Australian Academy of Science

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A vision for space science and technology in Australia

Securing and advancing Australia's interests through space research

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Cover image: On 12–13 October 2015, NASA astronaut Scott Kelly took a series of 17 photographs from the International Space Station during a single flyover of Australia. IMAGE CREDIT: NASA

Contents

Abbreviations and glossary

AIP	Australian Institute of Physics
ANU	Australian National University
ARC	Australian Research Council
ASRP	Australian Space Research Program
BoM	Bureau of Meteorology
CEOS	Committee of Earth Observation Satellites
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
COSPAR	Committee On Space Research, established by the International Council for Science in 1958 to promote international research in space
CRC	Cooperative Research Centre
CubeSat	Miniaturised satellite comprising multiples of 10x10x10 cm cubic units, usually using commercial electronic components
EOS	Earth observations from space
ESA	European Space Agency
G20	Group of Twenty leading industrialised countries
GIS	Geographic information systems
GNSS	Global navigation satellite system
GPS	Global positioning system
HF	High frequency radio transmission
JAXA	Japan Aerospace Exploration Agency, Japan's space agency
LEO	Low Earth orbiting (satellite)
MF	Medium frequency radio transmission
NASA	National Aeronautics and Space Administration, USA's space agency
NCSRS	National Committee for Space and Radio Science
OECD	Organisation for Economic Cooperation and Development
OTHR	Over-the-horizon radar
PNT	Positioning, navigation and timing
RMIT	RMIT University
RO	Radio occultation
SCC	Space Coordination Committee in the Department of Industry, Innovation and Science
SBAS	Satellite-based augmentation system, used to improve GNSS accuracy
SETI	Search for extra-terrestrial intelligence
SME	Small and medium enterprises
SSA	Space situational awareness: tracking, predicting locations and managing risks of collisions, of objects in space
SuperDARN	Super Dual Auroral Radar Network, international consortium of over-the-horizon research radars
STEM	Science, technology, engineering and mathematics
SWS	Space Weather Service at the Bureau of Meteorology
UNSW	University of New South Wales
VHF	Very high frequency radio transmission
VSSEC	Victorian Space Science Education Centre, a specialist science centre established and run by the Victorian Government

Executive summary

Advances in technology are transforming just about every facet of our lives. Space technology is already an integral, if widely unseen, part of Australian life. It is so heavily integrated into today's economy and wider society that denial of access, for example to global navigation satellite system (GNSS) services, of which GPS is the best known, would have extremely serious ramifications for Australia. All levels of government, industry and society now rely on data and information applications derived from Earth observations from space. These applications maintain our economic and societal wellbeing in areas including communications, weather and seasonal forecasting, onshore and offshore mining, mitigation of natural hazards and management of disasters, water resource management, national security, insurance assessment, and land use planning and monitoring[1]. Australia's extensive rural and remote areas also depend on satellite communications for essential telephony and internet connectivity.

Space science is the essential foundation that enables us to understand and operate technology in the unforgiving environment of space. By virtue of Australia's position on our planet, space technology must play a central role in affordable solutions to many of our pressing national challenges. It also presents Australia with unique opportunities to overcome the tyranny of distance presented by our sparsely populated continent.

Current paradigm shifts in space technology—particularly the increasing commercialisation of space activity and the miniaturisation of space hardware—present Australian researchers and industries with opportunities to play niche lead roles and benefit from the innovation spin-offs and export dollars that come with them. More broadly, this meets Australia's need to transform to a high-tech economy.

Australian space science and technology has significant strengths that play into global efforts such as space situational awareness, space weather, disruptive space technology developments based on small satellites, planetary science, and STEM outreach.

This view of Australia's Lake Eyre was taken from the space shuttle Columbia in 1990 during the STS-35 mission. IMAGE CREDIT: NASA

We envisage a future—by 2027 or sooner—in which Australia will have a vibrant space sector and space industry, underpinned by space science and technology, and by a national space agency.

Most importantly, Australia needs a coordination framework for space science and technology and for its translation to innovation, that positions the sector as a unified contributor to the national economy. Such a national framework, advised by an expert panel, would provide coordination, priority setting, and a degree of strategic funding, to assist the Australian space sector to mature and flourish.

1 http://www.aeoccg.org.au/aeocp-the-plan/

A vision of the future

The year is 2027.

Australia's population exceeds 28 million, with 5.7 million people living in Sydney and in Melbourne, and 3 million in each of Brisbane and Perth. Nearly 18% of the population is 65 or over, up from 15% in 2017.

The world's climate has warmed by about 1° on pre-industrial levels, and sea levels have risen by approximately 10 cm since 1990. Both sudden and prolonged extreme weather events are affecting global food and resource security, escalating regional tensions.

As it has done for 70 years, Australia continues to have primary stewardship of southern hemisphere climate science. Australian climate scientists are providing significant input to iterative mitigation and adaptation measures taking place on domestic and international scales. Thanks to state-of-the-art climate modelling capabilities and land- and space-based environmental monitoring infrastructure, Australians are receiving increasingly reliable and accurate medium- and long-term forecasting of weather and extreme events.

Australia's economy continues to be structured primarily around small and medium enterprises (SMEs), but the global shift toward renewable energy generation has spurred a resurgence of investment in Australia's minerals industry based on increasing demand for copper, lithium and other non-bulk commodities. Increases in Australia's agricultural productivity have consolidated its reputation as a major supplier for Asia. Modest advances in Australia's manufacturing and services sectors have been enabled by the rollout and subsequent improvements in the NBN as well as widespread adoption of 3D printing technologies and significant developments in nanoscale fabrication, machine learning and automation.

Australia's economy remains strong but is being surpassed in scale by a number of rapidly developing countries. After dropping out of the G20 in the early 2020s, Australia is now the 22nd largest economy in the world.

The 2017 International Astronautical Congress in Adelaide and the 2020 Committee on Space Research (COSPAR) Conference in Sydney announced Australia's space science and technology ambitions to the world, and under the direction of a new national agency, space science and industry in Australia is burgeoning.

- New start-up enterprises are developing and launching innovative small satellites for Australian and international customers, and advanced software, sensor and equipment manufacturers are accessing global space markets at unprecedented levels.
- Australia's robust Earth observation capabilities based on a network of Australian and international space assets are providing unprecedented capacity to monitor, model and predict climate variability, agricultural conditions and extreme weather events.
- Improvements in satellite-based positioning information have led to the widespread introduction of precision agriculture, while semiautonomous platforms are similarly revolutionising the logistics sector. The internet of things is a growing reality, facilitated by networks of nanosatellites developed by cutting edge Australian SMEs.
- Through domestic assets and firm international treaties, Australia has assured access to satellite imaging, communications and position, navigation and timing data, fundamental to intelligence, surveillance and reconnaissance operations underpinning national security.
- Through partnerships between defence, university and industry groups, Australia is developing and operating innovative small satellites to assure national security.
- Australia is the acknowledged world leader in orbital quantum sensing and computing research, with a range of promising applications in development.
- The technical expertise vested in Australia's space agency ensures Australia has a coordinated and streamlined space policy framework, as well as enabling engagement as an equal partner on global space initiatives and programs.
- Australia's comprehensive ground sensor network, international commercial and scientific collaborations and innovative workforce provide strategic partnership in global space situational awareness, environmental and remote sensing programs.

Underpinning this growth in Australia's space industry is a thriving space and radio research capability comprising a coordinated network of basic and applied space researchers, research engineers, and IT and data scientists across Australia's universities and publicly funded research organisations.

The period from 2017 to 2027 has been a decade of rapid transition in public understanding and support for space science and technology in Australia, allowing Australia's space industry to become a major driver of Australia's transition to a knowledge economy for the second half of the century.

The year is 2017.

The decade of transition is about to begin.

Introduction: Australian space science 2010–2017

Space science is a fundamental enabler of the many space-derived applications—including Earth observation from space, global positioning, navigation and timing services, and satellite communications—that benefit our society and economy. Space related products and services are currently used in every sector of the Australian economy, with the space industry generating annual revenue of $3–4 billion[2]. Revenue from the global space economy exceeds US$320 billion annually, mostly for commercial activities, but our share is only 0.8%. The Australian space workforce is highly educated and at the forefront of innovation, mostly employed in SMEs.

Australia has the scientific capability to discover, innovate in and utilise space science and technology to enhance our future national growth and prosperity. Opportunities for innovation in space-based technology cannot be pursued without this capability, as well as a clear awareness that it needs to be maintained in the long term.

Space science encompasses any of the scientific disciplines involved in studying our own planet from space, studying other planets and the many small bodies within our solar system and beyond, and developing and utilising the technology and data required to undertake these activities or use the space environment for other purposes including commercial, scientific and defence activities. Space science includes the study of:

- the sun and interplanetary environment
- Earth observation and climate
- geology and biology of other planets
- geodesy and positioning
- Earth's near-space environment, including the upper atmosphere and ionosphere
- space weather and impacts on technology
- space missions and technology
- ground instruments.

Applications of space science include:

- space vehicle design and development
- propulsion technologies, such as hypersonics and ion plasma thrusters
- weather prediction and climate modelling
- Earth observations
- precision navigation and timing services
- satellite enabled communication and data services
- over-the-horizon radar and surveillance
- space situational awareness and surveillance
- radio astronomy.

In the *2010–2019 Decadal Plan for Australian Space Science: Building a National Presence in Space*, the Australian space science community came together for the first time to create a plan for the development of a long-term, productive Australian presence in space via world-leading innovative space science and technology, strong education and outreach, and international collaborations.

The decadal plan proposed two new national bodies, education and training and community development and outreach priorities, and a portfolio of science and technology projects, to develop, extend, and support Australia's space capabilities. The plan was aspirational and aimed to build a sense of community among space scientists and external constituencies, with activities to foster widespread engagement in common goals while reinforcing the foundations of our current research capability.

In 2014 the Australian Academy of Science's National Committees for Space Science and for Radio Science merged to form the National Committee for Space and Radio Science (NCSRS). In 2015 the NCSRS conducted a survey of the national space science community to assess views on the value of and progress toward the goals of the decadal plan. Around 700 individuals were invited to complete the wide-ranging 82-question survey; 117 surveys were mostly completed and an additional 154 surveys were partially completed. The four broad themes of the plan and their goals were seen as still relevant:

- Sun and space to Earth—understanding how activity on the Sun and in space develops and affects humans and technology.
- Plasma to planets—understanding how Earth, the Moon, Sun and other solar system bodies formed and evolved.
- Remote sensing Australia, Earth and other bodies from space—knowledge of the atmosphere, oceans, and surface of Earth and of other solar system bodies based on space and ground observations and modelling.

2 A selective review of Australian space capabilities: growth opportunities in global supply chains and space enabled services, Asia Pacific Aerospace Consultants, 2015.

- Life and technology in space—developing instruments and technologies for space, understanding effects of space on human technologies, and quantifying how life developed on Earth and might exist elsewhere.

The landscape of the Australian space science sector has experienced substantial change since the decadal plan was completed, including the delivery of the Australian Space Research Program (ASRP), which provided $40 million in competitive funding over four years (2009–2013) to support space-related research, education and innovation activities. The scope of activities eligible [3] for funding under the ASRP was generally consistent with the definition of 'space science' used for the plan, although for the purposes of the ASRP, 'space-related' did not include astronomy, astrophysics and cosmology.

The Space Policy Unit, established within the then DIISRTE in 2009, identified the following strategic priorities for ASRP projects:

- Earth observation
- Satellite communications
- Position, navigation and timing
- Space situational awareness
- Excellence
- Collaboration between industry and universities
- International collaboration.

A subsequent independent evaluation found that all ASRP projects met their milestones and deliverables and that the program was successful in developing and building a range of niche space capabilities across a number of priority areas [4]. Consequently, over the period 2010 to 2015, some areas of space science research in Australia grew well beyond the expectations of the decadal plan, including the establishment of the ANU's Advanced Instrumentation and Technology Centre, UNSW's Australian Centre for Space Engineering and Research, the establishment of the CRC for Space Environment Management, the Mars Yard at the Museum of Applied Arts and Sciences (the Powerhouse Museum), and the awarding to Australia of half of the US$100 million Breakthrough Listen initiative for SETI (Search for Extraterrestrial Intelligence), for which the Parkes radio telescope will be used.

Furthermore, in 2013 a new national civil space policy, Australia's Satellite Utilisation Policy [5], was released. The policy focused primarily on applications of national significance, identifying seven principles for space industry development:

- Space applications of national significance
- Assuring access to space capability
- Strengthening and increasing international cooperation
- Contributing to a stable space environment
- Improving domestic coordination
- Supporting innovation, science and skills development
- Enhance and protect national security and economic wellbeing.

The 2016 Defence White Paper highlighted the importance of ensuring the security of Australia's space-enabled capabilities, and prioritised strengthening Defence's space surveillance and situational awareness capabilities [6]. Defence's Next Generation Technologies Fund also identified space capabilities as a priority area [7].

Subsequently, as the value of space as a platform for addressing national needs and challenges and building our economy became clearer, further initiatives emerged to advance the coordination of space interests in Australia. These included national infrastructure plans for space-based positioning and Earth observations from space, leading in 2016 to the Australian Earth Observation Community Plan to 2026 [8].

There has been much discussion in various forums on whether Australia should have a space agency. The decadal plan did not call for an agency per se, but a space advisory board or council to coordinate the Australian space science community and link it to government, industry and international space efforts. The lack of a strategic coordinated approach to Australia's interests in space can lead to scientific or technical gaps inconsistent with Australia's sovereign interests. For example, the Chinese International Space Weather Meridian Circle Program is proposing to establish instruments along the 120E/60W meridian passing through Australia and Antarctica to study the coupling and feedback between space weather drivers. Ground-based sensors include ionosondes, HF, VHF and MF radars, GPS receivers and magnetometers. Lack of a national coordination framework

3 Under the ASRP, 'space-related' was defined to mean:
(a) the designing, building, testing, installation, deployment and/or operation of hardware or systems developed:
(i) to be located in space;
(ii) for the purpose of getting into or returning from space; or
(iii) for the purpose of getting data or information to or from space;
(b) the design, development, testing, installation and/or use of applications that require the operation of hardware or systems listed at (a);
(c) governance arrangements (such as legal, management and advisory structures) to support space hardware, systems or applications listed at (a) and (b); or
(d) research into the environment in which space hardware or systems listed at (a) operate.
For the purposes of the ASRP, *space-related* did not include astronomy, astrophysics and cosmology.
4 Final evaluation of the Australian Space Research Program, 2015, http://www.spaceindustry.com.au/Documents/Final_evaluation.pdf
5 https://industry.gov.au/industry/IndustrySectors/space/Documents/Australias-satellite-utilisation-policy.pdf
6 2016 Defence White Paper (http://www.defence.gov.au/WhitePaper/Docs/2016-Defence-White-Paper.pdf)
7 2016 Defence Industry Policy Statement (http://www.defence.gov.au/whitepaper/Docs/2016-Defence-Industry-Policy-Statement.pdf)
8 http://www.aeoccg.org.au/aeocp-the-plan/

Case study: SuperDARN radars

A consortium involving La Trobe University, the University of Newcastle and the University of Adelaide, with support from industry partners and the US Air Force, developed three sophisticated over-the-horizon (OTH) research radars located in Tasmania (commenced 1999), near Invercargill in New Zealand (2004) and near Adelaide (2014). The radars contribute to the international SuperDARN program of about 35 such radars. The Australian radars were the first mid-latitude instruments and each has broken new technical and scientific ground, consolidating Australia's leadership in this field. Similar radars are now being established by SuperDARN partners across the US, Canada and Japan. The research and training outcomes are important to Australia's surveillance capability invested in the JORN over-the-horizon network, and for space weather applications. However, lack of national strategic direction has seen the attrition of much of Australia's university-based capacity in this field, so continued operation of the radars is not assured.

TIGER radar, Buckland Park, South Australia. One of the three SuperDARN installations in Australia. IMAGE CREDIT: LA TROBE UNIVERSITY

for space weather activities impacts on Australia's engagement with, and response to, such activities.

The Australian space sector has recently been proactive in seeking opportunities to increase international recognition and collaboration: amongst other achievements, Australia was Chair of the international Committee on Earth Observation Satellites (CEOS) for 2016, and Australia will host the annual International Astronautical Congress in Adelaide in 2017, and the biennial COSPAR (International Committee on Space Research) Scientific Assembly in Sydney in 2020.

The space science community must now work to ensure that Australia is in the best possible position to utilise and innovate in space science and technology to generate economic growth, societal benefits and enhanced national security.

Challenges and opportunities

Australia needs assured and secure access to space-based systems and services, similar to the need for terrestrial forms of critical infrastructure such as utilities and transport. Australia also needs to be able to exert sovereign responsibility over its areas of influence in the southern hemisphere, including Antarctica and the southern ocean. At the same time, unique features of Australia's land mass and geography present strategic advantages in developing niche space industries able to realise strategic market opportunities.

Significant challenges facing Australia include climate change mitigation, environmental management, agricultural biosecurity, national security and defence, and more broadly, the need to transform to an agile, innovative high-tech economy that can generate new sources of growth and maintain high-wage jobs.

The diverse applications of space science and technology provide numerous avenues of unrealised potential for innovation, economic growth and societal benefit. Space science and technology are also exciting fields for educators, students and young innovators to engage in mathematics, science, engineering and applications. It is essential to address challenges to growth in the Australian space sector to ensure we have the capabilities required to meet our nation's future needs from space technology, and to ensure that space science and technology contribute to our national development.

Research by the OECD has demonstrated that revenues generated by institutional investments in space over a decade lead to a multiplier effect of between 4.5 and 6.2 when considering the value chain and indirect effects only, and between 8.5 and 9.7 when including societal effects [9]. European Space Agency (ESA) member states report economic turnover multiplier effects from 4.5–4.7 (Norway, Denmark) to 3.6 (Ireland) and 1.0 (Portugal). In very small economies with no prior domestic space markets, the main factor affecting socio-economic returns is successful technology transfer outside the space domain of SMEs. The role of national space authorities is critical in identifying and mapping innovation pathways to stimulate these activities [10].

The 2015 National Innovation and Science Agenda [11] identifies obstacles to Australian growth through innovation, including insufficient access to early stage capital for many start-ups, the lowest level of industry–research collaboration in the OECD, falling maths skills amongst school students, and governments following on innovation rather than leading. The Australian space sector shares these broader challenges. The Australian Government's investment in non-military space research and development has been steadily declining to 0.3% of total government R&D outlays, among the lowest in the OECD [12].

The current paradigm shift in space technology to a domain that now includes small space systems also presents significant opportunity. Australia can play niche lead roles in this sector and benefit from the resultant advances in science, innovation spin-offs and export earnings.

This opportunity sits in the context of exponentially growing international commercial investment in space, with almost 50% of non-US world expenditure in 2015 being in the Asia–Pacific region [13]. The 15-year compound annual growth

These CubeSats are seen moments after being ejected from a small satellite deployer outside of the International Space Station's Kibo laboratory module on Wednesday, 16 May 2017. IMAGE CREDIT: NASA

Case study: CubeSats

An example of small space systems are the tiny satellites the size of shoe-boxes, known as CubeSats—an excellent and affordable technology development and education mechanism that provide handy space-derived data for certain applications. They can also provide a stepping stone in the maturation of Australia's space sector to somewhat larger, more sophisticated spacecraft capabilities provided by clothes-dryer-sized microsats.

9 OECD handbook on measuring the space economy, OECD publishing, doi:10.1787/9789264169166-en, 2012
10 M. Vööras et al., Ex ante assessment of economic and societal effects induced by space investments in a small emerging space country, IAC-13, E3.3, 5x16998, 2013, http://www.spaceindustry.com.au/project/documents/IAC-13,E3,3,5,x16998.pdf
11 http://www.innovation.gov.au/system/files/case-study/National%20Innovation%20and%20Science%20Agenda%20-%20Report.pdf
12 http://www.spaceindustry.com.au/Documents/2017%20Budget%20Green%20Paper%20v1.pdf
13 https://space.taurigroup.com/reports/Start_Up_Space.pdf

of the commercial space sector was 13.7% up to 2013, and 9.7% in 2014 [14].

A growing Australian space sector will build on the four key pillars of the 2015 National Innovation and Science Agenda:

1. Culture and Capital (transforming ideas into new businesses and new jobs)
2. Collaboration
3. Talent and Skills
4. Government as an exemplar.

Our vision is to strengthen space science and technology in Australia. This will:

- support fundamental sciences and related fields such as astronomy, atmospheric and Earth sciences
- grow the supply of highly trained workers, allowing the expansion of innovation industries
- amplify the economic, defence and educational benefits of space science services
- help improve Australians' understanding of science.

The skilled space workforce we envision in the late 2020s employs many more professions than scientists and engineers. Mature industries develop legal, technical, financial, policy and other supporting roles that all contribute their capability to the nation. The supporting systems that a mature space industry would develop would bring particularly relevant capabilities to a stronger, more secure Australia [15].

Australia has already developed many of the ingredients required to reap the benefits of a space industry—indeed, some areas are excelling. Substantial progress has also already been made within and between some organisations with significant stakes, including the Bureau of Meteorology, Geoscience Australia and the Department of Defence. However, these contributors, including the smaller actors and organisations, do not yet form a cohesive and unified sector that is able to provide the full depth and breadth of rigour necessary to underpin operational sovereign space capabilities. They must be nurtured and grown in strategically prioritised and assisted ways. A key missing ingredient is a national space coordination framework.

14 A selective review of Australian space capabilities, Asia Pacific Aerospace Consulting, 2015
15 Defence White Paper 2016 (and supporting documents) http://www.defence.gov.au/WhitePaper/Docs/2016-Defence-White-Paper.pdf.

Priorities for future success

1. Coordination and prioritisation: developing a strategic framework

The National Committee for Space and Radio Science commenced a mid-term review of the 2010–2019 decadal plan in 2015. The review process highlighted the continuing need to build community coordination and communication across the space science sector, and the Australian space community more generally. This was first identified as a priority in the decadal plan, and remains relevant.

Enhanced national coordination would:

- provide strategic direction for the growth of space R&D capacity in Australia and reduce fragmentation of effort with the development of strategic priorities
- enable consultation between federal and state government departments and agencies with space-related functions, non-government entities such as research organisations and industry associations, industry and venture capitalists
- aid security of long-term access to Earth observation and other data of national importance, and services adapted to national strategic needs
- reduce attrition of research in areas of national importance due to university-based research groups falling below critical mass and failing to achieve sustainable research funding, which in turn impacts on our capability in areas such as defence surveillance, space situational awareness (SSA), space weather risk prediction and risk mitigation, and engagement in major international consortia
- promote collaboration and cross-fertilisation between state-based education, training and outreach agencies, industry and other constituencies to enhance the development of human capital in STEM disciplines.

Growing a mature Australian space industry to meet national economic and security challenges and opportunities urgently requires a strong and decisive whole-of-government response. A coordination framework would be the most valuable first step beyond our current regulatory and policy activities to achieve this goal.

The objective of a coordinated strategy is to ensure that strategic space science and technology areas that are important to the nation are grown, tasked against the National Research Priorities [16] and aligned with Australia's competitive advantages.

A coordinated approach is now needed to strategically nurture and mature Australian space capability into a thriving space sector that will contribute to an innovation economy and help meet national socio-economic and security needs. The coordination that is required will mature with the space sector, and will go beyond the primarily policy and reporting functions of the Space Coordination Committee (SCC) within the Department of Industry, Innovation and Science. For example, the SCC includes government departments without representation from the legal, industry, university research or education and training sectors. It appears to support rather than develop and enact national strategies, and it is not evident whether international agencies know to approach the SCC when exploring opportunities for space R&D in Australia.

Australia will reach the point where it requires a full-featured Australian space agency, or an equivalent organisation that carries sufficient authority and autonomy to act on behalf of the government, industry and research sectors in negotiating joint arrangements with international partners.

Case study: Singapore

Singapore has successfully built a domestic space capability and space ecosystem through a pragmatic, strategically prioritised approach. Starting in 2013 with similar ingredients to those that exist in Australia, its approach involved government-led coordination, priority setting, and modest funds invested in government-driven space missions to develop the talent pool for industry and help satellite companies grow their business and collaborate with other countries' space agencies. Its whole-of-government approach has built a critical mass of space industry players closely coupled with the Singaporean innovation sector. As a result, Singapore has now developed and launched an Earth observation satellite to meet its own needs, is developing another of greater sophistication, and seeks to move into the same domain that makes sense for Australia—game-changing payloads on small spacecraft, in the high-growth Asia–Pacific market region.

16 http://www.science.gov.au/scienceGov/ScienceAndResearchPriorities/Pages/default.aspx

Our vision is that Australia builds a long-term, sustainable space economy to produce more world-class scientific discoveries and technology, drive innovation, enhance Australia's social capital, and advance national needs. The achievement of this vision would require a coordination framework providing strategic focus and nurturing collaboration between stakeholders.

An Australian space coordination framework would:

- be led at a high level with representatives from across whole-of-government, advised by a panel of scientific, technical, legal and policy experts
- ensure that the needs of defence, national security and civilian activities are met
- promote the advancement of fundamental and applied space science research involving collaboration between national and international groups
- provide a clear, authoritative Australian interface with international space agencies and activities
- provide policy and priority settings so that domestic space capability is developed that delivers a level of sovereignty, helps meet economic and national security needs, generates export earnings, and demonstrates Australia's commitment internationally
- provide modest yet sufficient funding to demand and drive activities aligned with strategic priorities, so that the sector matures in specific capability areas to meet national needs
- foster an environment in which commercial investment in the space sector can grow organically
- foster a broader growth in space-related skills across the innovation sector, through STEM outreach and through opportunities for Australia's young talent to engage in space activities, suitably guided and nurtured, that lead to a space talent pool and a space ideas pool.

New and disruptive capabilities addressing national and community needs are underpinned by a robust science and technology base. Australia has existing world-class research capabilities applicable to space science and technology that can evolve and grow through a focused coordinated strategy addressing priority needs. The space science and technology community spans the university, government and industry sectors, operates at different levels of technology readiness and has many drivers for science and technology investment.

Space science and technology is organised into three broad domains, each of which requires coordination for Australia's national benefit.

SPACE PHYSICS

This includes studies of the Sun, the space environment, the interaction of the Sun's outflowing plasma on the atmospheres of Earth and other planets, and the effects of space weather on human technology. Research priorities include:

- Earth's energy balance and application to climate modelling
- understanding the near space environment (where Earth orbiting satellites operate) to secure technical capabilities underpinning modern society
- reducing the economic impact of space weather through better forecasting
- monitoring crucial environmental phenomena such as the southern ozone hole.

On 24 June 2016, Expedition 48 Commander Jeff Williams of NASA photographed the brilliant lights of an aurora from the International Space Station. Williams wrote, 'We were treated to some spectacular aurora south of Australia today'. IMAGE CREDIT: NASA

PLANETARY SCIENCE

This includes studies of the composition, physical properties and evolution of Earth and other bodies within and beyond our solar system. It is enabled by measurements through space-based remote sensing and in-situ devices (enabled by space-based communication, position and timing capabilities). Research priorities include:

- Earth observation for weather, climate, environment, resource, disaster and national security monitoring, modelling and management
- understanding the origins and evolution of other planets and bodies to better understand our unique Earth
- studies of the drivers of life in space and its interaction with different environments.

Surface and geological processes on other planets deepen our understanding of analogous processes on our unique Earth.
IMAGE CREDIT: MARS EXPLORATION GALLERY, NASA

SPACE TECHNOLOGY AND APPLICATIONS

This includes the development of instruments, mission systems and other technology enabling humans to exploit the space environment for community, commercial and national security needs. Research priorities include:

- innovations that underpin space-based capabilities and services including crucial satellite-based positioning, navigation, timing and Earth observation
- technology and infrastructure enabling the space physics and planetary science goals
- technologies supporting the management, exploitation and delivery of space-based data.

Space technology supports the transition of space science and technology into commercial activities that further build expertise, capacity and economic value in the Australian space community.

According to the 2016 Defence White Paper, Australia is planning investments in modern space capabilities and the infrastructure, information and communications systems that support defence capability [17]. The Next Generation Technologies Fund identified space capabilities as a priority area [18]. The civilian science and technology efforts described in this document would contribute to leveraging the defence initiatives in a whole-of-government approach to addressing research and national security priorities.

The principles for developing the space physics, planetary science, and space technology and applications base are:

- striving for excellence through peer review and international comparison
- balancing competitive and collaborative research and development investment to facilitate transformative approaches
- understanding that learning from failure is a key to long-term success and robust growth
- including industry and end users early to focus on important outcomes.

2. Generating value: creating a thriving Australian space ecosystem based on world-class space science and technology

Australia cannot afford to lose the opportunity to grow its stake in the international space economy. A thriving Australian space industry must recognise and value the whole innovation ecosystem: basic science as the feedstock of industry innovation; and industry innovation which promotes interest in, and economic justification for, basic research. Australia needs to pursue priority areas (outlined in the previous section) in which it can capitalise on this symbiosis. In addition, Australia's role as an international scientific leader supports national and strategic interests.

17 http://www.defence.gov.au/WhitePaper/Docs/2016-Defence-White-Paper.pdf
18 http://www.defence.gov.au/whitepaper/Docs/2016-Defence-Industry-Policy-Statement.pdf

Case study: Satellite-based augmentation system (SBAS)

SBAS involves the use of geostationary satellites to provide integrity and improve the accuracy of GNSS services. Cumulative benefits to the agriculture, mining and construction sectors alone by 2030 are projected to be in the range $32–$58 billion if Australia has a standardised national positioning information capacity[1]. However, according to Geoscience Australia 'there is no coherent national network [of suitable ground stations] due to a lack of policy coordination and industry fragmentation'. A 2011 government review of SBAS concluded that 'any further work on SBAS would need to link with the Government's national space policy'[2]. In January 2017 the Australian Government announced a two-year investigation of the future of positioning technology in Australia.

1 crcsi.com.au/assets/Resources/ffa927a7-55d1-400a-b7d6-9234f4fe4ad2.pdf
2 infrastructure.gov.au/aviation/atmpolicy/files/SBAS_Review.pdf

Our vision is for a vibrant, growing space industry in Australia, developing products and services to support home-grown and international space science and technology projects.

Australia needs to move beyond being a passive consumer of space-based services to embrace the opportunities opening up for products and services derived from new technologies and capabilities.

Specifically, our vision for 2027 is of an Australian space industry that:

- works in partnership with government agencies and research providers and benefits directly from pure and applied space science research
- is internationally connected to the space science and technology community in the Asia–Pacific region, as well as being a recognised global player
- is world-class in several distinct, niche areas of expertise, that include (but are not limited to) small satellite development, instrumentation, propulsion, and a range of space-related services such as precise GNSS position, navigation and timing, as well as remote sensing imagery
- provides high-quality jobs across a range of sectors, including for graduates of tertiary space science and technology programs
- harnesses diverse skills, and has a workforce that reflects Australian society
- addresses domestic demand and stimulates international demand for products and services based on space science and technology
- contributes to the growth of our national environmental, social and economic capital
- is able to connect with other high-tech industries in innovative ways, such as quantum computing and communications via smallsat platforms.

OPPORTUNITIES FOR INDUSTRY GROWTH

- The 2015 National Innovation and Science Agenda provides the impetus to enable collaboration and innovation in space science and technology, in particular through developing R&D partnerships between universities, government agencies and industry, including start-ups and innovative small businesses. These activities could leverage Australia's reputation for world-class space science and its geographic and geopolitical advantages, and build on global and regional partnerships.
- Many major domestic programs are expanding their requirements for space science. These include national defence, Australia's engagement in space situational awareness, GNSS and Earth observation, space weather prediction and mitigation within the Bureau of Meteorology, and the growing requirement from the radio astronomy community to characterise the ionosphere.
- Miniaturised electronics and hardware, such as the CubeSat platform, have significantly reduced entry barriers to space, enabling small nations, commercial players, university student teams and even schools to become space faring. Achieving this with reliability in the harsh space environment is a significant step. Australia has an immediate opportunity to lead through the deployment to space of innovative, disruptive and potentially game-changing Australian applications on small spacecraft, such as:
  - quantum sensors that can yield precision measurements many orders of magnitude better than anything currently available
  - quantum and laser communications capabilities that can put Australia at the forefront of global secure communications developments
  - compact laser systems able to sensitively monitor atmospheric carbon cycle behaviour fundamental to climate change

Case studies

CRC for Spatial Information

Over two rounds of funding, this cooperative research centre has brought together academia, federal and state government agencies and over 50 companies to undertake R&D in geospatial technology, particularly in support of critical infrastructure including health, energy, agriculture, defence and urban planning. The CRCSI is expected to deliver outcomes worth $733 million, producing a benefit of $2.50 for each $1 invested. Starting in 2017, the CRCSI is partnering with Geoscience Australia and domestic and global partners to evaluate SBAS technology to improve the accuracy of GPS signals. The CRCSI has been at the forefront of exponential growth in geospatial positioning applications, but under CRC funding rules will wind up in 2018.

Myriota start up

In June 2017, Myriota was named Best Industrial Start Up Company and second best company overall at the world's largest internet of things (IoT) summit held in San Francisco. The Adelaide company has developed a low power, ultra low cost satellite IoT communications platform for data transmission from remote locations via LEO nanosatellites. Applications include agriculture, transport, utilities, logistics, mining and defence. There is a vast market for global low cost IoT connectivity. Myriota was founded in 2015 by Professor Alex Grant and Dr David Haley from the Institute for Telecommunications Research at the University of South Australia. Grant's strong background in wireless communications and Haley's work on the Australian microsatellite FedSat provided the experience and motivation for developing satellite-based communication technology.

Saber Astronautics

Co-founded by Dr Jason Held and Dr Dan Bunker, Saber Astronautics uses academic rigour and modern tools such as machine learning analytics and artificial intelligence to deliver cutting edge space certified mission control software. It also has a focus on technology to safely deorbit CubeSats, which soon are expected to proliferate in low Earth orbit. Due to the lack of a space economy in Australia, Saber Astronautics established a US subsidiary with experience in the US military sector. Saber also established a popular space internship program to attract and grow local talent, and is now a partner in an ARC Industrial Transformation Training Centre for CubeSats, Unmanned Aerial Vehicles, and their Applications, awarded to the University of Sydney in June 2017.

Atmospheric radio occultation

Radio occultation (RO) uses GPS signals to sound the upper atmosphere with high cadence, global coverage, and in all weather. It is the most precise technique for determining atmospheric temperature and hence is important in climate forecasting and modelling. A joint venture between the SPACE Research Centre at RMIT University and the Bureau of Meteorology has used RO to improve weather forecasting in the Australian region by up to 10 hours, and RO is considered one of the top data sources used to reduce forecasting error. The COSMIC (Constellation Observing System for Meteorology, Ionosphere, and Climate) microsatellite network, developed by the Taiwanese National Space Organization with US technical support, is the primary data source for such work worldwide. This is an example of the type of regionally and globally important niche space science activity Australia could undertake.

Space Weather Service (SWS)

The SWS in the Bureau of Meteorology monitors the ionosphere and space environment responsible for space weather effects that may impact Australian societal, industrial, economic and security activities. It operates an array of ground sensors and accesses satellite and ground data from international partners. Space weather services are provided for a range of civilian and government customers, in particular defence. An external review of the SWS in 2014 found an overwhelming requirement for Australian sovereign capacity in this area, and that the SWS 'is in the top tier of global space weather centres and arguably globally preeminent in ionospheric high frequency space weather services'. The SWS operates the World Data Centre for Space Weather on behalf of the International Council of Scientific Unions.

– world-class capabilities in distributed autonomous systems
– ability to develop hyperspectral remote sensing systems for water quality monitoring, agricultural biosecurity and national security applications
– transformative new applications of precision GNSS services, space science and data analytics in developing smart cities through distributed communications, advanced transportation systems and robotics, and in agriculture and mining
– expertise that can contribute to global efforts to understand the space environment and its effects on daily life on Earth.

- Australia will host major international space science and technology related conferences, including the International Astronautical Congress 2017 and the COSPAR (Committee on Space Research) Congress in 2020. These will provide opportunities to showcase Australian space capability on the international stage, and for Australian government, research and industry sectors to establish new international partnerships and access new customers.

Australia's space industry is currently fragmented, comparatively small relative to opportunity, and vulnerable. With the right policy support Australia can mobilise the sector to create a world-leading space industry, based on innovative and niche products, in a relatively short time. The solution is to create an environment which:

- encourages coordination and collaboration across the sector
- incentivises a focus on priority research areas
- enables long-term planning and substantial investment in R&D by the space industry
- supports strategic capacity building within industry
- facilitates enduring relationships between government, industry and research providers such as universities.

World-class space science research and technology development is already being conducted in Australia. Such excellence is found within industry, but often has been fostered in partnerships between industry and government or academia. The key to growing the volume of innovative space-related products and services is to incentivise the establishment of long-term partnerships, so that the proverbial 'whole is greater than the parts' amplifies the pockets of strength and skill that the Australian space industry possesses as well as harnessing complementary capabilities across the space science and technology sector.

3. Capability development: education, outreach and training

Australia's Chief Scientists have clearly described the critical importance of STEM engagement to secure Australia's social, cultural and economic prosperity. To address Australia's declining performance they have advocated a strategic whole-of-government, multisector approach through a high-level coordinating agency[19]. This parallels the current situation for space science and technology.

Space science is one of the 'wow sciences' that deals with inherently fascinating topics for many people. It has a key role to play in Australia's efforts to grow STEM engagement at all levels—space science and technology activities can be both inspiring and informative at community, school and tertiary levels. Many formal and informal space-related education outreach activities have developed across K–12, undergraduate, postgraduate and public audience spheres. Mostly these evolved as individual or localised initiatives. The inspirational nature of space exploration is widely recognised as both an enabler and a driver.

Our vision is that Australia develops a major education, training and outreach capacity based on space science and technology that helps develop human and social capacity through stimulating talent, improving scientific literacy, and exciting innovative thinking across a range of sectors.

Hands-on activities such as CubeSat development provide tremendous opportunities for STEM and industry engagement[20]. Programs such as iSTEM engage secondary students in enrichment activities not normally available at schools and focus on space science and technology. Other activities include programs such as the Mars Yard at Sydney's Museum of Applied Arts and Sciences (the Powerhouse Museum) and the Victorian Space Science Education Centre (VSSEC). Both of these centres have significantly increased the understanding of science among high school students attending these programs[21]. Other examples include Space Camp (both in Australia and travelling to the US Space Camp) and the South Australian Space School.

A number of undergraduate and postgraduate courses are now on offer. These include several courses at UNSW Sydney and Canberra, including one space postgraduate course, supported by the Australian Space Research Program.

Broader community education is not as well developed as the formal education sector. The challenge is to engage with public audiences as a unified, coherent space science program. Currently many organisations communicate their space-related news sporadically and in isolation of the work

19 Science, technology, engineering and mathematics in the national interest: a strategic approach, Office of the Chief Scientist, July 2013; Science, technology, engineering and mathematics: Australia's future, Office of the Chief Scientist, September 2014; Australia's STEM workforce: Science, technology, engineering and mathematics, Office of the Chief Scientist, March 2016.
20 Examples overseas include the NASA CubeSat Launch Initiative and the UK FunCube.
21 Astrobiology outreach and the nature of science: The role of creativity, *Astrobiology*, (2012) https://www.aca.unsw.edu.au/sites/default/files/publications/Fergussen, Oliver and Walter 2012.pdf

Case studies

Mars Yard

The Mars Yard at the NSW Museum of Applied Arts and Sciences was established in 2011 and—as intended from the outset—is now self-supporting. It serves thousands of students from their classrooms in schools across Australia and internationally as well as continuing with a strong planetary robotics research program. The 140 m^2 Mars Yard is the largest of its kind in a public space in the world and frequently hosts high-level international visitors, including from NASA. It was established with $2.9 million from the Australian Government's Australian Space Research Program and Broadband Enabled Education and Skills Program.

Students on the Mars Yard with the experimental Mars rover Mawson (right) and the student rover Snickers.

IMAGE CREDIT: LEFT, UNSW SYDNEY. RIGHT, WWW.THEMARSLAB.ORG/LAUNCH-OF-MARS-YARD-MAPS/

Victorian Space Science Education Centre (VSSEC)

VSSEC was established by the Victorian government in 2006 as a specialist science education centre. VSSEC promotes and demonstrates science education using space as a context, through a range of programs across primary, secondary and VET levels (including a CubeSat program involving eight schools in South Australia). The signature program revolves around a simulated Mars landscape and a mission control centre. Emphasis is on learning by doing and teamwork. VSSEC programs are integrated with classroom activities and embedded within the school curriculum. Professional development is provided to teachers. VSSEC receives support from university collaborators and agencies such as NASA, ESA and JAXA. It has hosted industry days, visits by astronauts, and the annual VSSEC–NASA Australian Space Prize.

Obelisk Systems and StarLAB

Based in the Hunter Valley, Obelisk Systems began as an aerospace and biotech company with a primary focus on the development of CubeSat technologies and a secondary focus on the development of prosthetic limbs. Obelisk was contracted to design CubeSat boards that would be flown to the International Space Station to provide students with a direct connection with space. It has since developed a STEM project based on developing sensors, software and hardware to drive a Mars Rover, with associated online learning modules. Starting in 2017 students can participate in a National Mars Rover Challenge.

being done by other groups. In contrast, the ability to engage audiences with space in Europe, the UK, China, the US and India is significantly more advanced because there is a central coherent story despite many different efforts under those umbrellas. This promotes the awareness of a coordinated effort and public support for space science activities, which in turn promotes the perception of an innovative, high-tech nation. Australia would have much to gain through the presence of a national space organisation—beginning with a national coordination framework.

Many talented Australians have moved overseas to be involved in or lead space-based education, research and industrial programs. The inevitable growth in opportunities in a maturing Australian space industry will provide incentives for the return of expatriates, with associated knowledge transfer. In this way, Australia has the opportunity to turn an 'education brain drain' into an innovation diaspora.

Opportunities for capability development include:

- increasing awareness among high school students and career advisers that maintaining subjects such as mathematics and physics will broaden students' career options, and by developing nationally accessible resources to provide an overview of space careers and opportunities in Australia
- unifying individual education outreach programs into a genuinely strong and accessible network, with the support of an Australian Government-led focus on STEM education, particularly by the Office of the Chief Scientist
- increasing K–12 curriculum development that uses the inherently inspirational nature of space as a way of generating interest in STEM
- supporting tertiary training until K–12 education efforts flow through into increased undergraduate numbers. There is currently a risk that Australia could lose this capability before it becomes financially viable within current university business models.

4. Major initiatives

Australia has a unique opportunity in the coming years: to unify Australian space science around challenges and capabilities of national importance.

The 2010 Decadal Plan for Space Science identified potential major projects that could make the most of this opportunity. This vision statement does not focus on specific projects but recognises the benefits of unified activity in a relatively undeveloped and fragmented sector that aims to solve big, important problems. Examples could include:

- leading the development of CubeSats as a national capability
- understanding and managing impacts of space weather
- improved tracking and de-orbiting or managing space debris
- developing a comprehensive ground-based sensor platform providing input to national positioning, Earth observation, surveillance programs, and national and global space weather programs.

Our vision for 2027 is a united Australian space research community that is strategically focused on a small number of major challenges and capabilities of national importance.

Top: Orbital ATK's Cygnus cargo spacecraft is captured using the Canadarm2 robotic arm on the International Space Station. IMAGE CREDIT: NASA

Above: The Deep Space Station 43 (DSS-43), a 64 metre antenna, was completed in April 1973 allowing communications with missions farther from Earth. Upgraded to 70 metres in diameter in 1987 to support Voyager 1 and 2, DSS-43 became the largest steerable antenna in the southern hemisphere (Canberra). IMAGE CREDIT: NASA

Vision statements

1. Our vision is to strengthen space science and technology in Australia. This will:
   - support fundamental sciences and related fields such as astronomy, atmospheric and Earth sciences
   - grow the supply of highly trained workers, allowing the expansion of innovation industries
   - amplify the economic, defence and educational benefits of space science services
   - help improve Australians' understanding of science.
2. Our vision is that Australia builds a long-term, sustainable space economy to produce more world-class scientific discoveries and technology, drive innovation, enhance Australia's social capital, and advance national needs. Achieving this requires a coordination framework providing strategic focus and nurturing collaboration between stakeholders.
3. Our vision is for a vibrant, growing space industry in Australia, developing products and services to support home-grown and international space science and technology projects.
4. Our vision is that Australia develops a major education, training and outreach capacity based on space science and technology that helps develop human and social capacity through stimulating talent, improving scientific literacy, and exciting innovative thinking across a range of sectors.
5. Our vision for 2027 is a united Australian space research community that is strategically focused on a small number of major challenges and capabilities of national importance.

During an International Space Station flyover of Australia, NASA astronaut Jeff Williams captured a colourful image of the unique terrain of the northwestern Australian coast. IMAGE CREDIT: NASA

Recommendations

Recommendation to the Australian Government

KEY PRIORITY

Together with the space industry and research sectors, establish a National Space Coordination Framework.

In the near term, a coordination framework for space science and technology will support the Australian space sector to innovate and mature.

A National Space Coordination Framework should:

- include whole-of-government representation including Defence
- be advised by an expert panel
- provide authoritative coordination and priority setting, and a degree of strategic funding to focus the sector towards achieving a level of sovereignty that meets Australia's needs
- be substantive and demonstrate commitment internationally.

This coordination framework could be developed by a new and dedicated agency, or it could precede and lay the basis for an Australian space agency in the medium term.

Recommendations to the Australian space science community

KEY PRIORITY

Build space science community coordination through establishment of a community database and peak body.

A peak body should:

- help the space science community self-organise
- foster communication within the space science community
- include representatives of research, academia, government and industry.

Expedition 52 Flight Engineer Jack Fischer of NASA captured this glowing green aurora seen from 250 miles up, aboard the International Space Station. IMAGE CREDIT: NASA

OTHER RECOMMENDATIONS

Encourage space scientists to better promote the benefits of their work and their community to the media (e.g. through the Australian Science Media Centre).

Improve communication between the National Committee for Space and Radio Science and the Space Industry Association of Australia.

Engage more widely in community-building activities in addition to the annual Australian Space Research Conference, including workshops, focus group meetings, and a stronger presence at the Australian Institute of Physics National Congress.

A vision for space science and technology in Australia
Securing and advancing Australia's interests through space research