected innovator, working with universities, governments, Australian businesses of all sizes across all major industries, and communities around the country. One of the largest and most multidisciplinary research and technology organisations in the world, we manage state-of-the-art research facilities for the nation, for greater collaboration and the development of new technologies to support Australia.

Capabilities & Expertise

Our scientists, researchers and engineers are internationally renowned experts in their fields and are trusted advisors in academia and to industry and government. They work across the entire science, technology, engineering, mathematics and innovation spectrum. Our researchers are supported by a variety of professional staff skilled in research, laboratory services, data collection and data management. Technical and corporate support staff deliver commercial services, intellectual property portfolio management, engineering services, field operations, information technology, information services, communications and financial, human resources, supply, facilities and general management services. CSIRO's capabilities are deployed throughout it's business units: Agriculture and Food, Space and Astronomy, the Australian Centre for Disease Preparedness, Data61, Energy, Environment, Health and Biosecurity, Manufacturing, Mineral Resources, and National Collections and Marine Infrastructure.

Unique Selling Points

In relation to quantum research, CSIRO has mature, as well as emerging capability from rapid expansion of our quantum workforce in the past two years to approximately 100 researchers. The majority of these are within our Data61 and Manufacturing units with established projects in post quantum cryptography (PQC), harnessing the power of quantum processors (annealers and NISQ QC's) for materials development, development of optical communications suitable for quantum communications to and between satellites, quantum machine learning for cyber security, materials and devices for quantum communication light sources and detectors, materials and device characterisation facilities, and quantum software and algorithms.

Defence Science & Technology Group

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Overview

The Defence Science & Technology Group (DSTG) is the Australian Government's lead agency responsible for applying science and technology to safeguard Australia and its national interests. The agency provides expert independent advice and S&T support for the Australian Defence Force and National Security. With a vision to becoming a global leader in defence science and technology, DSTG employs a large team of interdisciplinary expertise from across Australia and around the world. By collaborating with domestic and international experts, DSTG addresses diverse defence and security challenges. Their mission is to enhance the capabilities of the Australian Defence Force and the broader national security community, reinforcing Australia's protection and interests.

Capabilities & Expertise

Quantum technologies are an innovation, science and technology priority for Defence and DSTG's expertise spans quantum communications, quantum sensing, quantum networking and computing, and quantum position, navigation and timing (PNT). DSTG offers independent, research-based advice and innovative technology solutions, and foster collaborations with academia, industry, and government departments to explore quantum technologies' strategic impact. DSTG's unique position allows them to develop and de-risk cutting-edge quantum technologies applicable to defence and national security prior to industry transition.

Unique Selling Points

Unique world-class sovereign capabilities, with research staff and infrastructure covering the spectrum of defence science including quantum technologies; Deep knowledge of and responsiveness to the Australian defence environment and military capabilities; Proven record of linking research and innovation with applications, and researchers and innovators with end users; Active collaboration with defence and national security communities of interest nationally and internationally; Ability to integrate diverse and privileged information from multiple sources into coherent expert advice relevant to Defence, National Security and Government decision making, policy formulation and strategic planning; Ability to maintain commercially unviable technology capabilities that are critical to Defence; and Ability to work with academia and industry to foster a national science and technology base and transfer knowledge to support Defence capability development, acquisition and sustainment. This activity also generates economic value for the nation.

Chief Minister

Treasury and Economic Development Directorate

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Overview

The ACT Government has responsibility for state/territory functions as well as local government functions. Business and Innovation forms part of the Chief Minister, Treasury and Economic Development Directorate and is responsible for delivering a range of ACT Government programs to support Canberra's businesses and entrepreneurs to get started, grow, export and prosper. We welcome new technology, world-leading trials and innovations, and our focus is on developing strong collaboration and partnerships between the government, business community, our world-class education and research institutions and the surrounding Canberra Region to help sustainably grow Canberra into a truly international city and the knowledge capital of Australia. The ACT Government is committed to supporting local businesses and other organisations to access new markets, build a more diverse economy, attract leading talent, create new jobs and use our competitive strengths to drive innovation and investment.

Capabilities & Expertise

The Canberra Quantum Ecosystem consists of the ANU and its research school of physics, UNSW Canberra, and the University of Canberra, numerous ACT born quantum inspired spinout companies and various other players across adjacent ACT Government key sectors including cyber security, space and defence that are users of various quantum technology applications. The ACT is fortunate to have areas of academic and commercial expertise in each of the broad quantum domains: Communications, Computing and Sensing. The ANU is a leading institution in Australia in the areas of quantum communications networks and offers world class facilities to support quantum specific starts ups in the ACT. Our Canberra Quantum ecosystem is highly connected internationally through formal research relationships, commercial arrangements, international company equity and person to person contact.

Unique Selling Points

The ACT's efforts unite around the theme of quantum integration. With light as the ideal information carrier over distance, effort has been dedicated to integrating different quantum technologies with optical channels. The ANU is installing Australia's first optical ground station which provides a unique quantum communications testbed. It's interface with quantum memory technology will support planned missions with NASA and DLR. ACT scientists have key strengths in atom optics, quantum optics, quantum information theory, quantum computing, communications and sensing, gravitational wave sensing, precision optics, optical material science, space science, material modification and nanofabrication. The ACT nodes of NCRIS supported Australian National Fabrication Facility and the Heavy Ion Accelerators offer a unique in Australia opportunity to grow III-V semiconductors as well as characterisation and fabrication capabilities. Our local innovation ecosystem has also played a critical role in the formation and development of quantum inspired spin-out and start-up companies, particularly over the last 10 years and provides a ready connection to early-stage companies in adjacent sectors such as defence, space, cyber security and renewables.

Thank You

As Australia's national science agency and innovation catalyst, CSIRO is solving the greatest challenges through innovative science and technology.

CSIRO. Unlocking a better future for everyone.

For further information

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