2010-2019

Decadal Plan for Australian Space Science

Building a National Presence in Space

National Committee for Space Science
Australian Academy of Science

VISION:

Build Australia a long term, productive, presence in Space via world-leading innovative space science and technology, strong education and outreach, and international collaborations.

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Main cover image and theme images throughout the Plan represent: The ribbons of a solar flare or active region; the sheets of the aurora on Earth and other planets; channels, wadi, and other geographic features on Earth, Mars, other planets, and moons; and biological mats and films.
Top panel of cover page: Artistic view of Earth from space.

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Decadal Plan for Australian Space Science

Building a National Presence in Space

AUSTRALIAN ACADEMY OF SCIENCE
NATIONAL COMMITTEE FOR SPACE SCIENCE

Australian Academy of Science

Foreword

Space science impacts daily on our lives, whether through communication and navigation, our weather reports or the monitoring of the state of our planet. While driving many of the technological advances of the past half century, it has allowed us to leap beyond Earth to explore nearby planets and beyond and provided new understanding of the evolution of the universe and our position within it.

Australia and Australian scientists have made many contributions to space science since the 1950s, mostly on an opportunistic basis, through individual efforts or because Australia's geography is key to successful space missions.

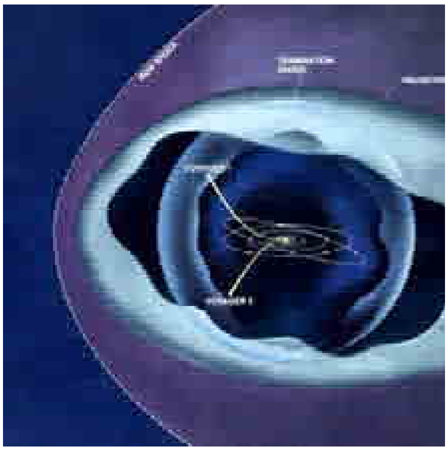
The Academy believes that greater benefits to Australian science and technology, and to the Australian community more broadly, can be achieved by international engagement in space research. This is why its National Committee for Space Science was tasked with preparing a forward-looking document on the potentials for Australian involvement. The report complements an earlier report, prepared jointly with the Australian Academy of Technological Sciences and Engineering, that provides an analysis of opportunities arising from Earth Observation from Space.

The current report embraces a number of exciting space science initiatives that could form the basis for a renewed national effort in this important area. The Australian Academy of Science welcomes the report and encourages discussion on its proposals.

Kurt Lambeck AO, Pres AA, FRS

(President, Australian Academy of Science)

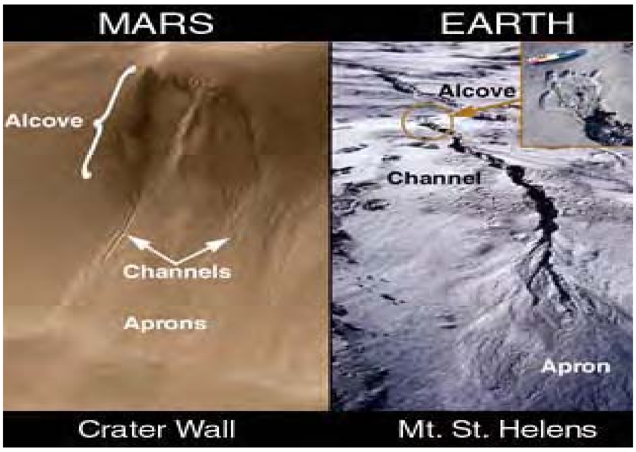
Data • Modelling • Theory • Computation • Education • Training



Solar System

Sun to Earth

Earth Observation & Climate



Planetary Evolution & Life

Space Missions & Technology

Ground Instuments & Antarctica

National Committee for Space Science (NCSS)
Australian Academy of Science

Building a National Presence in Space

Context for Space Science and the Decadal Plan

'Space' refers to multiple regions from Earth's middle atmosphere (about 40 kilometres above Earth's surface) to the Sun, the edge of the solar system, the galaxy, and eventually the distant Universe. In Australia 'astronomy' focuses on radio and optical observations of the galaxy and distant Universe, coordinated via a current decadal plan for astronomy, while 'space science' refers to study of the solar system, the region of space most important to humanity. 'Earth observation' from space, often called remote sensing, is a field of space science strongly connected to operational and applied interests, both commercial and government.

This document presents the first Decadal Plan for Australian Space Science, hereafter called 'the Plan'. It provides a consolidated vision for space science and technology in Australia, a case for why Australia should invest in a world-class space capability, and a research and education program to develop this capability.

The Plan includes Earth observation from space. A related standalone document describes a new Australian strategic plan for Earth observations from space[1], developed jointly by the Australian Academy of Science and the Australian Academy of Technological Sciences and Engineering (ATSE), that emphasizes the operational needs. The mid-term review of the Plan in 2014-2015 may result in an updated Plan in two parts, one for the solar system as a whole and one for Earth observation alone.

The Plan was released in draft form for public comment on 29 February 2008[2]. It predated and partly informed and motivated the August 2008 Cutler Report 'Venturous Australia'[3], the November 2008 Senate Report 'Lost in Space'[4] and the government's major investments into space announced in the May 2009 Federal Budget.

Indeed 2009 was a historic year for space research in Australia. The Australian Government made 'space and astronomy' one of three research areas in the Super Science Initiative. It also created the $40 M Australian Space Research Program and the Space Policy Unit. Government now recognizes the importance of space, both in the civil domain but also in the Defence White Paper.[5]

This final version of the Plan incorporates significant feedback on the Draft Plan. It complements and builds upon, but is not predicated on, the government's 2009 initiatives.

1 *The Australian Academy of Science and the Australian Academy of Technological Sciences and Engineering 'An Australian Strategic Plan for Earth Observations from Space', J. Zillman et al., July 2009.*

2 *Draft Release (29/2/2008_V3), First Decadal Plan for Australian Space Science, I.H. Cairns et al., 2008.*

3 *'Venturous Australia', T. Cutler & Company, 2008.*

4 *'Lost in Space? Setting a new direction for Australia's space science and industry sector' The Senate Standing Committee on Economics, A. Hurley et al., 2008.*

5 *'Defending Australia in the Asia Pacific Century: Force 2030', Defence White Paper 2009.*

Vision and Imperatives

The Plan's vision is 'Build Australia a long term, productive presence in Space via world-leading innovative space science and technology, strong education and outreach, and international collaborations'. The Plan was written with five key imperatives in mind:

(1) Enable Australia to develop a strong national capability in space science, technology, data, and assets that will benefit the nation in international, economic, and environmental affairs, partly support a space industry, and offset the risks of depending primarily on foreign space capabilities.

(2) Position Australians to solve major scientific and technological problems by empowering its space scientists to lead and participate in acclaimed national and international space projects, involving ground- and space-based experiments and theoretical modelling.

(3) Actively nurture, coordinate, and manage Australia's investment in space science so as to produce important scientific discoveries and technology.

(4) Leverage increased public investment in space science to strengthen the fundamental sciences and related fields (astronomy, atmospheric, and Earth sciences), provide better understanding of global issues like climate and environmental change, produce innovative highly trained workers and science- and mathematics-literate citizens, increase the economic benefits of space services, and mitigate space-related disruptions of the economy, government, and society.

(5) Provide government, community and business with the information needed to guide investment in space science and technology and to obtain the associated strong national and international benefits, ranging from national security to environmental integrity, education and training, and international prestige.

This Plan document outlines the importance and current status of space science in Australia, and the specific (but not proscriptive) scientific goals of the Australian space science community for the period 2010-2019. Actions are recommended that build on and extend existing Australian strengths in research, that develop our nation's capabilities while achieving these goals, and that will enhance collaboration domestically and with international partners.

The Steering Committee and the National Committee for Space Science

Contents

Note that Appendices F – O predate completion of the Decadal Plan. Accordingly the recommendations and information in these Appendices are extended and superceded by those in the Decadal Plan itself.

Appendix P, the standalone joint Academies strategic plan for Earth observation from space, is provided here for convenience.

Appendices F – P are available on the accompanying CD.

Executive Summary

Executive Summary

'Space science' refers both to the science that can be done from space and the science of space. It includes everything from Earth's middle atmosphere (from about 40 km above Earth's surface) to the centre of the Sun and the boundaries of the solar system, including the planets, observing Earth from orbit (remote sensing), planetary geology and atmospheres, climate change, development of life, and requisite space technology.

Space science is a key component of Australia's scientific landscape. Space phenomena are key drivers of numerous Earth system processes. They also provide unique opportunities for unexpected and exciting discoveries in the enabling and applied sciences and engineering. Space science is both an existing and an emerging area of strength for Australian science and technology.

The National Committee for Space Science (NCSS) and Australia's space scientists present here the first Decadal Plan for Australian Space Science and outline the level of support necessary to accomplish the Plan's goals.

The Plan describes the collective vision and recommendations of the Australian space science community. It is for an enhanced, recognizably Australian, innovative, well supported, national space science program that:

- develops a world-recognized space capability and related infrastructure for Australia;
- performs world-class scientific and technological research, both fundamental and applied;
- enables provision of improved space-related services and innovative products;
- increases the numbers and scientific/engineering literacy of school and university students and Australia's workforce, reversing current trends; and
- better positions Australia's economy, government, and society in the world.

Australia should invest in the Decadal Plan for Australian Space Science, bearing in mind the strong context provided by the new operationally-focused joint Academies strategic plan for Earth observation from space[1], because:

(1) Space science has strong national and international benefits for Australia (Detail Boxes 1 and 2) and a natural focus on Australasia and Antarctica, especially via observations of Earth from space.

(2) Space Science is inspirational and well suited to education and training in the fundamental sciences, mathematics, engineering, and commerce.

(3) Space science produces crucial discoveries and capabilities for modern society, eg:

   - the dynamic Sun and solar wind, and their impacts on Earth;
   - operational GPS navigation, timing, and geodetic services;
   - Earth observation (eg weather, environment, disaster monitoring, and national security) and communication satellites;
   - the greenhouse effect and global warming on Earth and Venus;
   - space weather effects on GPS, radio communications, spacecraft operations, geomagnetic prospecting, pipelines, & other critical systems;
   - rapid formation and evolution, and the geology and hydrology of the Earth, Moon, Mars, asteroids and meteorites in the solar system;
   - rapid emergence of life on Earth and perhaps the solar system; and
   - the ozone hole over Australasia and Antarctica.

(4) Space science naturally promotes a global view, which is increasingly vital for a finite world with a strongly coupled economy and ecosystem, and yet links Earth science to the distant cosmos.

(5) Space Science provides strong potential for productively linking Australian universities, government departments (eg Defence; Environment, Water, Heritage and the Arts (DEWHA); and Innovation, Industry, Science and Research (DIISR)) and units (Australian Antarctic Division, Bureau of Meteorology, CSIRO, Defence Science and Technology Organisation, Geoscience Australia, and IPS Radio and Space Services), domestic and international industry, other professions (eg engineering, education, and business), professional societies, and the public.

(6) Australia has world-leading space scientists doing visionary, state-of-the-art, innovative science and technology research.

Figure 1: The proposed entity CASS (Coordination of Australian Space Science) works with government to connect and leverage Australia's space science interests and capabilities (universities, government units, and industry) into a national effort. Resulting national benefits are shown in gold text and the Plan's major reseach projects in white text, including SpaceShip Australis (SSA), Marabibi Constellation, International Collaborations and Future Opportunities (ICFO), and Sundiver. The link to the proposed National Institute for Space Science (NISS) is also shown. CASS will work with government to connect Australia's space effort to international space agencies and industry.

(7) The proposed research effort is high value, low expense, and has a high multiplier benefit. Over the next 10 years it includes:

   (a) Investment into new large projects that build capability, develop community infrastructure, and address broad-themed fundamental and applied science at an indicative cost of almost \$140 M[6], being

   - less than \$1 per Australian per year.

   (b) Development of a real, active Australian presence in space with multiple, strong, international collaborations and links (Figure 1):

   - A new entity CASS Ltd (Coordination of Australian Space Science) to manage investment and link Australian stakeholders;
   - A new National Institute for Space Science (NISS) that builds capability, computation and theory skills, and data networks across space science;
   - New science themes and specific (but not proscriptive) goals determined and agreed to by the Australian space science community;
   - A ground-based state-of-the-art network (SpaceShip Australis) to make Australasia the world's best instrumented and modelled region for predicting space weather from the Sun to the ground;
   - A flexible, long term, indigenous space capability, built via the novel Marabibi Constellation of nano, micro, and small satellites, that pursues world-first, student-focused, research on space weather, space technology, and Earth observation;
   - A new program (ICFO) to fund Australian participation in future international space efforts (eg human medicine, Earth observation, & exploration);
   - Major education, training and outreach programs that build new capabilities and leverage existing capabilities;
   - Medium-sized collaborations that build capacity and infrastructure while pursuing major research innovations from digital radars to image analysis laboratories to propulsion;
   - Development of a capability for interplanetary and planetary spacecraft projects, via a design study of a concept (Sundiver) with multiple novel capabilities and visionary science goals.

This vision is compatible with a longer duration and fiscally enhanced version of the government's 2009 Australian Space Research Program, with CASS a natural complement to the Space Policy Unit. The combined research and infrastructure efforts envisaged will lead directly to international collaborations on space, provide a natural path towards the proposed National Institute for Space Science, and fit elegantly into a future Australian Space Agency. The Plan will develop a strong, internationally recognized, Australian space capability, create active partnerships of Australian and international stakeholders in space, and provide strong economic, educational, government, and strategic benefits to Australia.

6 In 2009 Australian dollars with exchange rates as of September 2009. Here and below all \$ symbols refer to Australian dollars and US\$ to American dollars. The symbol AU\$ is only used only where necessary to avoid confusion.

DETAIL BOX 1 – National Benefits of Space Science

The benefits to Australia of a coordinated national effort in space science include:

(1) Enhanced human capital (education, training, skills, and literacy) due to the exploratory, inspirational and interdisciplinary nature of space science, which increases study of the 'enabling' sciences, engineering, business, law, and human aspects of space.

(2) Inspiration for Australians to achieve internationally significant research goals and to develop global perspectives.

(3) Improved capabilities in space applications and services for both public good and commercial entities, related to upsets in critical infrastructure (eg communications and GPS) and important public services (eg monitoring and forecasting weather and climate, national mapping, assessing and managing natural resources, and reducing natural disasters).

(4) Development of a world-recognized space capability that increases the Nation's technical and public standing and supports Australia's territorial claims and involvement in United Nations and other international bodies related to space and global issues.

(5) New discoveries in the fundamental science and technology of space that address national research priorities, as well as crucial applied science and services, and build upon existing world-leading Australian efforts.

(6) A unique point of contact to Australia's space capability for international and domestic partners, whether industry, government, education, or public outreach.

(7) A complete and diversified research portfolio for Australia, since space science links Earth science to the nearby stars and distant cosmos but also has many practical benefits.

(8) An increased focus on Australia's and humanity's local environment, which is Earth and the solar system (ie space science).

DETAIL BOX 2 – Plan's relevance to current National Research Priorities (NRPs) and Priority Goals (PGs)

The Plan directly addresses the first priority area, 'space and astronomy', of Australia's 2009 SuperScience Initiative, as well as all four NRPs and numerous PGs, with science driving technology and vice versa.

NRP 3, 'Frontier Technologies for Building and Transforming Australian Industries' because the Plan involves:

- PG 'breakthrough science' across the entire gamut of space science, from solar eruptions to space weather at Earth, to ionospheric variability and climate change, to formation of planets and moons, to the evolution of life;
- PG 'frontier technologies' due to world leadership by Australian space scientists and technologists in radars, spacecraft propulsion, advanced isotopic and chemical analyzes, communication antennas, software architecture, and timing electronics, for example;
- PG 'advanced materials' for instrument design and spacecraft structure; and
- PG 'smart information use' for studies of spacecraft software architecture and design (eg using internet protocols, not proprietary code) and the accessing and analysis of electronic data.

NRP 4, 'Safeguarding Australia', because the Plan addresses:

- PG 'critical infrastructure' via the prediction and mitigation of space weather disruptions on vital infrastructure for government, industry, and society, both for space-based assets (eg communications, GPS, remote sensing, disaster monitoring, geodesy, and weather prediction) and ground assets (eg JORN radars, high-tech factories, mineral prospectors, and pipelines);
- PG 'transformational Defence technologies' associated with extending and developing the above space- and ground-based technological infrastructure, Earth observation, mitigation and prediction of space weather effects, and developing access-to-space technology that informs development of strategic high-speed transport; and
- PG 'protecting Australia from invasive diseases and pests' through Earth observation, via remote sensing of changing fauna, vegetation, and environmental conditions.

DETAIL BOX 2 – Plan's relevance to current National Research Priorities (NRPs) and Priority Goals (PGs)

NRP 1, 'An Environmentally Sustainable Australia', due to the Plan's research on Earth observation, planetary geology, astrobiology, and space technology:

- PG 'Responding to climate change and variability', via models of Earth's atmosphere, meteorology, and climate change, studying the ancient and recent geological and fossil records, analyzing geodetic and remote sensing data, and development of 'clean skies' flight technology;
- PG 'Water - a critical resource' via Earth observation data and associated atmospheric, geological, and astrobiological data analyzes and models;
- PG 'Overcoming soil loss, salinity, and acidity' by coupling Earth observation data to expertise in planetary geology, astrobiology, and agriculture;
- PG 'Transforming existing industries' using evidence-based models, geodesy, and other Earth observation data. Examples are water and environmental conditions (agriculture and town planning) and minerals and magnetic fields (mining); and
- PG 'Sustainable use of Australia's biodiversity' involves all the above.

NRP 2, 'Promoting and Maintaining Good Health', due to the Plan's research on human aspects of spaceflight, medical aspects of radiation, and space weather research:

- PG 'Ageing well, ageing productively' since medical experiments in space are identifying biological mechanisms for aging, and radiation dosimetry research informs medical science; and
- PG 'Preventive healthcare', because space experiments show diet can reduce radiation damage, while space weather research can reduce radiation exposure.

Chapter I
Space Science and its Importance to Australia

Chapter 1

Space Science and its Importance to Australia

1.1 Introduction

Space is all around us. Without knowing it, every Australian uses, needs, and is at the mercy of space. Every day Earth is bombarded by deadly solar radiation and cosmic rays; every hour satellites pass overhead watching the Earth for us; every minute people use space communications for their news, television, mobile phones, and to navigate cars, planes, and boats. Energy from space drives the weather and without satellite data we cannot predict the weather accurately. Australians rely on space – and space science – for commerce, entertainment, transport, Defence, safety, and the environment. We use space for police and military work, to discover minerals, identify and interpret changed environmental conditions, and to detect bushfires. Global warming cannot be tackled without space data. Space is also a unique source of inspiration, with the potential to draw young and not so young Australians into science, engineering, mathematics, and other studies that develop their talents into capabilities increasingly needed by the nation. It has the ability to inspire the Australian public to take pride in its skills and to join international partners in exploring one of humanity's frontiers, the solar system.

Australia has world-class space scientists. We lead the world in specific areas of space science, and have a geographical footprint with unique strengths for space science. Yet Australia is only now developing a strategic plan and government program for space.

Space science is a primary strategic focus for international research and is actively promoted by most of the world's governments. The reasons given here (Detail Boxes 1 and 2) and by other countries for investing in space include inspirational fundamental science and technology, applied science and services of direct societal importance, national pride and prestige, the development and maintenance of expert capability in science and technology, and cultivation of commercial and governmental interests.

These latter needs are especially significant. The value of space science to the national interest is growing in all countries. Space science increasingly:

- underpins modern communications infrastructure;
- encompasses critical areas of environmental monitoring (eg tracking bushfires, monitoring water supply and crops, and evaluating weather patterns); and
- is a growing area of interest for national Defence organizations.

The world's investment in space science and technology is of order one trillion dollars per year. This stimulates major economic activity: the 'multiplier' or 'spin-off' factors, meaning the ratio of resulting economic turnover compared with government or other direct investments in space, are estimated to be 3-5 for Norway, the UK, and the USA[7].

The increasing sensitivity of the world's infrastructure to space phenomena leads to unprecedented possible future economic risks: if the 14-15 May 1921 space weather event occurred now, it is predicted that the US power grid would be severely damaged, with long-term blackouts, chronic shortages and economic dislocations for 4 months to 10 years, with a price tag greater than US$1 trillion[8]. Australia would suffer huge costs.

Many other aspects of terrestrial infrastructure (eg communications and transport), space systems, and human society depend on space. For instance[8]: (1) Repeating an airborne or seismic survey, or repositioning an oil rig, due to loss of GPS positions, can cost $50 K to over $2 M[9]. (2) Rerouting high-latitude flights to avoid high radiation levels costs $10 - $100 K per flight. (3) Many satellites have been degraded or lost due to space weather. Examples include[8] the Anik E2 satellite in 1994, whose on-orbit restoration cost over US$50 M, and loss of the US$640 M ADEOS satellite in 2003, with the US$150 M SeaWinds instrument.

Space has major strategic importance for nations. One of the principles of the USA's October 2006 National Space Policy is that the USA 'considers space capabilities – including the ground and space segments and supporting links – vital to its national interests.' Australia's Department of Defence increasingly thinks this, recently acquiring a US Defence communications satellite valued at over AU$1 billion.

Australia's Government engages in space-related activities for strategic, economic, and social reasons. Its Space Engagement Policy Framework has four themes:

(1) Ensuring access to space services;

(2) Supporting world-class science and research related to national priorities;

(3) Growing Australian space industries; and

(4) Safeguarding Australia's national security.

The Decadal Plan developed here addresses these themes. It is closely aligned with Australian Government needs.

The National Committee for Space Science (NCSS; Appendix A) of the Australian Academy of Science aims to foster Australian space science and to link the Australian community internally and internationally. To achieve this, NCSS developed this Decadal Plan for Australian space science through a Steering Committee (Appendix B) composed of scientists and other expert stakeholders from universities, government units, and industry. The Steering Committee created 10 Working Groups on specific topics with wide representation and expertise – involving over 100 people (Appendix C) – and has written the Plan with comments from many additional people (Appendix D).

The Plan and its components have been presented, discussed and approved at eight major workshops and conferences (Appendix E), including meetings of the Australian space science community.

The Plan has been endorsed by major stakeholders, including the:

- Australian Academy of Science and its National Committees for Antarctic Science, Astronomy, Earth System Science, and Space Science;
- Australian Academy of Technological Sciences and Engineering (ATSE);

7 *OECD, The Space Economy at a Glance 2007.*

8 *'Severe Space Weather Events – Understanding Societal and Economic Impacts Workshop Report', National Academy of Science (USA), http://www.nap.edu/catalog/12507.html, 2008.*

9 *Here and below $1000 is denoted $1 K and $1,000,000 is denoted $1 M.*

- Australian Centre for Astrobiology, University of New South Wales;
- Solar Terrestrial and Space Physics Group of the Australian Institute of Physics;
- The Geological Society of Australia's Specialist Group in Planetary Geoscience;
- Australian Space Industry Chamber of Commerce;
- Mars Society Australia;
- National Space Society of Australia; and the
- Victorian Space Science Education Centre.

This first Decadal Plan for Australian Space Science outlines the collective vision and aspirations of the Australian space science community. It presents a new and exciting strategy for space science in our country.

I.2 The Importance of Space Science

Space science is a key component of Australia's scientific landscape (see Detail Box 3). In general terms, 'space science' refers both to the science of space, meaning here everything in our solar system beyond about 40 km of Earth's surface, and to the science that can be done from space. Both aspects of space science have considerable significance for our country. Space-derived phenomena are important drivers of numerous Earth system processes and space science also provides unique opportunities for unexpected and exciting scientific discoveries.

The Sun is the ultimate driver of Earth's biosphere, human society, and the whole Earth system, including the circulation properties of the atmosphere and ocean. The Sun's variability influences climate and leads to space weather effects. Accordingly, many remote sensing and Earth observation data (including GPS, geodetic, and Global Navigation Satellite System (GNSS) data) depend intrinsically on space. This is not just because of the observing location and space weather, but also because many terrestrial regions probed with these data are coupled to space via solar radiation, energetic particles, and varying magnetic and electric fields. Understanding these effects is thus vital to Australia's use of Earth observation data. Australia should therefore aim to have a space capability that encompasses the whole of space science, not just Earth observation. Conversely, Earth observation should be an important part of Australia's space capability.

In the following pages, the importance of space science for Australia is described within the context of:

(i) our growing understanding of the impact that space itself has on Earth systems;

(ii) the rising relevance of new space technologies for observing Earth; and

(iii) the mounting opportunities for scientific and technological discovery in space science.

BOX 3 – What is Space Science?

'Space Science' refers both to the science that can be done from space and the science of space. The former can include almost all aspects of Earth and its atmosphere observable from space. The latter can embrace almost everything from Earth's surface to the distant cosmos, thereby including astronomy and all of Earth's atmosphere. Here, however, it means everything in our solar system beyond about 40 km above Earth's surface. Our space science is sometimes classified under five headings:

(1) Space physics studies the Sun, the interaction of the Sun's outflowing plasma (the solar wind) with the rest of the solar system (the heliosphere), the properties of the magnetospheres, ionospheres, and atmospheres of planets and moons, and the effects of the resulting 'space weather' on human technology and society. Plasmas, composed of electrons and other charged particles, and embedded magnetic fields are of crucial importance;

(2) Planetary science studies the compositions, physical properties and evolution of Earth, other planets, moons, asteroids, comets, dust, and other bodies over time, including their atmospheres, surfaces, interiors, overall 'geology', and their origins in the primordial solar nebula;

(3) Earth observation from space, often called remote sensing from orbit, uses satellite and ground-truth measurements to study Earth's climate, environment, human modifications, and weather, and the properties and interactions of the atmosphere, biosphere, land, and oceans;

(4) Astrobiology studies the origin and evolution of life in space, specifically on Earth but also more generally for the solar system and Universe, and interactions between life and its environment; and

(5) Space technology involves developing instruments and other technology for space, including those required for human exploration and habitation. This includes propulsion systems for access to space and space transport, and atmospheric entry systems for planetary exploration and return to Earth. It also includes studying the effects of space weather on technology, and crucial spacecraft tracking and data download infrastructure for foreign space programs, including the European Space Agency (ESA) and the US National Aeronatics and Space Administration (NASA).

(i) Impacts of Space on Earth

Some impacts of space on Earth are obvious. The Sun is a star about 1.4 million km in diameter, whose apparent visible surface has a temperature of around 6000 degrees celsius. The Sun supports the majority of Earth's biosphere and life as we know it, as it has since Earth developed from the solar nebula.

The Sun is not quiescent. As well as light, the Sun continually sheds a flow of plasma called the solar wind that travels outward through the solar system at a supersonic speed of about 500 km per second. The Sun's magnetic field is drawn out with the solar wind into interplanetary space. Sunspots are immense regions of magnetic complexity where loops of magnetic field erupt from the surface of the Sun, often breaking and releasing the energy equivalent of a hundred million nuclear bombs, much of it in just a few seconds. These events, known as solar flares, can produce copious X-rays and eject huge numbers of energetic particles into interplanetary space.

It is also possible for magnetic loops to lift off from the solar surface and travel beyond the Earth into interplanetary space, carrying up to a billion tonnes of plasma. These events are called coronal mass ejections (CMEs).

When CMEs reach Earth they distort and disrupt Earth's magnetic field, heightening activity in the polar and equatorial regions, and posing serious risks to the health of humans and their technology (eg satellite electronics) in space, in the atmosphere, and on Earth's surface. The effects of CMEs and the energetic particles from solar flares include large changes in the density, chemical composition, and ionization fraction of Earth's atmosphere and ionosphere (above 20 km altitude but with associated links to clouds and climate; Figure I.2.1), dropouts and other defects in GPS and radio communications, damaging voltages induced in power grids and pipelines, and increased radiation exposure for astronauts and airplane travellers. Collectively, these and related events are termed 'space weather'. Theoretical models are required to forecast the severity and arrival time of space weather events. These models must be closely coupled to observations of energetic events on the Sun through space to Earth's surface, including both electromagnetic fields and particles. The forecasts must describe the complex processes occurring within the magnetosphere, ionosphere, and atmosphere of Earth (or any other planet) and interplanetary space.

The dynamic Sun and solar wind can modify the properties of Earth's magnetosphere, ionosphere, and neutral atmosphere on timescales of seconds to years and even billions of years. They may contribute to global climate change, as recent work suggests significant changes in solar activity over the last 100 to 10,000 years.

Energetic particles like cosmic rays cause significant radiation damage to humans and technology, with many major spacecraft failures and communication difficulties traced to enhanced levels of energetic particles. These particles also cause genetic mutations, especially in space and for air travellers on polar and high-latitude flights.

Modern economies are not impervious to effects of space weather. For instance, GPS signals are used throughout the agriculture, mining, transport and travel industries, as well as for Defence and surveying. They time stamp financial transactions worth billions of dollars per day globally. GPS dropouts and other radio communication failures thus cause significant difficulties. Less probably, debris from satellites (however formed) may also cause economically important events in space and on the ground, while meteorites and asteroids have the potential to cause mass extinctions.

The actual and potential impacts of the Sun and space upon Earth are thus significant for all modern technological societies. Historically, research into the plasma and electrodynamic coupling effects from space to Earth has focused on the auroral and polar regions because Earth's magnetic field funnels energetic electrons, ions and assorted electromagnetic waves into these regions. Likewise, research into the impacts of the Sun's radiation has focused on the near-equatorial latitudes of Earth since the Sun's radiation causes maximum heating and ionization of the atmosphere there. Since Australia's territories, including Antarctic claims and Defence interests, span from the equator to the South Pole, the impacts of the Sun and space on Earth are of particular relevance to Australia.

Modern space science is increasingly focused on the interconnectedness of Earth and space systems. New research shows substantial coupling of Earth's atmosphere, the region of space primarily controlled by Earth's magnetic field (the magnetosphere), and interplanetary space, both by plasma processes and by associated electrodynamic interactions (eg thunderstorms, the equatorial electrojet, auroral currents, and geomagnetic activity). The role and significance of energy coupling from polar and equatorial latitudes to the mid-latitude regions characteristic of the Australian continent, both between different levels of the atmosphere and between space and the lower atmosphere, are areas of active current research. At the same time, new atmospheric effects of relevance to Australia are being discovered. An older but familiar example is the southern ozone hole, which determines the ozone levels and ground radiation events across the southern hemisphere – including over Australia.

Over the coming decade, significant new discoveries are expected on the impacts of space on the Earth that are especially relevant to understanding the Australian region, including Antarctica. These will lead to greater scientific understanding across space science and related fields, and to improved services that rely on space assets.

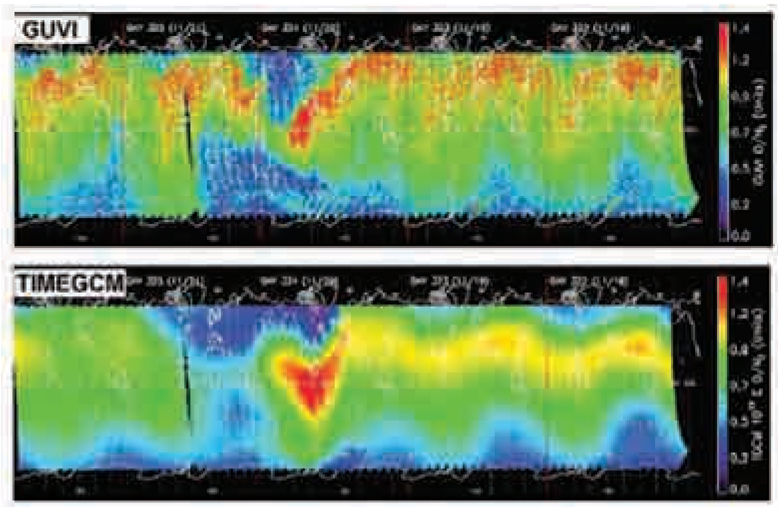


Figure I.2.1: NASA TIMED spacecraft observations of the ozone in the middle atmosphere (GUVI) and a model (TIMEGCM) showing the response to a strong space weather event on 20-21 November (starting at the centre of the image). Here time increases right to left as TIMED's orbital swathes are displayed.

BOX 4 – Space science produces crucial discoveries for modern society

Topics of direct interest and relevance to Australia include:

(1) the ozone hole over Australasia and Antarctica;

(2) the greenhouse effects and global warming on Earth and Venus;

(3) the dynamic Sun and solar wind, and their effects on Earth;

(4) operational GPS navigation, timing, and geodetic services;

(5) Earth observation (eg weather, environment, disaster monitoring, and national security) and communication satellites;

(6) space weather effects on GPS, radio communications, spacecraft operations, geomagnetic prospecting, and other critical systems:

(7) rapid coalescence, evolution, geology, and hydrology of the Earth, Moon, Mars, asteroids, and meteorites in the early solar system;

(8) rapid emergence of life on Earth and perhaps the solar system; and

(9) nuclear fusion as the Sun's energy source, with relevance to our needs, and evidence for finite-mass neutrinos.

(ii) Observing Earth from Space

Satellites are excellent platforms for observing the Earth and monitoring the neutral and ionized atmosphere, oceans, and the surfaces of Australia, Antarctica, and the Earth as a whole (Figure I.2.2). Already, new space-based technologies are transforming the way we observe, understand, and plan to sustain our world. Environmental monitoring and mapping of change in key natural resources are now well-established areas of research and application for space-derived information.

Figure 1.2.2: View from space by a NASA spacecraft.

For example, the first comprehensive digital mapping program of the Great Barrier Reef was initiated in 1981 by Australian researchers. They used satellite images obtained from the early 'Landsat' satellites and customized software called 'MicroBRIAN' ('Microcomputer Barrier Reef Image Analysis'). Subsequently, these techniques were extended to map the detailed diversity and health of many parts of the reef. Terrestrial applications have also flourished since the advent of operational systems like Landsat. In particular, digital mapping programs of forest cover, to monitor illegal land clearing or for carbon accounting purposes, are now used by several Australian state and federal agencies. Similarly, Australia's drought in recent years suggests that mapping water flows and moisture content from space will become increasingly crucial.

Scientific, strategic, and operational aspects of Earth observations from space are all important, with the scientific and operational uses of data increasingly linked for some applications. Additional context here is provided by the new joint Academy strategic plan for Earth observations from space[1], focused primarily on operational aspects. It sets out a range of future opportunities for use of Earth observations from space in such nationally important applications as climate change, water resource management, natural disaster reduction, transport, agriculture, forestry and ecosystems, coasts and oceans, and national security.

Space observations have led to dramatic improvements in weather forecasting over the last 50 years: inclusion of more space data over the last two years has led to a doubling of Australia's 'forecasting skill' scores. In addition, though, computational models show increasing skill scores as higher layers of the atmosphere are included. This points to the increasing importance of including the effects of the Sun and space into atmospheric, weather, and climate models for Australian forecasting.

Space geodesy techniques, including Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and GNSS, (such as the US's GPS and Russia's GLONASS) are used for defining the terrestrial and celestial reference frames, and Earth's rotation parameters linking the two frames. In addition, a range of other satellite missions support geodesy, including gravity mapping satellites, satellite radar and laser altimetry satellites, and radar observing satellites. All contribute to the precise monitoring of Earth's shape and the 4D positions of points on it (from which deformation and geodynamics can be inferred) and LEO satellites, as well as precise gravitational models of the Earth for a variety of geoscience, oceanographic, hydrological and atmospheric applications. Australia's investment in geodesy is considerable, most recently through the National Collaborative Research Infrastructure Strategy (NCRIS) capability 'Structure and Evolution of the Australian Continent', via funding of a nationwide network of permanent GPS receivers dedicated to the geosciences and atmospheric sciences, and three VLBI antennas for terrestrial-celestial reference frame studies. This is part of the AuScope program. Australia's ground network is part of the next generation global geodetic network, known as the global geodetic Observing System (GGOS), currently being established for high accuracy, synoptic monitoring of global change parameters that have a geometry and gravity 'signature'. These include sea level rise, ice sheet melting, and changes in ocean circulation and the global water cycle. The scientific goal of modern geodesy is the integrated monitoring and modelling of the 'Earth system'. GPS/GNSS is the critical tool for achieving this mission.

Observing Earth from space thus has broad applications. Moreover the technology has undergone a revolution in recent decades and new instruments are providing a growing diversity of data. Spectrometers, hyperspectral instruments, synthetic aperture imaging radars, laser-ranging 'lidars', atmospheric profilers, and other instruments are used increasingly to detect bushfires, other natural disasters, and changes in vegetation, rainfall, weather, sea state, wave patterns, and human activities. They are providing extensive datasets on time scales from seconds to years and spatial scales from one meter to Earth's radius.

Critically, the importance of Earth observation is expanding dramatically. Practical and routine applications now include monitoring cloud dynamics and rainfall, prospecting for valuable minerals, estimating crop production and biodiversity, and surveying the status and health of forests and coastal ecosystems (eg mangroves and coral reefs). Equally important is the specific role that remote observation of Earth's atmosphere, oceans and surface contribute to understanding the impacts of climate change.

This public good research has direct national and economic benefit to Australia, providing strong strategic incentives to develop indigenous capabilities. In Australia, remote sensing observations from space or from aircraft often offer the only practical means of monitoring the large, remote parts of our continent, and of assessing the impacts of drought, climate shifts, greenhouse gases, natural disasters, soil degradation, and human intervention on our landscapes. Likewise, in the field of regional- and continental-scale ecosystem research, space observations of land-cover dynamics and state are the only practical means for scaling in situ ground measurements of vegetation state, functions and diversity to regional and continental scales.

To be effective, space-based instruments need to be designed for Australian conditions (eg vegetation), have direct down-links for data transfer, have appropriate orbits and observing time over the target (most foreign satellites focus on downloading over Australia, not observing), and be tested against ground-truth data.

Observing from space what is happening today across Australia and analyzing what happened in the past are key to forecasting what will happen in the future. These observations and models are vital if we are to develop and ensure our ability to understand the nation's physical and ecological systems, to anticipate and respond to global trends, and to control and sustain our environment.

(iii) Opportunities for Scientific and Technological Discovery

Over many decades, space science has provided valuable opportunities for researchers all around the world to make fundamental scientific discoveries and to develop new technologies – sometimes with applications on Earth and in space (Detail Box 4).

Australians currently produce a remarkable amount of unique world-leading space technology, including novel satellite propulsion devices, sensors, and communications systems, as well as new scientific instruments that measure phenomena in space, in the air, and on the ground. For instance, Australia's hypersonics community leads the world in scramjet technology, with the HyShot flights from Woomera achieving the world's first scramjet combustion in flight. This is not only a stepping stone to strategic hypersonic cruise vehicles but also cheaper and safer access to space. Moreover, in the defence and national security arenas Australia has made major contributions to data fusion, radar, and unmanned flight (UAV) systems of allied nations, the details of which are classified.

The use of space technologies increasingly extends beyond fundamental research to services. However, space is a harsh environment, with temperature extremes and high levels of cosmic rays, impacting charged particles, ultraviolet radiation, and X-rays. These damage human technology and biological systems. Since Australia's government and society rely increasingly on space for communications, navigation/positioning, and Earth observation, the effects of space weather events on human technologies and services need to be predicted, quantified, and mitigated where possible. This is an important emerging goal for technological development globally, and it is highly relevant to Australia.

Australia is also positioned to play an important part in solving some of the fundamental problems humanity faces concerning the origin, evolution, and fate of the solar system, and of life itself. Modern planetary science uses the tools of chemistry, physics, geology, biology, and astronomy to explore the diverse physical environments found in our solar system and predicted for exoplanets discovered around other stars. In our solar system these environments range from the icy lakes of Titan to the ancient cratered landscapes of the Moon, from the windswept deserts of Mars (Figure I.2.3) to the cool blue oceans of Earth, and from the hell of Venus's greenhouse atmosphere to the gas giants. Australia's strong (but still developing) human capital and infrastructure in space science are highly complementary to its capabilities in Earth science and astronomy.

Australia's geological record is a crucial asset that positions Australia to play a leading role in understanding the emergence of life here on Earth – and indeed elsewhere in the universe. Australia's Pilbara region has already yielded a diversity of geological and astrobiological features of interest. These natural assets include some of the oldest rocks on Earth that show fossil evidence for ancient life, ancient hydrothermal systems, and fossil microbes from a deep, hot biosphere (rather than a biosphere driven by sunlight).

Life does not appear to be common in our solar system, yet we are here. Plausible ingredients for life and a biosphere to develop on a planet include an atmosphere, liquid water, and an ionosphere or magnetic barrier to the solar wind. These depend critically upon interactions with the Sun, solar wind, and cosmic rays, as well as on collisions with asteroids, meteorites, and other bodies. Australian and international scientists are beginning to develop the models required to understand these interactions. At the same time, there is a growing capability for conducting laboratory analyses of the chemical and physical composition of meteorites, dust from space, and samples of other planets and asteroids. Measurements of the Sun's composition, which constrain age, origin, and history of the solar system, are also steadily improving.

A unique opportunity is approaching. It is to develop the first comprehensive understanding of the composition, history (including collisions), large-scale planetary processes, and characteristics of the planets and other bodies across the solar system. This will involve combining the new compositional information with theoretical models, knowledge from the Pilbara and Earth's other old geological formations, and new images and spectral data of the surfaces and atmospheres of planets, moons, asteroids, and comets.

Comparisons of surface and atmospheric features on other planets and moons with Earth offer many noteworthy opportunities. As well as constraining the geology and evolution, these studies may predict the amount and state of water (eg ice or liquid; Figure I.2.3) and provide new insights into the effects of greenhouse gases (like CO_2, methane, and water vapour) and aerosols on climates, eg for Earth, Venus, Mars, and Titan.

These data are highly relevant to deciding whether life may have or still does exist on other planets or moons, whether in our solar system or around other stars. Further progress requires development of new technologies and techniques for laboratory analysis and remote sensing, new data sets, and better theoretical modelling. Australian space researchers are well placed to participate in this work and so to make major discoveries that could change forever the way we understand our place in the universe.

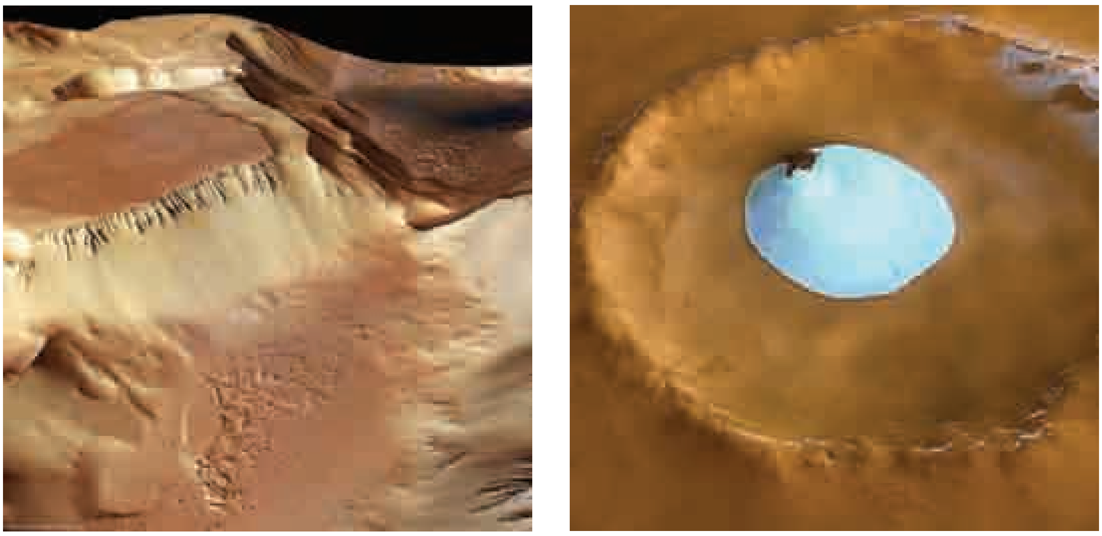


Figure I.2.3: Images from ESA's Mars Express spacecraft of the Noctis Labyrinthus region (left) and water ice in the Louth Crater (right) on Mars.

I.3 Australian Advantage

Not only is space science highly relevant to Australia, but Australia also has a strong track-record across the field. Our community of space scientists is relatively small, but our research is disproportionately highly cited in the global scientific literature.

- Scientific articles published by Australian space scientists are referenced in the global scientific literature roughly 40% more often than those by non-Australians[10].
- Space science is Australia's most highly cited field of research, with geoscience second.

Australian space scientists are decidedly highly international in their work and in their collaborations. Australian-led examples of international collaborations include:

- FedSat, launched in 2003, led to excellent work on space weather and communications with American and other colleagues;
- The TIGER (Tasman International Geospace Environment Radar) radars based in Tasmania and South Island, New Zealand, have innovative Australian designs and are vital members of the international Super-DARN network;
- The Advanced Along-Track Scanning Radiometer on ESA's Envisat mission (launched 2002), developed jointly by Australia's CSIRO and the UK, is providing state-of-the-art climate and environmental data. Previous versions flew on the European satellites ERS-1 and -2;
- The Australian Centre for Astrobiology, University of New South Wales, has Associate Membership of the NASA Astrobiology Institute, one of only two international organizations to hold this status; and
- In 2002 the HyShot collaboration between Australia's hypersonics community and US colleagues launched the first scramjet to successfully demonstrate supersonic combustion in flight in Earth's atmosphere. This is continuing with the current Australia-US HIFiRE program.

Equally significant is the invitation of Australian space scientists to participate in a large number of international space missions, including Atomic Clocks in Space (ACES, ESA, launch 2010), Envisat (ESA, 2002), Hayabusa (Japan, 2003), Mars Express (ESA, 2003), Venus Express (ESA, 2005), Solar Terrestrial Relations Observatory (STEREO, NASA, 2006), and Lunar Reconnaissance Orbiter (NASA, 2009), as well as in the Australia-US Murchison Widefield Array (MWA) radio project (2010) located in Western Australia.

Australian space science initiatives, moreover, are strongly relevant to the international research community. Australia's IPS Radio and Space Services (IPS), a unit of the Bureau of Meteorology (BoM), is a World Data Centre and a global provider of Australian space weather data. Australian space scientists have also had significant influence on international space policy via the United Nations (eg the Committee on the Peaceful Uses of Outer Space (COPUOS) Treaty), and on space science via its links with the UK, European, and US space programs.

Australia provides vital spacecraft tracking and data download infrastructure to the US and European space programs. These include radio-telescope and communication facilities at Tidbinbilla and Parkes (NASA's Deep Space Network) and New Norcia and Perth (ESA Spacecraft Operations), as well as data downloads for numerous Earth observation satellites. Significantly, many satellite orbits and schedules favour transmiting data down to Australia rather than observing. Much better coverage and data for Australia's region would be obtained from Australia-focused satellites.

Emphatically, the quality and global relevance of space science in our country is viewed by the Australian Academy of Science as both an existing and an emerging area of strength for Australian science and technology.

Chapter I
Space Science and its Importance to Australia

Australia's participation in space science is actually long-standing: Australia was the fourth nation from which a satellite were launched into orbit. This is not widely known in Australia, or the world. Most of the Australian public is surprised to hear of the successes, existence, scale, and history of the Australian space science community, often assuming wrongly that we work for foreign programs like NASA or that Australia is officially part of NASA or ESA.

The main reason for Australia's high-quality track record in space science is that the country has been able to develop and keep a core of committed, passionate, and talented scientists, sometimes attracting them back from overseas. Australia's space science community contains internationally recognized experts in many areas, including:

- solar and interplanetary physics;
- cosmochemistry and associated dating of the solar system;
- coupling of the Sun and Earth's magnetosphere to the ionosphere and atmosphere,
- space plasma physics;
- space weather;
- Earth observation from space, including climate, atmosphere and surface;
- geodesy and geospatial information science;
- planetary geology, formerly called comparative planetology;
- astrobiology;
- propulsion systems;
- radiation dosimetry for humans and spacecraft systems; and
- advanced timing and communication electronics.

Two additional important reasons for the excellent standing and potential of Australian space science are Australia's geographic position and geophysical footprint. Australia has United Nations responsibility for approximately ⅛ of the globe. Our region of national interest stretches continuously from the equator, through the mid-latitudes, through the southern auroral region, right down to the southern geographic and geomagnetic poles in Antarctica. The consequences of this are significant.

The sheer size of Australian territories increases the extent (compared with other countries) to which our weather systems and environment are influenced by events in space. Our position as a major landmass in the southern hemisphere, and Antarctica's positioning across the southern geomagnetic pole and auroral region, also impact upon the extent to which we are able to track unique events in space. Australia's geographical and geophysical footprints are unique for – and very well suited to – research on the Sun, Earth, and solar system as a whole.

Australian researchers thus work across all latitudes, from the southern poles to the equator. Consequently they are exceptionally well positioned to develop a systemic view of the interactions between Earth and space, and to foster scientific programs to explore the coupling of Earth's equatorial, polar, and mid-latitude systems and the impacts of space upon these systems. This is a comparative advantage for the nation.

For these reasons, at the present time Australia is strongly placed to not only support high quality research in space science but also to attract significant international research partnerships. This provides Australia with opportunities to take part in the development of international space science, to guide the directions that science takes, and to benefit from space science to an extent that is highly disproportionate compared with the size of the Australian economy or our space science community.

10 Thomson Scientific, 1996-2005 Decade. See Section II.1 for more detail.

I.4 Strategic Reasons for Involvement in International Space Science

Australia has world-class space scientists, leads the world in specific areas of space science, and has special advantages in space science due to its unique geographic position and scale. Yet Australia faces significant challenges in maximizing national benefits from its current opportunities:

(1) Australia is not taking part as a nation in international space efforts, although it is recognized as a location for foreign assets.

(2) Australia needs to lead space projects in order to build a capability in space science and technology that other nations recognize as a basis for involvement in international scientific, industrial, and security arenas related to space.

(3) Foreign and Australian groups do not know who manages Australian space science and space efforts. Prior to the Australian Government's May 2009 actions there was no specific government office, program or funding for space. While the new Space Policy Unit and Australian Space Research Program represent first steps in these directions, their policies and programs are unknown today and no single coordinating body exists for space science or space itself.

(4) Space science is one of the new interdisciplinary fields, along with genetics, nanotechnology, complex systems (like climate), and others that determine international status and ranking. Despite having excellent scientists, Australia's reputation as a nation in space science is decreasing relative to other nations.

(5) Australia has no organized program to develop, link, maintain, and optimize its existing assets and expertise in space science, or to bridge the various university, government, and industry divides, or to minimize the risks of total dependence on foreign-controlled space assets.

(6) Antarctic ground and satellite programs focused on space science (including Earth observation) would provide year-around capabilities and justifications for presence, and strengthen Australia's claims and management capabilities for Antarctica and the southern oceans – unlike summer-only research.

(7) Australia has multiple concerns about the scientific and technological training of its workforce and the corresponding literacy and interest of its population.

The benefits of addressing these issues are many. The most important benefits relate to our country's ability to make unexpected and exciting scientific and technological discoveries, to build our reputation as a technologically sophisticated nation, and to understand and monitor space-derived phenomena and Earth system processes. An enhanced and better coordinated space science capability should bring a number of practical benefits, particularly relating to environmental forecasting, disaster monitoring, and national security.

There will be further benefits to investing in Australia's space capabilities that extend beyond the obvious scientific issues. Addressing points (1) to (7) above has particular strategic and policy implications for: (i) international relations; (ii) Australia's long-term economic security and territorial claims; (iii) improving government efficiency; and (iv) addressing broader skills shortages not directly related to space.

(i) International Relations

Space science naturally has a global nature and importance. Not only does it link fundamental or 'enabling' sciences like physics, geology, chemistry, biology, and mathematics to engineering and to commercial and Defence activity, it also inevitably involves international relations. It is therefore a natural field for positive interaction between countries and for government collaboration.

As summarized earlier, Australia's world-class space scientists, leadership in areas of space science, and global geographical footprint with unique strengths for space science, should make Australia an attractive partner. However, until recently the Australian Government had no official program, specific funding, or office for space science or space as a whole. Past approaches by foreign governments and space agencies for joint projects were seldom accepted. The lack of a single point of contact within government was often reported to be a major barrier to realizing Australia's potential for domestic and international space efforts.

The Australian Government's May 2009 Budget announcements represent a fundamental change in government attitude and thinking toward space. Space is now recognized as the first (under 'space and astronomy') of the nation's three research priorities under the Super Science Initiative. The other two, 'marine and climate science' and 'nanotechnology and future industries' also rely heavily on space. Further, the new Space Policy Unit and Australian Space Research Program represent positive initiatives, as a government office and funding program dedicated to space, respectively. Their policies and programs are under development, and still no single coordinating body exists for space science or space itself, so Australia's domestic and international linkage mechanisms are currently incomplete.

Australia's attractiveness as a partner will inevitably decrease if it does not enhance its capabilities in space science and technology. Indeed, there is already evidence of this occurring. In the past, Australia has had significant influence on international space policy via the United Nations. Currently, however, Australia is not widely recognized as relevant to international space policy, as recent efforts to remove Australia from several UN committees suggest. Arguably, nation members of the UN Security Council and other strategic committees require demonstrable capability in space.

On the other hand, should Australia grow its capabilities in space science, and be open to international collaboration, then it faces clear opportunities for leveraging its strong advantages in this field: not only to attract foreign investment and foreign scientific assets to Australia, but also to build strong inter-governmental relationships. With one partner, of course, Australia already does this to some extent. Over many decades, Australia's unique position and the capabilities of its space scientists have contributed continuously to the strength of Australia's strategic relationship with the USA, albeit primarily in the Defence and national security arenas. Even with this nation, however, we have exploited only to a limited degree our opportunities for leveraging Australia's advantages in space science in order to pursue relationship-building opportunities.

Many nations and unions of nations have approached Australia's Government and Academy of Science to collaborate on space, including Argentina, China, the European Union, India, Japan, Ukraine, and the USA. The research program proposed below presents strong opportunities to collaborate with all of these, plus our other Asian and Oceanian neighbours. Indeed, Japanese and Taiwanese scientists have already offered an instrument for the Marabibi Constellation project (Section III.5.1), which strongly complements Ukraine's proposed Ionosat project, while the proposed SpaceShip Australis project (Section III.5.1) would complement research by all these entities.

__Recommendation 1:__ Australia should invest in a strong capability in space science and engineering in order to grow its own economy and industry, develop its scientific and technical infrastructure, increase the long-term opportunities available to its citizens, and build stronger international relationships with other nations.

(ii) Long-term Economic Security

Australia's territorial and maritime interests represent a long-term asset for all Australians. Many of our territorial claims, however, carry obligations. Use of scientific assets within the Australian footprint year-round is one way for Australia to support its claims over territory and to fulfill its associated treaty responsibilities. In this sense, a space science program with a strong ground-based component is one method for demonstrating our long-term interests. Space research has a natural all-year advantage compared with summer-only programs.

Nowadays access to land and sea, while important for our long-term economic security, is increasingly matched by broader strategic needs: Australia needs to have guaranteed access to international technologies and technological infrastructure and, perhaps more importantly, needs to develop and retain the ability to use, refine, and innovate them.

A large range of space science assets exist across Australasia, Antarctica and near-Earth space that are used by Australian government agencies, space scientists, members of the public, and industry. Uses range from Defence to science to industry while the benefits run the gamut from public good to individual enrichment. Indeed space assets provide Australians with a vast, and growing, range of services including:

- identification of natural disasters and weather;
- geodetic and geospatial information;
- GPS location and navigation;
- communications (phone, data, radio, and TV);
- remote sensing for Defence purposes;
- space weather prediction and mitigation; and
- Earth observation and management of natural resources (eg salination, vegetation, minerals, fisheries).

Existing space assets targeting these services have a large replacement cost. They require a substantial annual budget and are invariably supported with huge 'in kind' contributions from foreign interests. Currently, for example, Australia is entirely dependent upon Japanese, US and Chinese weather satellites, most government and public communications are carried on foreign-controlled satellites, and almost all remote sensing and intelligence data are provided by foreign-controlled satellites. Similarly, GPS is a US military owned system and could, theoretically, be turned off or impaired at any time.

Depending on foreign strategic space assets always carries the risk that we could lose access to these assets. In addition, large foreign 'in-kind' contributions are likely to entail hidden non-economic costs, such as reduced flexibility in government foreign policy, strategic dependence on foreign partners, or an 'IOU' for a potentially unknown future benefit. More importantly, the failure to develop and demonstrate these skills in international collaborations or indigenous projects diminishes our future economic competitiveness.

Recommendation 2: *Australia should invest in an enhanced Australian space capability in order to manage more effectively the risks of dependence on foreign space assets and to ensure Australia's long-term economic security.*

(iii) Improved governance and management

Are Australia's current space science assets (see Section II.2 for details) managed in a cohesive and effective way at a national level? Are there agreed goals and can long-term plans be made with reasonable certitude? This Plan addresses these issues.

There are many Australian Government departments with interests in space science via Earth observation (eg the atmosphere, climate change, sea levels, and monitoring of the environment and natural disasters) and other areas of science (eg astronomy, the geosciences, physics, chemistry, and engineering) as well as through education, Defence, innovation, industry, and international collaborations. They include:

- Department of Climate Change and Energy Efficiency, including the former Australian Greenhouse Office (AGO),
- Department of Defence and its
  - Defence Science and Technology Organisation (DSTO),
- Department of Education, Employment, and Workplace Relations (DEEWR),
- Department of Environment, Water, Heritage and the Arts (DEWHA), & units
  - Australian Antarctic Division (AAD),
  - Bureau of Meteorology (BoM), and
    - IPS Radio and Space Services (IPS), a unit of BoM,
- Department of Foreign Affairs and Trade (DFAT),
- Department of Innovation, Industry, Science and Research (DIISR), and its
  - Australian Government Space Forum (AGSF),
  - Australian Research Council (ARC),
  - Commonwealth Scientific & Industrial Research Organisation (CSIRO), the new CSIRO Astronomy and Space Science Division, and the former CSIRO Space Sciences and Technology (CSST), and
  - Space Policy Unit (SPU),
- Department of Resources, Energy, and Tourism (DRET), and its unit
  - Geoscience Australia (GA).

The state governments in Victoria and South Australia have also taken a strong interest in space science, with associated funding for education. In fact, space is prominent in primary and secondary school curricula across the nation.

The Space Policy Unit has had whole of government responsibility for space policy since its creation in May 2009. It has not yet had time to develop a comprehensive approach to space. Previously, government investments in space research were formulated at a departmental level rather than as a whole of government activity, although AGSF provided a forum for exchange of information on government space-related policies and activities.

Numerous Australian universities have excellent space science research groups and associated assets (see Section II.3). Similarly, corporations with expertise in space, whether Australian or foreign, perform some research here for or with government and universities. Examples are British Aerospace (BAe) and Optus. The Federal Government is the ultimate funding source for universities and arguably the dominant one for industry too. Once again, few of these are linked or managed together (TIGER, FedSat, and HyShot are exceptions), either between universities or between universities and government.

An approach to policy formulation that coordinates space science research (and develops its benefits) across the disparate areas of government, universities, and industry will ultimately help government to achieve some of its most important objectives, on behalf of all Australians. Moreover, strategic and effective coordination of government investment in space science that raises the efficiency and effectiveness with which the community is able to operate will bring the additional advantage of improving the performance of Australia's space science community.

Recommendation 3: *Over time the Australian Government and its Space Policy Unit should work with stakeholders in Australian space science and engineering to coordinate space efforts across government and the nation in a strategic way that:*

- *develops a demonstrably Australian capability in space science and industry,*
- *maximizes the scientific and innovation benefits,*
- *gives consideration to government's broader objectives in national security and foreign affairs, public-good services, telecommunications, and economic policy,*
- *empowers Australian stakeholders in space science to achieve agreed goals, and*
- *develops and supports executive structures - eg the entity Coordination of Australian Space Science (CASS Ltd) - to accomplish agreed goals and boards/councils (eg a Space Advisory Council) to provide advice.*

(iv) Overcoming Skills Shortages

Scientific and technological literacy is a critical issue for all societies. This is true whether one considers a society's ability to develop specific skills or its more generic capacity for adopting and adapting to new technologies and knowledge.

There is mounting evidence, for example, that all developed nations face challenges in this and coming decades in replacing the technical skill sets of their ageing workforces – and this at a time when such skills are only growing in importance.

The Australian Government's July 2006 Audit of science, engineering and technology skills found that there is a steadily growing demand for science, engineering and technology skills in our society. This demand growth covers many engineering disciplines and sciences such as Earth sciences, chemistry, geospatial information and entomology. There is also a strong demand for high level mathematical skills. Indeed, the report suggests that Australia may experience a shortage of 20,000 scientists by 2013. Furthermore the numbers of students enrolling in science, engineering, and technology studies in Australian universities is declining.

Likewise, science literacy among Australian high school students appears to be waning. Figures for 2004 from the Organisation for Economic Co-operation and Development (OECD) placed Australia fifth in global science literacy, and the International Association for the Evaluation of Educational Achievement placed Australia eighth in 2003. More recently, research conducted at Macquarie University and UNSW has suggested that Australian students know very little about the nature and processes of science, both at Year 10 level and at first year university level. It is also extremely salutary to note that the World Economic Forum's Global Competitiveness Report of 2006 placed Australia 29th in the quality of mathematics and science teaching and 12th for the quality of the education system. The former ranking placed Australia behind India, the Czech Republic, Tunisia, Romania, Estonia, Barbados, Lithuania, and Indonesia.

Australian students may have ambivalent feelings about science but the Australian public is fascinated with space. By way of illustration:

- 85% of visitors to Sydney's Powerhouse Museum view the space exhibit;
- Over 23,000 paying customers per month attended the 'To Mars and Beyond' exhibition at the National Museum of Australia (Canberra) and Museum Victoria (Melbourne) during 2001 and 2002;
- The visitor centres at Australia's elements of NASA's Deep Space Network (specifically the Tidbinbilla Tracking Station), the Parkes radio telescope, and the Narrabri radio array, receive about 70,000, 110,000, and 10,000 visitors per year, respectively;
- Publication of two successful home-grown magazines focused strongly on space and astronomy: *Sky and Space* sells about 4000 copies per issue while *Cosmos* sells about 22,000 copies per issue and reaches 60% of Australian high schools;
- Australian readership of *Cosmos, Sky and Space, Australian Sky & Telescope, Australasian Science*, and *New Scientist* exceeds a combined 300,000 per issue;
- The wiki website for a 2007 virtual field trip on astrobiology to the Pilbara received almost 6 million hits in two years, and the associated issue of *Cosmos* (April 2007) is the magazine's second highest selling issue;
- 'The Dish' movie, dealing with Australia's tracking and communication contributions to Apollo 11, made $10 M in its first 20 weeks and is the fifth highest grossing Australian movie;

- The Victorian Government invested over $6.4 M in the Victorian Space Science Education Centre (VSSEC), which opened on 17 July 2006; and
- The Australian Centre for Astrobiology has enjoyed hundreds of interactions with the national and international media, and millions of internet 'hits'.

Space is considered an exciting and important part of the science curriculum for primary and secondary schools. In NSW, for instance, it is studied in Years 3-4, 5-6, 8, and 10 by all students, and is a Physics elective for Years 11 and 12. However, presently there are very limited references to Australian space science (most are to infrastructure assets and not to scientific results). How much more effective would the education be if students learn about Australia's contributions to the global space science effort, are stimulated to study science and technology by Australian examples, and feel empowered that they and Australia can (and do) contribute significantly and innovatively to global science, technology, education, and society?

At a time where enrolments in science and mathematics have been declining, a strong investment in space science programs is an important way to capture student, community, and corporate interest. Space science affords novel, collaborative ways to engage students across the sciences, with the potential to inspire students more broadly. Space research promotes a nation's hi-tech profile nationally and internationally in education, outreach, and industry. It combines the enabling sciences into an excellent vehicle for explaining and illustrating the inspirational nature of discovery (Figure I.4.1).

Recommendation 4: *An innovative and invigorating Australian program in space science should be pursued as one government approach to reverse current educational trends and to better position Australia's economy and citizens in global society.*

Figure I.4.1: View of Mars from 1000 km altitude during the swing-by of Mars by ESA's Rosetta spacecraft in February 2007.

I.5 A First Decadal Plan for Australian Space Science

The Australian Government, the Australian Research Council (ARC), and the Committee for the National Collaborative Research Infrastructure Strategy (NCRIS) have repeatedly stated that they prefer research communities to undertake their own strategic reviews of scientific goals, projects, and funding.

The Australian Academy of Science's National Committee for Space Science (NCSS) is responsible for fostering the science, linking Australian scientists together and to their overseas colleagues, and for advising the Academy's Council on policy for science in general and space science in particular.

This first Decadal Plan for Australian Space Science presents the scientific goals of the Australian space science community for the period 2010-2019 and describes the associated benefits to Australia.

The goals and recommendations in this Plan build upon and develop Australia's existing capabilities in space science and have the potential to cultivate broad benefits for Australian society. The Plan recognizes international trends in space science and policy. For example, one principle of the 2006 US National Space Policy is that 'The United States considers space capabilities – including the ground and space segments and supporting links – vital to its national interests' and some of the goals are to:

- implement and sustain an innovative human and robotic exploration program;
- increase the benefits of civil exploration, scientific discovery, and environmental activities;
- enable a robust science and technology base supporting national security, homeland security, and civil space activities; and
- encourage international cooperation with foreign nations and/or consortia on space activities that are of mutual benefit and that further the peaceful exploration and use of space, as well as to advance national security, homeland security, and foreign policy objectives.

This principle and these goals (with the relegation of human space exploration to a minor role) arguably apply to Australia as well. But there are also unique aspects to Australia's situation – as we have already seen and as will be accentuated further below – that require specific, tailored, policy solutions.

Contrary to popular perceptions, a space science plan need not be costly. An Australian plan for space science must be balanced and effective in light of what is affordable to Australian taxpayers. There is an enormous amount of very important, fundamental, and practical space science that can be performed extremely cost-effectively on a relatively small scale and yet attract international attention.

'Piggy-back' launches for 100 kg satellites are now available from several providers at about AU$2 M. At the same time, ground-based facilities, which are vital to establish scientific links from space through the atmosphere to Earth's surface, are relatively inexpensive (typically less than $5 M). Similarly, at least two international corporations now advertise building and launching small satellites of less than 100 kg in mass and 1 m in characteristic size for less than $15 M.

Space science provides very high value and is not prohibitively expensive for a country of Australia's scale. NASA does spend over US$15 billion per year and Canada on the order of AU$300 M per year. Other countries have had major impacts on the field with much lower investment. Sweden has developed a world-class space effort with multiple scientific breakthroughs using small spacecraft that cost less than $15 M each. Australia might emulate this example.

The Decadal Plan is intended to build a true Australian presence in space by investing almost $140 M from new government funding sources into large projects that combine research infrastructure with exciting and broad-based science,[11] yielding:

- a cohesive Australian capability in space science and technology research that results in world-class research of great international significance,
- a dedicated and innovative program of education, training, and public outreach based on Australian space science and technology,
- a new entity Coordination of Australian Space Science (CASS) Ltd, that will link Australian stakeholders, manage investment optimally, and work with government to develop Australia's space capability and maximize the benefits of investment in space science;
- a new National Institute for Space Science (NISS) to build capability and capacity, especially in computational modelling, theory, and data networks across space science;
- a novel, ground-based network (SpaceShip Australis) that will make Australia's space neighbourhood one of the best measured and modelled, leading to world-first predictions for space weather and its diverse effects on government, industry, and society;
- a demonstrable Austalian near-Earth space capability with a long-term future and strong international collaborations, built using an innovative constellation of nano, micro, and small satellites that perform world-first, student-focused, research on space weather, space technology, and Earth observation (Marabibi Constellation);
- a new program to support Australian collaboration in international missions (ICFO);
- medium-sized infrastructure/science projects that range from digital radars to image analysis laboratories to propulsion; and
- development of a capability for deep-space interplanetary and planetary projects via a detailed design study of an innovative and challenging mission concept (Sundiver), with multiple novel capabilities and visionary goals.

The Plan will galvanize and inspire Australia's space scientists, governments, industry, and society. It provides sensible, practical suggestions to Australian governments about how they can develop a sustainable, vibrant, world-class community of space scientists in Australia. This community will participate officially in the international space effort and help build a better future for all Australians. The Plan will lead to a new National Institute for Space Science and strong engagement with international space agencies.

Although space science is distinct, it is strongly interdisciplinary and closely linked to other fields of science. The Plan is carefully designed to complement other current initiatives in Australian science and innovation. Underlying space science are the 'enabling' fields of physics, geology, chemistry, biology and mathematics. Space science will lead to education and training in the enabling sciences, and will excite and motivate students to study these disciplines. New results in space science will lead to progress in the enabling sciences and vice versa, with widespread benefits.

11 While indicative only, careful estimates for the budgets of large projects total $135 M over the decade from new government sources outside the ARC and ASRP. Including the indicative minimum decadal estimate for CASS ($2 M) leads to $137 M. The medium-sized projects (indicative budget of $19 M) and education, training, and outreach programs (less than $10 M) are expected to be funded by existing government programs (ARC and ASRP) and other Australian stakeholders in space, and so are outside the category of 'new government funding source'.

Two neighbouring areas already have Decadal Plans: Astronomy, which addresses scientific phenomena beyond the solar system, and Geosciences, which deals primarily with the solid Earth. While strongly complementary, there is minimal overlap in funded projects with either of these plans.

- **Astronomy Decadal Plan**[12] – The Space Plan focuses on solar system science while the Astronomy Plan focuses on optical and radio astronomy of the Milky Way and beyond. However, the Space Plan's emphasis on space weather and Earth's dynamic ionosphere and atmosphere will strongly improve the utility and viability of locating the Square Kilometer Array (SKA) in Australia, as well as optimizing the SKA's science return.

- **Geosciences Strategic Plan**[13] – The Geosciences Plan does not address space phenomena in any detail: however, it requires continual access to Earth observation data and is supportive in the overlap areas of Earth observation, planetary science, and astrobiology.

It is noted that this Plan for space science does not address operational aspects of Earth observation from space. These are addressed in the recent *Australian Strategic Plan for Earth Observations from Space*[14], and should be addressed in associated future developments: the mid-term 2014-2015 review of the space Decadal Plan may result in a revised Plan in two parts, one for the solar system as a whole and one specifically for Earth observations from space.

Importantly, some research infrastructure can be used for space science and either astronomy or Earth science. Examples include the new NCRIS-funded geospatial component of AuScope, the Square Kilometer Array if and when implemented, and the MWA radio telescope. In all three cases important space phenomena occur and cause effects unwanted by the Earth sciences and astronomy communities. These effects can be identified and used to understand space phenomena, and then removed from the data by space scientists.

Synergies have been carefully considered throughout the formulation of this Plan, which is intended to assist rather than compete with the plans of related research communities. Ultimately, constructive engagement between, and funding of, communities will optimize the scientific return and benefits to Australia. Detailed recommendations on how to accomplish shared goals are given in Chapter III.

In brief, the space science plan developed in this document provides the fundamental, but previously missing, unified science goals and capabilities to understand our solar system and its effects on life on Earth, and to thereby provide the scientific links between Earth's surface and the distant cosmos.

12 The Australian Academy of Science, 'New Horizons: A Decadal Plan for Australian Astronomy 2006-2015', November 2005.

13 The Australian Academy of Science, 'National Strategic Plan for the Geosciences', P. McFadden et al., October 2005.

14 'An Australian Strategic Plan for Earth Observations from Space', J. Zillman et al., July 2009.

Chapter II
Status of Australian Space Science

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Status of Australian Space Science

This section describes the current status of Australian efforts in space science and technology. It starts by assessing Australia's place in international space science using publication citations, invitations to collaborate on current and future international space missions, the institutions and countries with which Australian space scientists collaborate, and international science and technology fora that Australians have leadership roles in (Section II.1). The minimum scale of the Australian space science community is then estimated in terms of people, assets, and budgets (Section II.2). Section II.3 describes the institutions and research groups driving Australian space science and technology, while Section II.4 gives some examples of recent discoveries.

II.1 Australia's Place in International Space Science

Space science is a research field in which Australia excels, both compared with other research fields and compared with other nations.

Australia makes major contributions to international space science, primarily via academic collaborations and not government agreements. One way to see this is via the publication statistics in Thomson Scientific's study for the decade 1996-2005. Noting that the Plan's definition of space science includes Thomson's categories 'space science' (which also includes astronomy) and 'geosciences' (so as to include atmospheric and Earth observation aspects of the Plan), Thomson found:

- Scientific articles published by Australian space scientists are cited in the global literature 38% more than articles by non-Australians, arguing global excellence;
- Space science is Australia's most highly cited field of research, with geoscience second;
- Australia's space scientists contribute to the global scientific literature at a rate almost 52% higher than Australia's average rate, with 4.4% of the total and about 4400 papers in the decade; and
- Australian space science's 4.4% share of the global scientific literature was ranked 7th by field, with geosciences ranked 3rd at 5.0%. In comparison Australia's average share was 2.9%, with medical/biological fields at 2.8% - 3.7% and overcitation rates from -11% to only +16%.

The excellence of Australian space scientists has been recognized overseas by invitations to join international collaborations and space projects. Australian-led examples are detailed in Section I.3, including FedSat, the TIGER radars, the AATSR instrument on ESA's Envisat, and the HyShot collaboration on hypersonic flight. Invitations to join international projects have led to the current participations:

- Two Co-Investigators on NASA's Solar Terrestrial Relations Observatory (STEREO), launched 26 October 2006 to study solar and interplanetary physics and space weather, with responsibilities for theory and data interpretation;
- A radiation microdosimetry instrument developed and launched on the 2007 US MidSTAR satellite, to investigate radiobiological effects in Low Earth Orbit;
- The World Data Centre for Solar-Terrestrial Science is located in Sydney, led by IPS Radio and Space Services, and is a vital member of the global network;
- Leadership and operation of solar radio instruments at Learmonth (in partnership with the US Air Force) and Culgoora, for space weather prediction and associated alerts in Australia and worldwide;
- Leadership of the HIFiRE program for advanced hypersonic flight, with DSTO and the US Air Force;
- Leadership of a high-tech Virtual Field Trip to the Pilbara (plus DVD) on development of life on Earth and elsewhere, developed by the Australian Centre for Astrobiology (ACA) under a NASA Space Act Agreement. This led to Cosmos magazine's largest selling issue and 280,000 wiki page hits in the 10 months to February 2008;
- ACA was invited to join the NASA Astrobiology Institute as Associate Member;
- Active membership through CSIRO of the International Space Exploration Coordination Group (ISECG), formerly the Global Exploration Strategy (GES) working group, relevant to future human exploration of the Moon and Mars;
- A contract with Astrium/EADS to develop a novel plasma thruster;
- Project members in AMPERE, a Johns Hopkins-Boeing-National Science Foundation project using the former Iridium satellites to study auroral currents;
- Operation of the Tidbinbilla Tracking Station and Parkes radio telescope for NASA's Deep Space Network (DSN) and the New Norcia telescopes for ESA;
- Multiple project members and co-leadership of solar, heliospheric, and ionospheric research for the US-Australia Murchison Widefield Array (MWA) radio project, located near Murchison, Western Australia;
- Project members on Japan's Hayabusa sample-return mission to asteroid Itokawa (launch 2003, return to Earth 2010), with mission design, hypersonic entry capsule design, and data analysis responsibilities and likely participation in Japan's Hayabusa-II mission;
- Two Supporting Investigators for ESA's Venus Express missions, one of only eight teams selected worldwide, working on models of the Venusian atmosphere and both Venus Express and ground-based observations;
- Member of the MARS-XRD team, producing an X-ray diffraction instrument for in situ analysis of Martian rocks for ESA's ExoMars mission (scheduled 2013);

- Leading a joint program of the Mars Society Australia and NASA's Ames Research Centre to educate, train, and exchange science teachers and students using science field trips relevant to exploration of the Moon and Mars; and
- Operation of ground stations for reception and transfer of data for multiple international remote sensing missions, including the Advanced Land Observing Satellite (ALOS).

A partial list of current invitations to participate in future space projects include:

- Leadership and extension of the HyShot and HIFiRE hypersonics programs towards direct access to space and hypersonic reentry for planetary missions;
- Co-Investigators providing state-of-the-art clocks for ESA's Atomic Clocks in Space (ACES) project on the International Space Station;
- Co-Investigators for magnetometer design and data analysis for Canada's Orbitals mission;
- Co-Investigator on the science and operation of magnetometers in the expanded CARISMA (Canadian Array for Real-time Investigations on Magnetic Activity) ground-based project funded by the Canadian Space Agency;
- Co-Investigator, instrument provision, and theoretical helioseismological expertise for the German-led Visible-Light Imager and Magnetograph (VIM) instrument for ESA's Solar Orbiter mission;
- Co-Investigator with expertise in wave theories for the French-US Radio and Plasma Wave (RPW) instrument proposed for ESA's Solar Orbiter; and
- Co-Investigator for mission design, data analysis, and theory for the Heliospheric Explorer (HEX) concept proposed to ESA.

Australia's space scientists collaborate globally. Existing collaborations include the following countries and institutions:

- Belgium (Royal Belgian Observatory, Von Karman Instit. for Fluid Dynamics);
- Canada (National Research Council, U. Alberta, U. Calgary);
- China (Chinese Academy of Sciences, Chinese Academy of Surveying and Mapping, Chinese Earthquake Administration, National Astronomical Observatories, Polar Research Instit. of China, Solar Activity Prediction Centre, State Bureau of Surveying and Mapping);
- ESA/Europe (Astrium/EADS, European Space Agency Technology Division (ESTEC));
- France (Centre National d'Etudes Spatiales, U. Orleans, Laboratoire de Physique et Chimie de l'Environment, Observatoire de Paris, Office National d'Etudes Aerospatiale (ONERA), and U. Orleans)
- Germany (German Aerospace Center (DLR), multiple Max Planck Institutes, Aachen U., Tech. U. Munich, U. Bundeswehr, and U. Kiel);
- India (Indian Inst. for Astrophysics, Indian Inst. of Science);
- Italy (Int. Res. School of Planetary Sciences, Italian Aerospace Agency (CIRA), Inst. Naz. di Astrofisica – Inst. di Astrof. Spaziale e Fisica Cosmica);
- Japan (Earth Remote Sensing Data Analysis Center, JAXA, Kyushu U., National Institute of

Information & Communications Technology (NICT), Space Environment Research Centre, Space Forecast Centre, U. Kyoto, Tohoku U.);

- South Africa (SA Government Department of Communication, U. Natal);
- UK (Astrium/EADS, British Antarctic Survey, Imperial College, Institute of Engineering Surveying & Space Geodesy, U. Leicester); and
- USA (California Institute of Technology (Caltech), Dartmouth College, Jet Propulsion Lab (JPL), Johns Hopkins U., Massachusetts Institute of Technology (MIT), NASA Goddard, NASA Johnson, National Oceanic and Atmospheric Administration (NOAA), Oregon State U., Southwest Research Institute, Space Environment Lab., Space Weather Prediction Center, Space Science Institute, SRI International, Stanford U., U. Alabama-Huntsville, UC Berkeley, UC Los Angeles (UCLA), UC Riverside, U. Hawai'i, U. Iowa, US Air Force Research Labs, US Geological Survey, US Naval Academy).

International fora that Australia's space scientists currently lead, participate officially in, or recently led (2001-2009) include the following:

- American Geophysical Union (AGU; Associate Editors of the Journal of Geophysical Research, the journals *Radio Science* and *Space Weather*, and Reviews Editor for *The Radio Science Bulletin*);
- American Institute for Astronautics and Aeronautics (AIAA; Member of HyTASP technical committee, Member of Steering Committee for International Space planes and Hypersonic Systems and Technologies Conference Series);
- Asia Oceania Geosciences Society (AOGS; Secretary General, President and Vice-President of Solar Terrestrial (ST) section, ST Secretary for Cosmic Rays; Editor-in-Chief for ST sections);
- Climate and Weather of the Sun Earth System (CAWSES; Vice President, Member of Science Steering Committee);
- Committee on Space Planes Research (COSPAR, a committee of the International Council for Science (ICSU); Council, National Delegate, Member of Working Group on the International Reference Ionosphere);
- European Congress on Aerospace Sciences (EUCASS; member of the Hypersonics Sub-Committee);
- Geochemical Society (Member of the Board of Directors);
- Global Geodetic Observing System (GGOS; Member, Steering Committee);
- International Academy of Astronautics (Member, Commission VI, Societal Impact of Space Exploration);
- International Space Exploration Coordination Group (ISECG; National Delegate via CSIRO) - formerly the Global Exploration Strategy (GES) working group;
- International Association of Geodesy (IAG; Vice President);
- International Association for Geomagnetism and Aeronomy (IAGA; President, Chair of Division IV, Chair of Working Group V-8, National Delegate);
- International Association of Meteorology and Atmospheric Sciences (IAMAS; Vice President);
- International Astronomical Union (IAU; Vice Presidents of Division II and Commission 10);
- International GNSS Service (IGS; Member of Executive & Governing Board);

- International Heliophysical Year (IHY; Council member, National Coordinator);
- International Living With a Star (ILWS; National Representative);
- International Polar Year (IPY; Co-Chair of the WMO-ICSU IPY Committee; National Coordinator);
- International Shock Waves Institute (ISWI; Associate Editor of Shock Waves Journal);
- International Society for Photogrammetry & Remote Sensing (ISPRS; President);
- International Union for Geodesy and Geophysics (IUGG; President);
- International Union of Radio Science (URSI; Vice President, Member of the Working Group on the International Reference Ionosphere, Members of Working Groups 1 and 4 of Commission G);
- Ionosonde Network Advisory Group (INAG, Working Group 1 of Commission G of URSI; Editor of INAG Bulletin and past Chair);
- Meteoritical Society (Member, Executive Council);
- NASA Astrobiology Institute (Associate Member);
- NASA Lunar Science Institute;
- Scientific Commission on Solar Terrestrial Physics (SCOSTEP, an ICSU committee; President, Member of Steering Committee for the Planetary Scale Mesopause Observing System; National Delegate, multiple Scientific Discipline Representatives);
- Scientific Committee on Antarctic Research (SCAR, a committee of ICSU; Working Group on Solar Terrestrial and Astrophysical Research);
- World Meteorology Organisation (WMO) – ICSU International Polar Year Committee (Co-Chair);
- WMO – IOC – ICSU Joint Scientific Committee for the World Climate Research Programme (WCRP; Chair); and
- WMO – IOC – UNEP – ICSU Steering Committee for the Global Climate Observing System (GCOS; Chair).

Clearly, Australia's space scientists are internationally competitive and well regarded overseas, and space science is an excellent field for further investment by Australia.

II.2 Australian Space Science: Numbers, Assets, and Budgets

Australia's space science community currently has significant scale, both domestically and internationally, in terms of personnel, assets, and budgets. The 2008 data below place lower limits on these scales. Development of a more accurate census is an expected outcome of the Decadal Plan, together with performance metrics.

The numbers below are believed to be accurate for the space physics (and space weather), planetary science, astrobiology, and space technology portions of the 2008 space science community at universities, BoM, IPS, and AAD, as well as CSIRO's CSST and Deep Space Network staff. Not included are DSTO, GA, the thousands of science and operational government, commercial, and academic users of Earth observation, GPS, communication, and other space services, the National Measurement Laboratory, university engineers, most industry firms, and most of CSIRO.

II.2.1 People

Based on these figures, Australia's space science community has over 162 paid, full-time equivalent (FTE), professional staff, distributed over all five research areas but dominated by space physics/weather and space technology - see Figure II.2.1. Over 105 of these are scientists and technologists, with about 35 additional computing and technical staff.

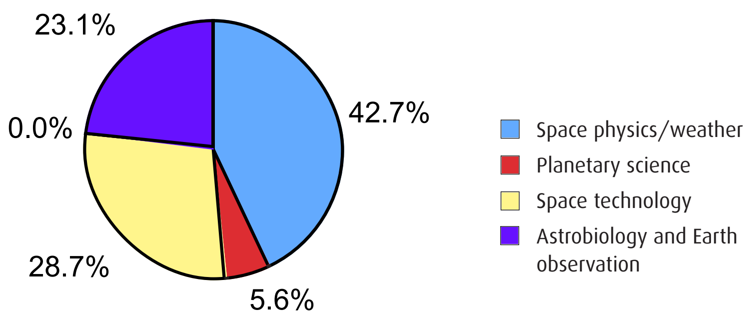


Figure II.2.1: Distribution of professional space science staff over the areas: (1) Space physics/weather, (2) planetary science, (3) space technology, and (4) astrobiology and Earth observation combined. The 143 staff shown here (of the 162 FTE) are from 19 institutions and companies.

In 2006 over 73 students were enrolled in PhD degrees in space science, meaning approximately 20 students graduate each year with PhDs in space science. Space technology (especially hypersonics) dominated but astrobiology, space physics/weather and planetary science all have large numbers. From 2001 to 2005 at least 21 students graduated with PhDs in space physics/weather.

The age distribution for the professional staff is evenly distributed over the decades (Figure II.2.2), with the expected decreases in the retirement years and also in the 21-30 decade (because usually staff are older than 25 when appointed and take overseas postdoctoral fellowships when 21-30 years old). This distribution and the numbers of enrolled and graduating PhD students demonstrate that space science is a healthy and viable community that is able to capitalize effectively on further government and commercial investment.

Australian business has serious commitments to space. Mimix Broadband, maker of advanced microwave and wireless microelectronic components, has 11 FTE Australian staff that support space science. British Aerospace (BAe) has an extensive professional Australian staff supporting radars and other space science-relevant work for government and industrial clients. Optus, part of SingTel Group (Asia's largest communications group), has designed nine and currently operates five satellites from Australian facilities. Cisco, Ball Aerospace, Kintner Aerospace, EOS and other corporations have offices in Australia for space-related business.

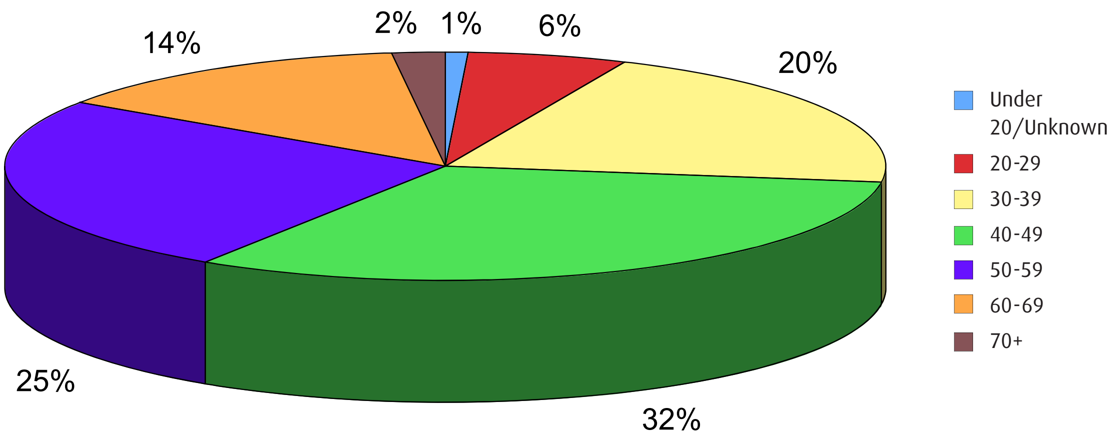


Figure II.2.2: Age distributions of the sample of space scientists for which age data were provided. They comprise 103 staff members from 18 institutions and companies.

In addition, scientists and technologists working in their own time in organizations like the Mars Society of Australia (MSA) perform space research that is recognized by NASA and ESA. MSA lists over 24 FTE staff doing this for the period 2001-2006.

Finally, operational users of civil space data in Australia plausibly exceed 1000 FTE, ranging from government (council, state, and federal) to transport, communication, agriculture, and other industries. FTE users in Defence likely exceed 1000.

Figure II.2.3: Location and types of Australian-owned observational assets for space science. The Key is at the middle left. Details are in Appendix F.

II.2.2 Assets: Replacement Costs and Locations

Australia has extensive assets for space science spread across the Australasian region, from Malaysia and the Philippines to Antarctica and from Christmas Island to New Zealand, Nieu, and Tonga (Figure II.2.3). **Over 90 systems exist**, as detailed in Appendix F, not including the NASA and ESA tracking stations, and satellite-data downlink stations. The primary research foci are on space physics and space weather (including atmospheric science), comprising the majority of Antarctic and Australasian assets, and on laboratory investigations relevant to planetary science and astrobiology. These assets are the bedrock on which the proposed project SpaceShip Australis (Section III.5.1) is based.

Even restricted to the universities, IPS, and the upper atmosphere / space portion of AAD, the replacement costs for these ground-based assets for space science exceed $56 M (Figure II.2.4).

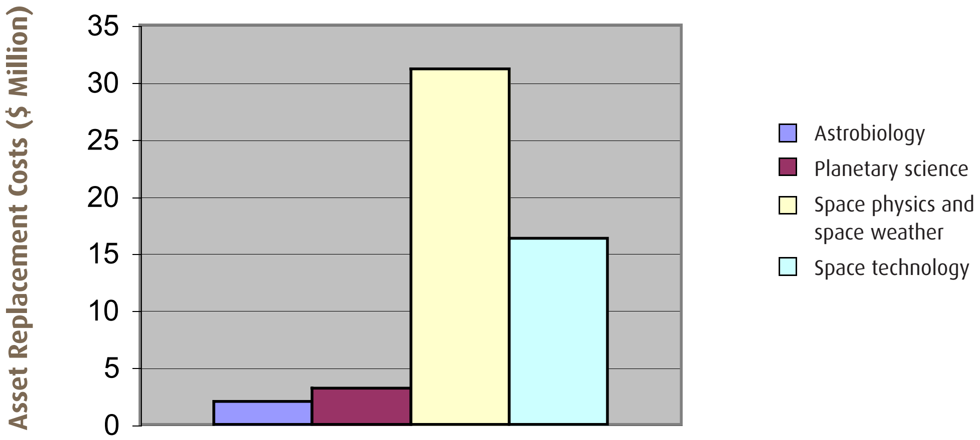


Figure II.2.4: Estimated replacement costs of science and technology assets for a portion of the Australian space science community.

Australian space science assets are predominantly in space physics/weather and space technology, with $31 M and $16 M, respectively. For space physics/weather the dominant contributions are for AAD's extensive atmospheric and space weather assets and the space weather assets of IPS (totaling near $25 M), with Universities contributing about $6.6 M. Space technology assets are dominated by $14 M for hypersonics and $2.0 M for advanced clocks and communication systems. Assets in astrobiology and planetary science are $2 M and $3.2 M, respectively. These are mostly for advanced mass spectrometers and geochemical analysis equipment, with space science only allocated a 10% fraction of the total replacement cost. The total replacement cost is therefore a factor of 10 higher.

Australia's FedSat satellite was launched in December 2002 and provided valuable data that are still being analyzed extensively. FedSat's replacement cost is estimated to be an additional $35 M over the amounts in Figure II.2.4, evenly split between space physics / weather and space technology. Thus, even a partial census of Australian space assets shows a minimum replacement cost of $91 M.

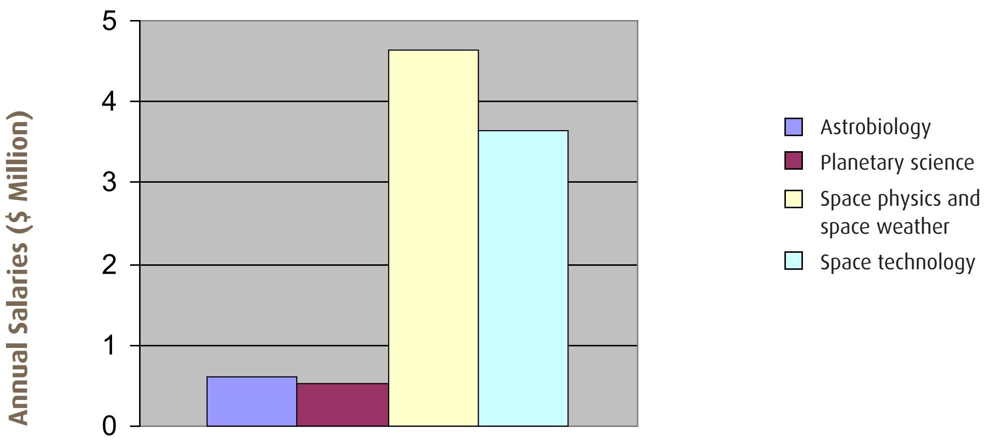


Figure II.2.5: Annual salaries for portions of the Australian space science community.

II.2.3 Annual Budgets and Running Costs.

Total annual salary budget for the universities, IPS, and the upper atmosphere/space portion of AAD is approximately $9.4 M, while the corresponding running costs are $1.3 M. These are conservative lower limits to the salary budgets and running costs for the Australian space science community, and are approximately 12% and 1.5%, respectively, of the minimum replacement costs for assets.

Figure II.2.5 shows how the annual salaries are spread over the research areas. Again space physics/weather and space technology dominate, with about $4.6 M and $3.7 M per year, respectively. Astrobiology and planetary science have annual salaries near $0.6 M and $0.5 M, in part due to salary splitting with other areas (eg geology and astronomy – counterparts exist for space physics/weather and space technology also).

Annual running costs for the research areas are in Figure II.2.6. Space physics/weather and space technology dominate, with about $0.84 M and $0.44 M, respectively.

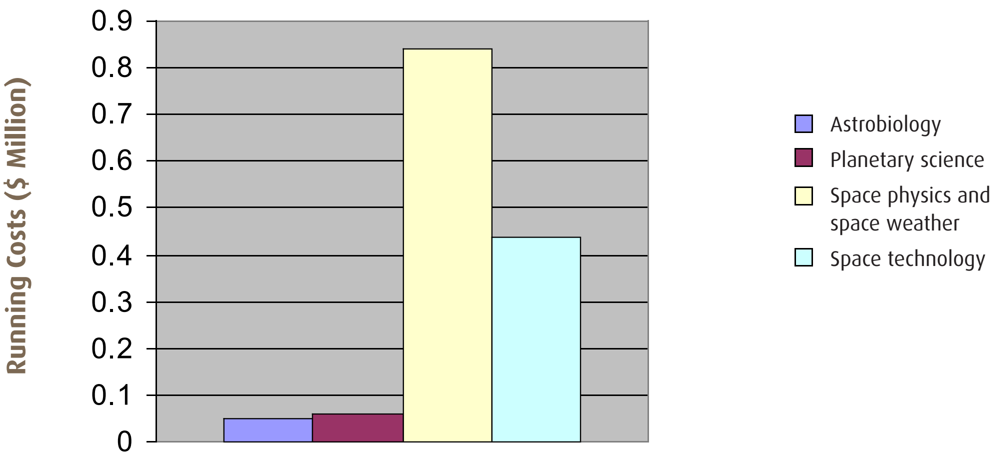


Figure II.2.6: Annual running costs for portions of the Australian space science community.

II.2.4 Comparisons

These assets and replacement costs do not include existing and planned GPS receiver arrays (eg the National Geospatial Reference System and AuScope), radio telescopes for tracking and data reception from NASA and ESA spacecraft, ground reception stations for multiple international Earth observation missions, ground meteorological stations, or infrastructure required (eg computers) to use Earth observation data. This infrastructure, much of which is primarily operational, is plausibly valued above $200 M. Most can be used for space science.

Additional replacement costs above include: replacement of Australia's presently free access to weather satellites, conservatively budgeted at $1000 M; the costs of many forms of Earth observation data currently obtained free (budgeted at $100 M per year); and the development cost of Defence's JORN radars ($1800 M).[15]

15 Risks associated with these dependences are discussed in Sections I.4(i), (ii), and (iii).

II.3 Institutions and Groups Driving Australian Space Science

Australian space scientists belong to over 15 academic and 14 government institutions spread across Australia, in all states and territories except Northern Territory (Figure II.3.1), including:

- 16 academic major research universities, often with several research groups;
- Eight CSIRO Divisions and CSIRO Space Science and Technology (CSST) have interests and expertise in space science (DIISR);
- Australian Antarctic Division (DEWHA);
- Bureau of Meteorology (DEWHA);
- Defence Science and Technology Organization (Defence);
- Geoscience Australia (DRET); and
- IPS Radio and Space Services (BoM, DEWHA).

In addition, the former Australian Greenhouse Office (DCCEE) contains atmospheric and Earth observation scientists who can be considered space scientists, and the Victorian Space Science Education Centre (VSSEC) drives significant education and outreach in space science and the underlying enabling sciences and mathematics.

Australia's expertise in space science covers all five areas (Section II.2.1) and is widely distributed across the country. Impressively, both the universities and the government institutions have expertise in all five areas. More details are provided in Appendix G.

Figure II.2.3 shows Australia's extensive observational assets. There are also satellite data acquisition stations near Perth, Casey, Crib Point, Alice Springs, Adelaide, Darwin and Townsville.

Australia also has great expertise in theory, computation, and modelling. This expertise is primarily concentrated at the Australian National University, BoM, CSIRO, DSTO, IPS, Monash University, and the Universities of Newcastle and Sydney. This expertise provides the critical underpinning for the experimental, observational, and technology development activities in space science. Often it leads to the higher value science and technology, since data and associated analysis techniques are often expected to be freely available shortly after measurement, thereby tending towards a 'commodity' product. In comparison, theory, computation, and modelling lead to predictive capabilities and detailed understanding, the goal of most scientific developments. Developing and extending these capabilities in theory, computation, and modelling is a major focus of this Plan. Accordingly, these capabilities are a major focus of the desired National Institute of Space Science (NISS) and are specifically built into the Flagship projects SpaceShip Australis (SSA) and Marabibi Constellation.

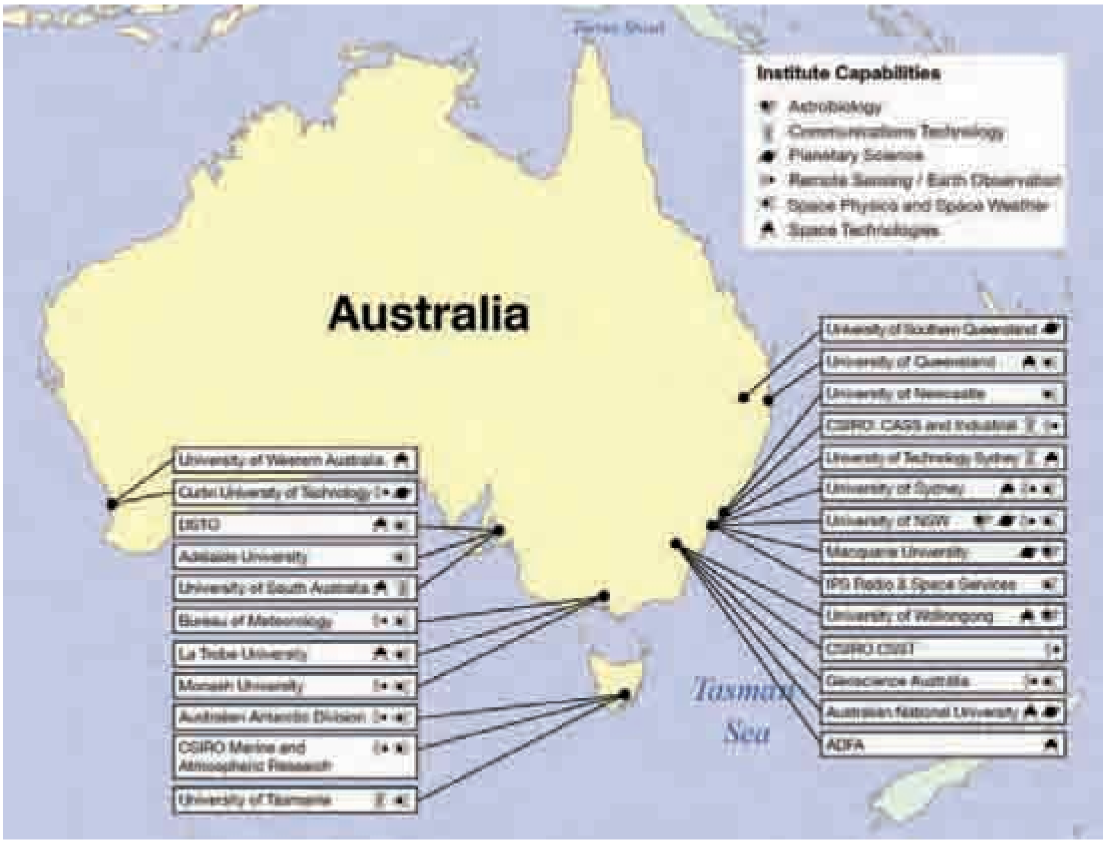


Figure II.3.1: Headquarters and research fields of Australian institutions with expertise in space science.
The Key is at the top right.

II.4 Examples of Australian Space Science, excluding Earth Observation

Solar flares and associated modelling

The solar group in the Centre for Stellar and Planetary Astrophysics (CSPA) at Monash currently consists of two academics and four PhD students. Two of their major research areas are: (i) probing below sunspots using theory, computer codes, and solar surface data from NASA's Solar and Heliospheric Observatory (SOHO) and (ii) detection with holographic techniques of 'sunquakes' produced during solar flares (Figure II.4.1). These are detected by imaging and identifying the acoustic sources rather than the radiating wave pattern associated with quakes. The goals are to identify the excitation mechanism, based on modelling and multi-wavelength observations of the progenitor flares, and to explain why many very large flares do not produce quakes, whereas some medium size flares do. This has the potential to reveal new insights into flares.

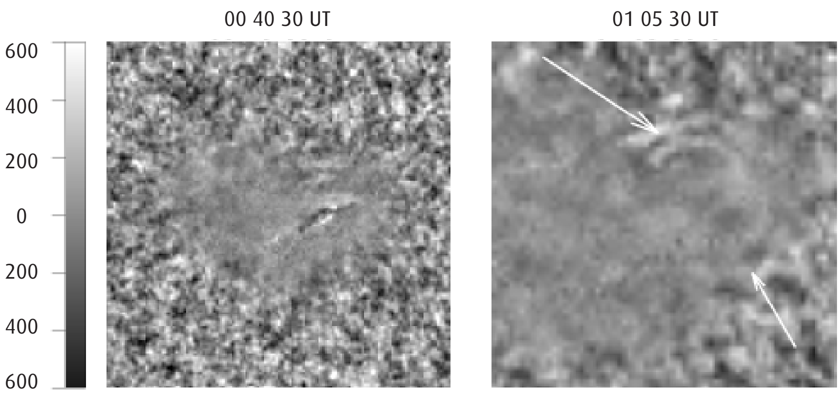


Figure II.4.1: Doppler-difference images from SOHO of a ring of waves moving outward from the site of the 15 January 2005 flare. (Left panel) Doppler signature during the flare's impulsive phase, at 00:40:30 UT. (Right panel) Arrows show the sunquake ripples propagating outwards 25 minutes later.

Theories for solar and interplanetary radio bursts & the STEREO spacecraft

Solar flares and coronal mass ejections lead to energetic electrons and shock waves moving through the corona and the interplanetary medium. The Space Physics group (five academics, four postdocs, and eight PhD students) at the University of Sydney's School of Physics developed and is refining state-of-the-art theories for the radio emissions and plasma waves associated with these phenomena. This involves analytic theory and numerical simulations, models for the solar wind plasma and magnetic field that are driven by spacecraft data, and comparisons of theoretical predictions with spacecraft observations. The group's principals helped design the radio and plasma waves instrument S/Waves on NASA's Solar Terrestrial Relations Observatory (STEREO) mission, launched October 2006. They are official Co-Investigators on STEREO. Their goals are to use radio triangulation, in situ observations, and theoretical models to identify and track solar phenomena directed towards Earth (eg Figure II.4.2), understand and predict the space weather, and understand the detailed plasma physics.

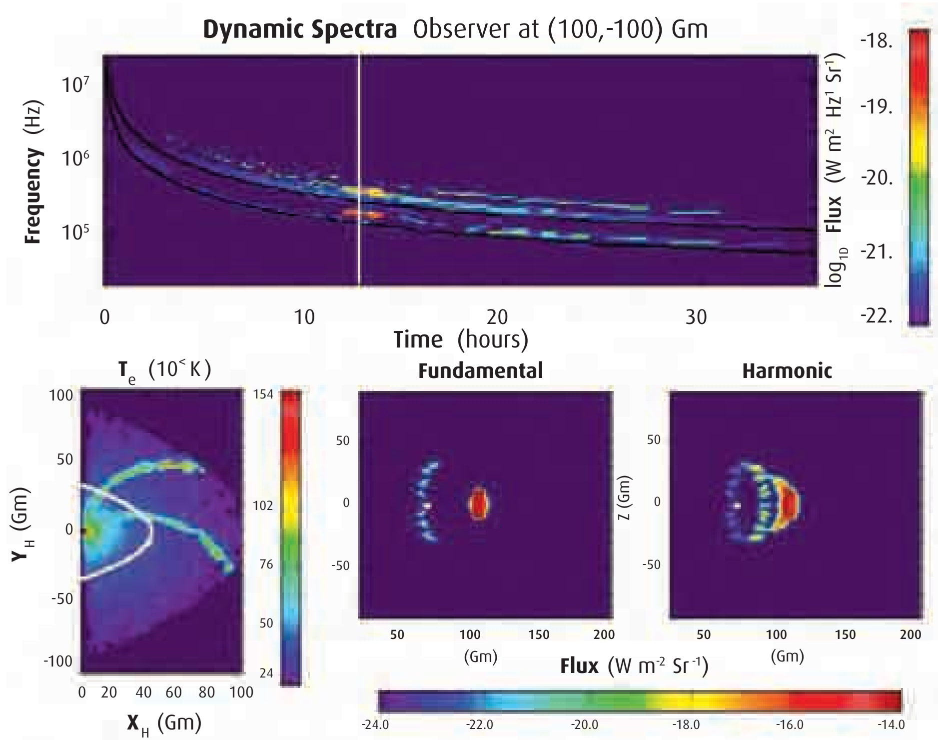


Figure II.4.2: (top) Radio intensity predicted as a function of frequency and time for a shock driven by a CME directed at Earth; (left) birds-eye view of solar wind structures in the electron temperature and the shock (white parabola) at the time of the vertical white line in the top panel; (bottom center and right) snapshots at this time of radio sources on the shock seen by a side observer (eg STEREO). The three-dimensional structure is seen.

IPS World Data Centre and global provider of space weather data

The World Data Centre (WDC) for Solar Terrestrial Science, hosted at IPS Radio and Space Services, is the national archive for solar-terrestrial data. Fully-released WDC data sets are available on the IPS WDC website (access by www.ips.gov.au) and restricted (currently non-WDC) data sets are stored and maintained at IPS in WDC formats in anticipation of their future release to the WDC. The data acquisition philosophy is to obtain as wide a range of relevant national data sets as possible.

Currently, the WDC contains data sets from IPS instruments across Australia, its islands, and neighbouring countries that probe the ionospheric electron density (ionosondes and riometers), ground-based magnetic fluctuations (magnetometers), and solar radio emissions (Learmonth and Culgoora Solar Observatories). The archive also includes data from University of Newcastle instruments in Antarctica (magnetometers and a riometer) and on the FedSat spacecraft (magnetometer) and AAD instruments in Antarctica measuring cosmic rays, the auroral lights, and magnetic fluctuations. Important non-WDC data sets include radar data from the TIGER (Bruny Island) and Unwin (New Zealand) radars, and radio propagation data related to scintillations and the ionosphere's total electron content.

Data processing and handling are automated as much as possible, with new methods under development in some cases, especially for quality control. Various digital media are supported – currently network drives, DVD, CD, and magnetic tape - with plans to constantly update with new technologies. Past records back to 1933 include film (safety and nitrate film), and paper records, both on-site and with National Archives of Australia.

Cosmic rays & space weather

Cosmic rays are affected by, and are a source of, space weather phenomena. CMEs and the shocks they drive act as permeable barriers to cosmic rays, significantly reducing the cosmic ray intensity behind the shock and changing the angular distribution. The decrease takes a few hours whilst the recovery to normal levels takes days to a week. The Kingston and Mawson telescopes detect the muon component of cosmic rays. They are operated by the Australian Antarctic Division (AAD) as part of a global ground based network that can observe approaching CMEs many hours in advance of arrival by monitoring the angular distribution. This is an important, but not fully developed, predictive capability for space weather events.

In addition, solar flares can produce high levels of high energy cosmic rays. The 20 January 2005 flare produced relativistic protons that increased radiation levels at ground level by a factor of almost 50 times, and by much higher factors in space (Figure II.4.3). Such events have rise times of the order of tens of minutes and can last from hours to a day. AAD's Mawson neutron monitor is part of the Spaceship Earth network that produces nowcast warnings within minutes of an event onset. These warnings are of great value to spacecraft and airline operators trying to reduce and mitigate radiation exposures and other disruptions due to space weather events.

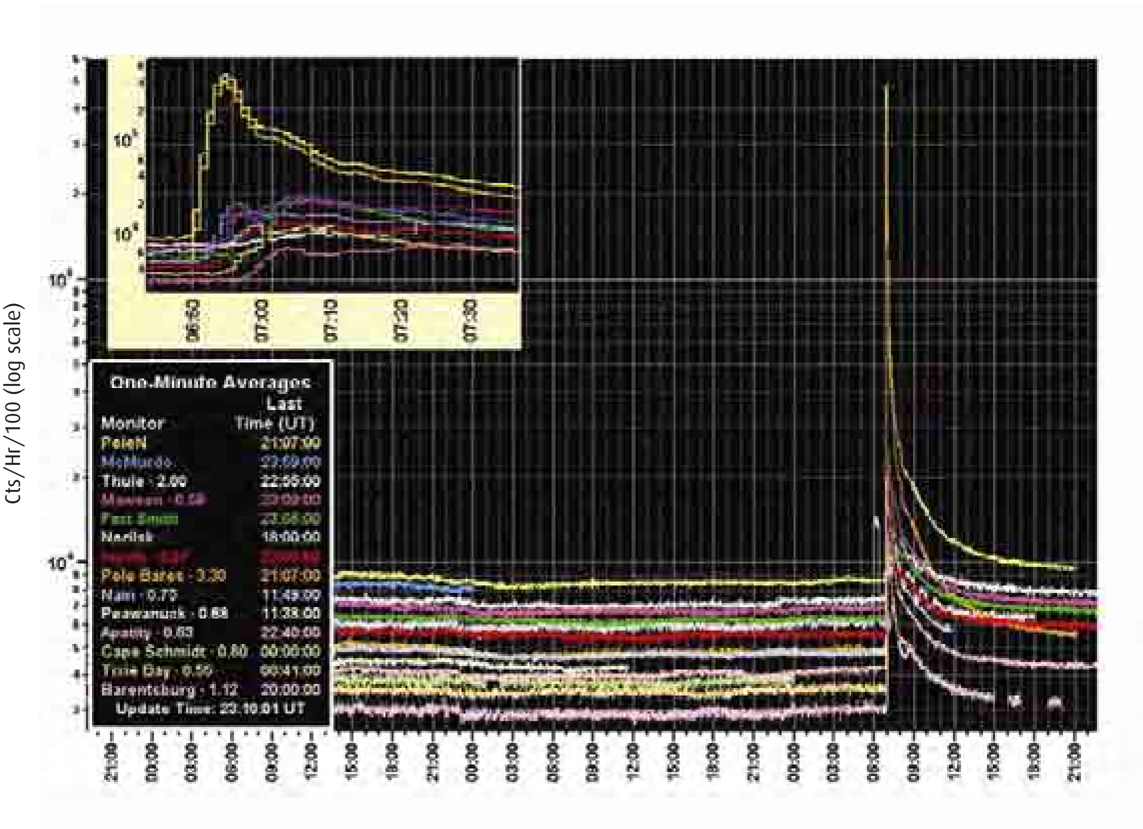


Figure II.4.3: Spaceship Earth real time observation of the 20 January 2005 solar proton event.

FedSat, ionospheric tomography, and changes during space weather events

GPS signals are modified as they propagate through the plasmasphere and ionosphere. In fact, correcting for ionospheric effects is essential in all GPS applications. These effects are determined by the total amount of ionization along the signal path. This can be determined from the GPS signals and used to study the Earth's plasma envelope using several techniques, including tomography. Tomography using GPS ground-based receivers is generally restricted to below about 800 km altitude as most of the ionization exists below this height. In contrast, GPS receivers on Low Earth Orbiting (LEO) satellites such as FedSat, which orbits at 800 km, can be used to image the ionization structure at both higher and lower altitudes. This is of increasing importance due to the recent Australian discovery of plumes of ionization moving plasma from the ionosphere to the plasmasphere, particularly as a consequence of geomagnetic storms.

FedSat provided the first tomographic images of a plume extending along magnetic field lines from the ionosphere to the plasmasphere (Figure II.4.4). FedSat data are being used systematically to study the dynamic 3D structure of the plasmasphere. This cannot be done with other single instruments, since most satellite instruments only sample conditions in the vicinity of the satellite's orbit. Extension of this tomographic capability is proposed in Flagship projects SpaceShip Australis and Marabibi Contellation.

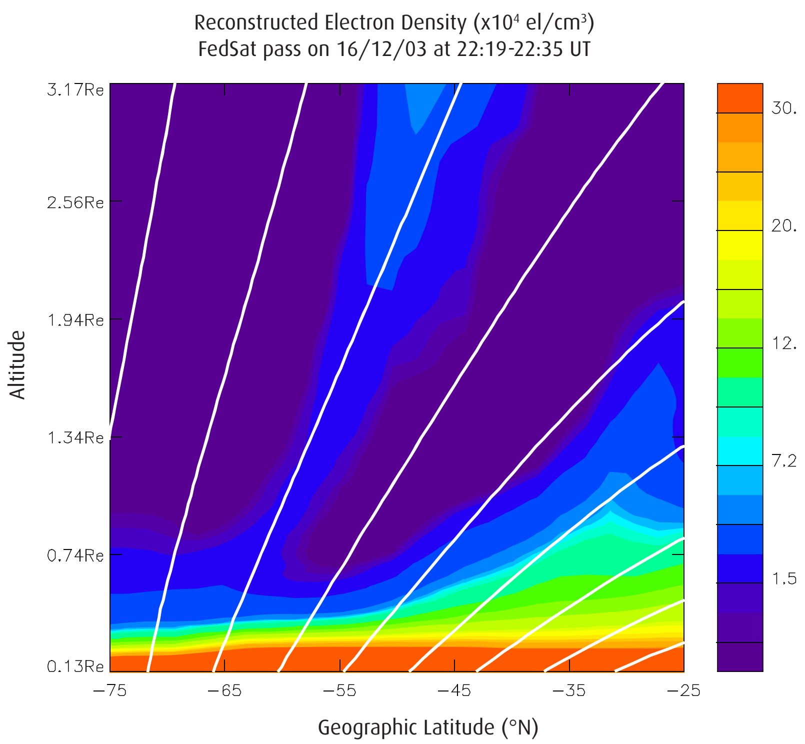


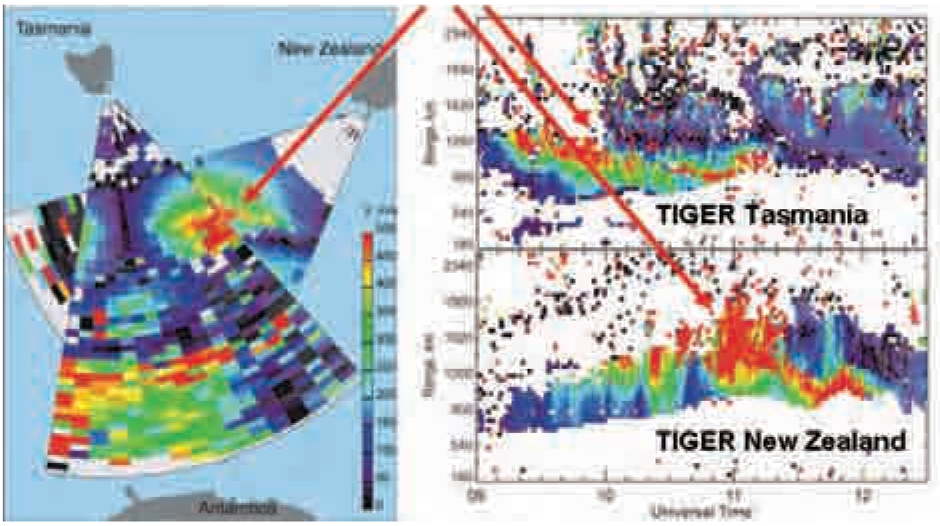
Figure II.4.4: Tomographically reconstructed density distribution using data recorded by the GPS receiver on FedSat. It shows an enhanced ionization plume moving upwards from the auroral region near 60 degrees southern latitude.

TIGER radar and travelling atmospheric gravity waves

The Tasman International Geospace Environment Radar (TIGER) consists of high frequency (HF) over-the-horizon radars, one in Tasmania and one in New Zealand (Figure II.4.5). TIGER is a key component of the southern hemisphere segment of the international Super Dual Auroral Radar Network (SuperDARN) that maps ionospheric convection at high latitudes. TIGER is used to study a variety of ionospheric phenomena that result from magnetosphere-ionosphere coupling.

TIGER has discovered a new class of intense westward flows located in the high latitude ionosphere immediately equatorward of the auroral oval (Figure II.4.5). These flows also exist in the magnetosphere. This discovery is important because the flow channels are synchronized with global substorm activity and the flows are the dominant signature of the magnetospheric substorm in terms of electric field strength.

TIGER is an excellent tool for studying the propagation of Atmospheric Gravity Waves (AGWs) propagating equatorward from sources located in the southern auroral zone (Figure II.4.6). Many travel very long distances, affecting HF systems operating in Australia such as JORN, and perhaps soon the MWA and SKA. It is important to characterize AGWs, their effects on the atmosphere and HF systems, and find ways to mitigate them.



Auroral Westward Flow Channel

Figure II.4.5: TIGER data for an auroral westward flow event, showing Doppler speed in colour (red is large). Overlapping radar scans (left) and time series of data for each radar (right).

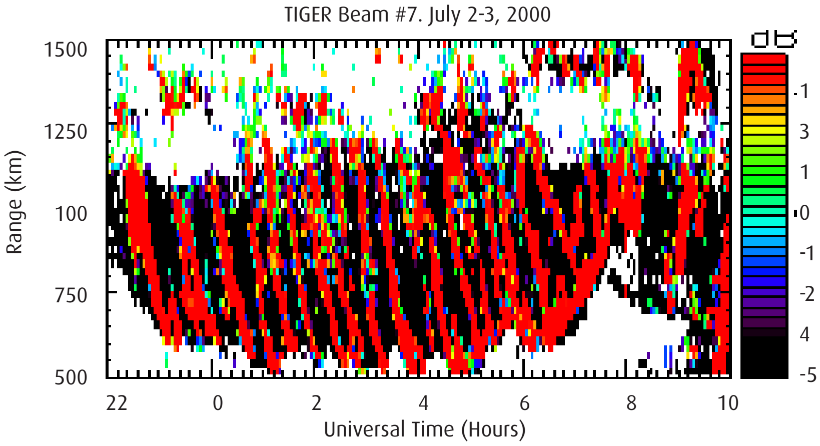


Figure II.4.6: AGWs observed by TIGER to travel northwards from the southern auroral region near Antarctica.

Atmosphere and meteor trails

The middle atmosphere encompasses heights between about 10 and 100 km of Earth's surface and includes the ozone layer. Middle atmosphere research carried out at the University of Adelaide (UoA) and AAD includes studies of winds, gas and ionic constituents, and temperatures. The UoA group studies middle atmosphere dynamics at stations located from the equator to the Antarctic. These observations provide the most comprehensive view in the southern hemisphere of atmosphere dynamics on both short (minutes) and long (climate) time scales. The Adelaide group also makes long-term studies of airglow emissions from heights of order 80-100 km (the mesosphere-lower thermosphere (MLT) region), including over solar cycles. In the same height range radar observations of meteor trails give information on winds. High resolution studies of the trails themselves give the meteorites' speed and deceleration, which helps determine the structure and composition of the incoming meteorites.

AAD uses a comprehensive suite of instruments located in Antarctica to investigate the structure and processes associated with the extreme conditions encountered in the Antarctic middle atmosphere in both summer and winter. Instrumentation includes a laser ranging (lidar) system to measure temperature, radar systems to study dynamics in both the lower and middle atmosphere, and hydroxyl (OH) airglow spectrometers for MLT temperatures. Processes studied include stratospheric clouds that cause strong ozone holes in winter and spring, and the high-altitude 'noctilucent' clouds seen at twilight during the southern hemisphere's summer, which may be a signature of climate change.

Cosmochemistry and Hayabusa

Australia has major strengths, especially at the Australian National University (ANU) and Curtin University of Technology, in cosmochemistry: this means the laboratory study of extraterrestrial materials such as meteorites, cosmic dust, and lunar samples in order to understand the origin and evolution of the solar system. One example is the invited participation of Australian cosmochemists in Japan's MUSES-C mission (spacecraft Hayabusa), which in 2005 imaged and characterized the S-type asteroid Itokawa (Figure II.4.7) and attempted the first ever direct sampling of an asteroid surface. The current plan is for Hayabusa to return to Earth in 2010 and land its sample near Woomera (SA). Hayabusa's accomplishments include detailed correlations of spectral variations with the distribution of rocks and dust on the asteroid's surface. These data have led to new insights into processes that modify asteroid surfaces in space and new explanations for longstanding discrepancies between observations of meteorites and asteroids.

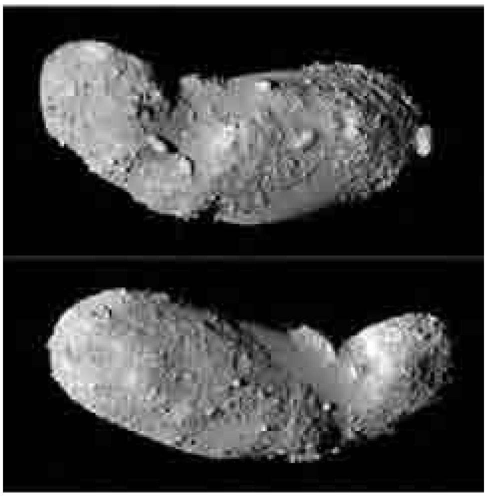


Figure II.4.7: Asteroid Itokawa as viewed by Hayabusa.

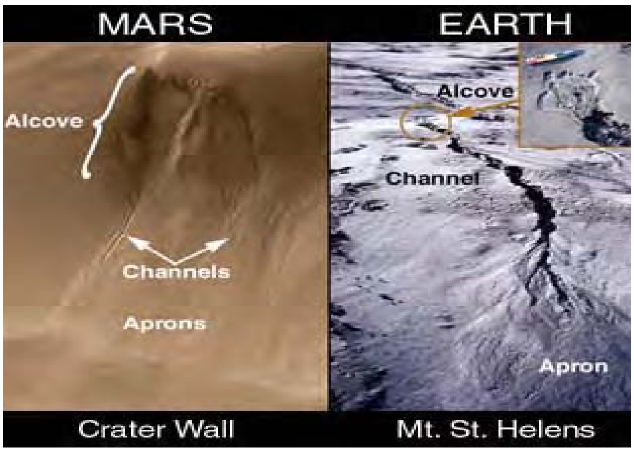


Figure II.4.8: Similar geological features observed on Mars and Earth.

Planetary geology and geophysics

Australia is eminently placed at the forefront of planetary geology and geophysics, which studies the structure and geological evolution of the terrestrial planets Mercury, Venus, Earth, and Mars. Research groups are at ANU, Geoscience Australia (GA), Macquarie University, Monash University, University of Technology Sydney (UTS), University of New South Wales (UNSW). University of Southern Queensland (USQ), and Mars Society Australia (MSA). Remote sensing data obtained by spacecraft are used to identify surface landforms, relevant processes (eg plate tectonics), and probe the deep interiors (Figure II.4.8). Thence plausible models and constraints are derived for the formation and evolution of the terrestrial planets, and so the Solar System. For example, UTS researchers used data from NASA and ESA missions to Mars, in collaboration with the International Research School of Planetary Sciences (Pescara, Italy), to identify volcanic and tectonic landforms in the ancient southern terrains of Mars. Similarly, MSA scientists, in longstanding collaborations with NASA scientists, are studying erosional landforms in Australia and their Martian analogs. They are also developing MARS-OZ, a planned experimental facility in South Australia, to train personnel and test equipment in arid conditions similar to those likely to exist in future landing regions on Mars. Finally, planetary geologists at USQ used Clementine spacecraft data to map the composition of the Moon's surface, providing hard evidence of the extent and significance of the various igneous rocks that cover the surface of the Moon.

Mars analogue research

The Arkaroola region of Australia's Flinders Ranges has a diversity of geological features of interest for Mars research and exploration. These include a wide range of sedimentary, metamorphic, and igneous rocks, fossils of ancient life (stromatolites), ancient hydrothermal systems, and fossil microbes from a deep, hot biosphere. The landscape is a complex palimpsest of deep weathering and ancient marine shoreline deposits, overprinted by subsequent activities by modern hot springs and artesian seeps, and the salt lakes, dune fields, and gravel outwash plains of the present desert environment. The diversity of rock types and regolith materials provides an ideal test bed for remote sensing systems, ground instruments, and laboratory geochemical and biological equipment. The range of terrain, rock, rocky slopes and gorges to dunes, boulder-covered outwash deposits, and smooth, dust-mantled plains, provide excellent opportunities for testing mobile exploration systems. The area is also ideal for training and education at all levels because of the diversity of Mars-analogue sites. Researchers from the Mars Society Australia have used the region for several research activities.

Astrobiology

The oldest convincing evidence of life on Earth is found in the Pilbara region of Western Australia (WA). The evidence is both morphological and chemical. It is found in rocks 3.4-3.5 billion years old. While some of this research is decades old, new observations and techniques have greatly expanded the horizons of this field. One example is by using very detailed geological mapping followed by spatially resolved chemical analyzes at the scale of micrometers. It also involves the study of extant microbial ecosystems considered to be analogous to the ancient systems. The link to space science lies in the development of techniques to search for life beyond Earth, most of which, if it exists, is likely to be microbial.

Australia is uniquely positioned to lead this research. There is a long history of such work here, extending back to and beyond the research of Sir Douglas Mawson. That history and the fact that we are the custodians of a unique rock record give Australia special opportunities. That is widely recognized and is leading to major international research programs focused on the Pilbara, most notably by NASA and the Australian Centre for Astrobiology (ACA).

The research in the Pilbara is in its infancy. With rare exceptions, the detailed geological mapping (by Geological Survey of WA and others) still awaits petrographic and microchemical studies. When combined, the results have been spectacular.

Hypersonics

Hypersonics is the science and technology of flight at more than approximately five times the speed of sound, or Mach 5. At low hypersonic speeds (less than Mach 10), the application is typically hypersonic transport vehicles, for both civilian and military purposes. At hypervelocity speeds (greater than Mach 10), the application is access to space and planetary exploration. With our high enthalpy shock tunnels and expansion tubes and their associated diagnostic techniques, Australia has conducted world-class research in the field for four decades (Figure II.4.9). Efforts have focused on both hypervelocity planetary entry physics, for Earth and other planets, and on supersonic combustion ramjet (scramjet) propulsion for atmospheric transport and access to space.

For example, Australian researchers were the first to fly a scramjet vehicle with positive net thrust in a wind tunnel. With the HyShot program, Australia was the first to successfully produce in-flight supersonic combustion at hypersonic flight speeds. Examples of planetary re-entry research include: collaborative studies with NASA of the aerothermodynamics of entry vehicle concepts such as the Aeroassist Flight Experiment and torroidal ballutes (tethered toroidal balloons for planetary entry deceleration); and work with the former Japanese Institute of Space and Astronautical Science (now part of JAXA) on the Hayabusa MUSES-C asteroid sample return capsule.

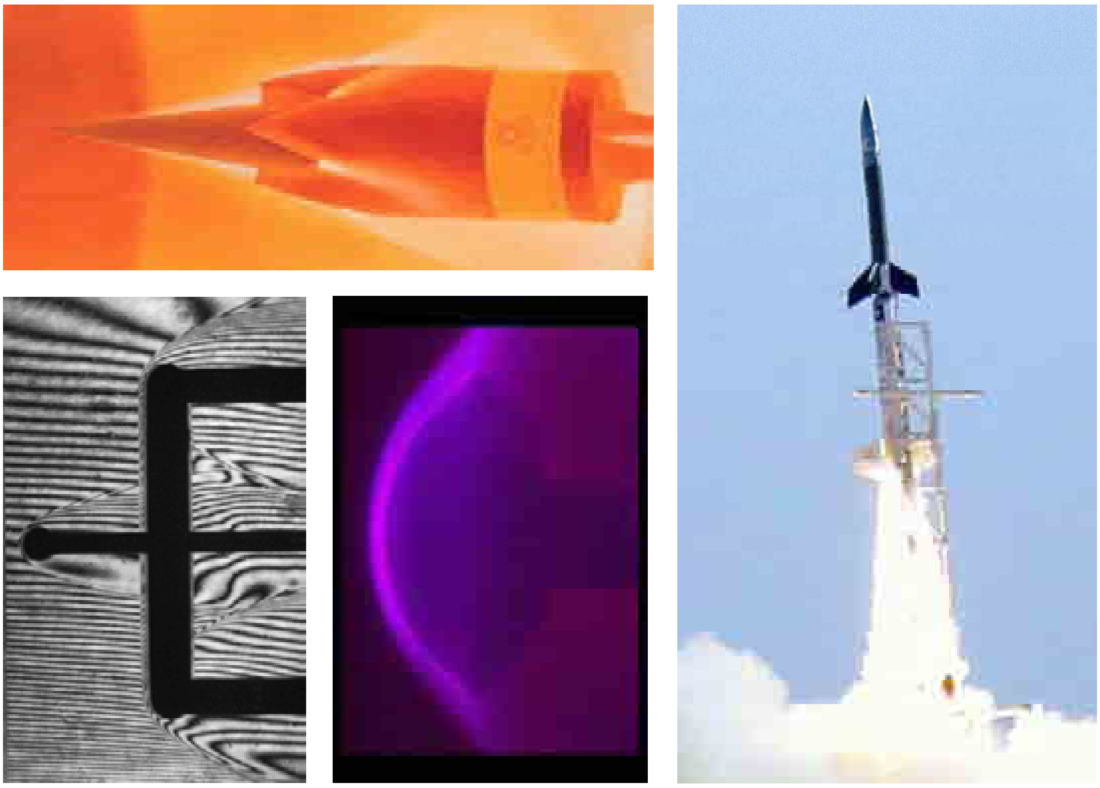
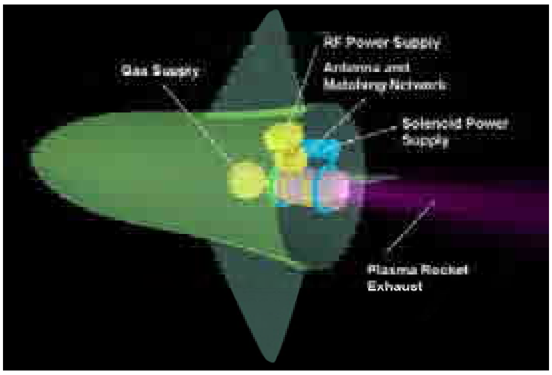


Figure II.4.9: Examples of hypersonics simulations, experiments and flights.

Plasma thrusters for space propulsion

Two types of plasma-based thrusters for space propulsion are being developed by the Space Plasma Power and Propulsion (SPPP) group at the ANU (Figure II.4.10), and one at the University of Sydney. One type, the Helicon Double Layer Thruster (HDLT), based on SPPP's recent discovery of current-free double layers, led to ESA inviting SPPP to construct a prototype thruster, funded by a DEST contract with the Cooperative Research Centre for Satellite Systems and AUSPACE Pty Ltd. Tested successfully by ESTEC in April 2005, a second contract was signed in late 2006 with AUSPACE on behalf of ASTRIUM, the largest space company in Europe. The second type, a new ion thruster with multiple stages and voltage grids, was conceived by SPPP and ESTEC in April 2005. The ion thruster was designed and built from scratch by a small team in only three months. Test campaigns in late 2005 and mid 2006 at ESTEC were very successful, with the thruster achieving a 30 kV voltage with an ion current of 10 milliAmps.

A major program exists to simulate and model the double layer plasma phenomena observed in the ANU thrusters. Computer simulations using millions of particles show the plasma dynamics, while analytical modelling allows more dimensions to be considered. Both techniques are vital for discovering the fundamental physical processes and optimizing the thruster design for actual applications in space.



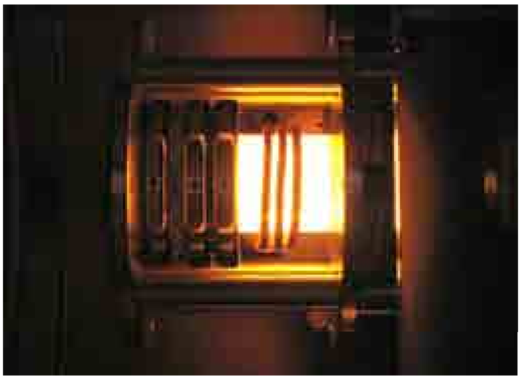


Figure II.4.10: Plasma thuster (left) concept and (right) device.

The Atomic Clock Ensemble in Space (ACES) mission

Atomic Clock Ensemble in Space (ACES) is an ESA mission in fundamental physics which will be launched in 2014. It is based on the operation of high stability and accuracy atomic clocks in the microgravity environment of the International Space Station (ISS). The time scale generated by the ACES clocks on-board the ISS will be delivered to Earth through a high-performance two-way time and frequency transfer link (see Figure II.4.11). The clock signal will be used to perform space-to-ground and ground-to-ground comparisons of atomic frequency standards. The University of Western Australia (UWA, Perth) and the National Measurement Institute (NMI, Sydney) have become an official user group of ACES, and as a precursor to ACES have set up a facility to compare clocks by both GPS carrier phase and two-way satellite time and frequency transfer. This involves sending and receiving transmissions to and from UWA and NMI via a geostationary Intelsat satellite, with time references provided by hydrogen maser, cryogenic sapphire oscillator, and GPS signals. For ACES the company Time Tech will provide the final ground-station modem/transceivers. This will allow highly precise clock comparisons between UWA and a worldwide network of the most accurate clocks yet built.

Figure II.4.11: The ACES mission. Ultra-stable atomic clocks on-board the International Space Station are compared to a network of ground clocks through a high performance two-way time transfer system

Radiation dosimetry, space medicine, and space technology

Solar particle events and cosmic rays cause serious radiation problems for humans and human technology. As well as single event upsets (SEU) in spacecraft and avionic electronics, they induce cancers in astronauts and high altitude aircraft crew (e.g. commercial aviation). A team from the University of Wollongong's Centre for Medical Radiation Physics (CMRP) has invented and developed the first solid state Silicon on Insulator (SOI) microdosimeter for measuring the radiation dose in multiple space environments. The CMRP team, located within the School of Engineering Physics, consists of six academics, two Postdoctoral Fellows and over 40 postgraduate students (three are recipients of gold medals from the Australian Institute of Nuclear Science and Engineering (AINSE)). Since 2004, CMRP has obtained two NASA grants jointly with the US Naval Academy, under the National Space Biomedical program, and has developed a MicroDosimetry INstrument (MIDN) for Lunar and Mars manned missions (Figure II.4.12). MIDN was successfully tested at Brookhaven National Laboratory in the USA and launched into space on the US MidSTAR satellite. New instruments under development will be used in spacecraft and space suits to assess the radiation dose equivalent for astronauts and spacecraft electronics, aiding in decision making. CMRP's instrumentation program is supported by Monte Carlo simulations of radiation transport on cellular and DNA levels. These space R&D programs involve close collaboration with ANSTO and the Semiconductor Nanofabrication Facility at the University of New South Wales. The University of Wollongong is the only Australian university chosen by NASA to develop solid state microdosimetry instrumentation for space missions.

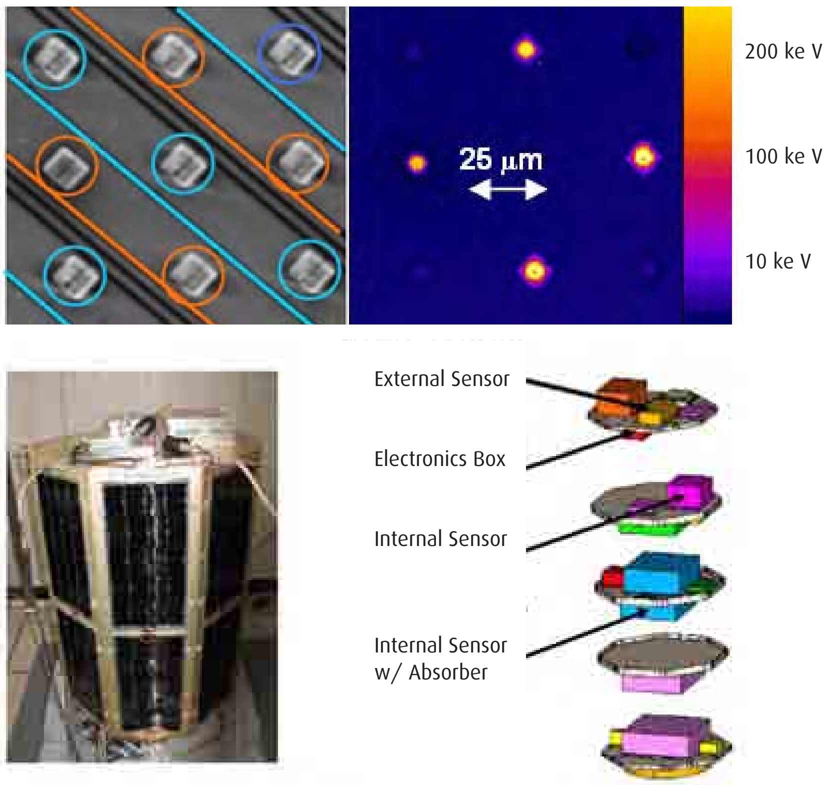


Figure II.4.12 (Top) (Left): Fragment of a CMRP microdosimeter chip and (right) the energy deposited on cellular scales by 3 MeV alpha particles. (Bottom): CMRP microdosimeters installed in the MIDN instrument inside and outside the 2007 US MidSTAR satellite, to investigate radiobiological effects in Low Earth Orbit. Collaborative research with US Naval Academy supported by NASA.

Chapter III

The New Plan for Australian Space Science

Chapter III

The New Plan for Australian Space Science

The Plan is intended to galvanize, inspire, and develop the community of space scientists currently working in Australia, as well as Australian governments, industry, and society. It provides sensible, practical suggestions to Australian governments about how they can help develop a sustainable, vibrant, world-class community of space scientists in Australia. This community will participate officially in the international space effort and help build a better future for all Australians.

The three organizing principles for the Plan's research are that:

(1) World-class Australian researchers exist in target or neighbouring research areas;

(2) The research areas either involve world-recognized Australian expertise, can be considered national priorities, or directly address the 'local' Australian region; and

(3) Australia's limited funds can be leveraged so that participation adds unique value and benefits to Australia and, ideally, the international community.

The Plan builds on existing strengths in Australian research in order to build a true national presence in global space research for less than $140 M from new government funding sources.[16] It identifies exciting, large-scale scientific themes and underlying fundamental and applied (but non-prescriptive) science goals, and addresses them with new large research and infrastructure projects that will build our nation's space capability and expertise and also link us with international collaborators. While remaining open to future opportunities and better ways to achieve its goals, the Plan involves:

- a ground-based state-of-the-art network (SpaceShip Australis) that will make the Australian region the best instrumented and modelled for measuring and predicting space weather and its diverse effects on government, industry, and society;
- building Australia a flexible, long-term space capability and associated infrastructure while pursuing world-first, student-focused research, strong education and training opportunities, and international collaborations via a constellation of nano to small satellites in Earth orbit (Marabibi Constellation) and a design study of an interplanetary spacecraft concept (Sundiver);
- a new program for Australians to propose instruments and collaborate as national representatives in international space projects, including for the International Space Exploration Coordination Group's (ISECG) research on humans in space;
- high-profile medium-sized infrastructure and science collaborations on hypersonic flight, digital radars, spacecraft propulsion, and image analysis, among others.

16 In 2009 dollars with September 2009 exchange rates. This sum does not include funding from the Australian Space Research Program and Australian Research Council for Medium and Small Projects.

In addition, in the Plan the Australian space science community will link itself, government, industry, and other stakeholders in space in order to:

- form a new entity (Coordination of Australian Space Science Ltd (CASS)) to coordinate, develop, and represent the Australian space science community, to manage some government investment, and to be a point-of-contact for government and industry;
- build a new National Institute for Space Science (NISS) to develop Australia's space capability and strongly engage with industry and international space agencies;
- develop and implement major new initiatives and capabilities in education and training via partnerships with education centres, industry, and government; and
- develop stronger and more highly valued relationships with the public, government, and industry for mutual benefit.

The Plan provides a comprehensive approach to create a true Australian capability in space that builds upon the Australian Government's exciting and historic 2009 space initiatives.

III.1 The Vision

The vision of the Australian space science community is:

'Build Australia a long term, productive presence in space via world-leading innovative space science and technology, strong education and outreach, and international collaborations.'

Expanded aspects of this vision are:

(1) Australia's space science community develops sustainably, coordinates with other stakeholders, is nurtured actively by government, and manages investment in space so as to produce more world-class scientific discoveries and technology;

(2) Australia's space scientists lead acclaimed national space projects with international partners, and participate in international space projects as national representatives, that position Australians to solve major scientific and technological problems;

(3) Australia develops a strong national capability in space science and technology, including ground- and space-based assets/data and theoretical models, that will benefit the nation in international, economic, and environmental affairs, and offset the risks of depending primarily on foreign-controlled space assets;

(4) Australia will develop a major education, training, and outreach capability based on space science and technology, that coordinates and leverages existing and new projects, both national and international;

(5) Australia's space science capability, including education and training, is leveraged to benefit the fundamental sciences and related fields (astronomy, atmospheric, and Earth sciences), to address government and business issues involving the supply of highly trained workers and mathematics- and science-literate citizens, and to help society understand global issues like climate change, environmental monitoring, and humanity's place in the universe;

(6) Australia's increased space capabilities will amplify the economic, Defence, and educational benefits of space services and mitigate space-related disruptions; and

(7) Australia's government, community and business will recognize and invest in the strong national and international benefits of space science and technology, ranging from national security to environmental integrity, to education and training, and to international prestige, territorial claims, and capabilities.

III.2 Global Science Themes

The Australian space science community has identified four exciting and visionary Global Themes to direct and motivate its research for at least the next decade, endorsing them at multiple workshops (Appendix E). Research efforts specific to the current Plan are organized under the Global Themes and described in Sections III.3 to III.5. Each Theme addresses unresolved scientific and technical issues of great significance, widespread interest, and large scale. Success will then lead to large impact and flow-on benefits, both in Australia and world-wide.

By design, each Theme draws together multiple parts of the space science community, both in terms of research area and groups, and each Theme links with the others so as to cover space science, the enabling sciences, and related fields of science and engineering. All Global Themes have an Australian focus but will naturally attract, and lead to participation in, both international and Australian-led projects relevant to Australia, Antarctica, and space. The Themes are:

Theme SSE 'Sun and Space to Earth':

Understanding quantitatively how and when activity on the Sun and in space develops and affects humans and their technology, from the Sun to Earth's surface. This research will also help model the climate, atmosphere, and surface of Australia and Antarctica from the distant past into the future, linking with Themes P2P, RS, and LIFTS. The underlying strategic aims are to:

(1) predict, test, and model events in Australia's domain of interest in space (from the ground to the Sun) and throughout the solar system;

(2) protect Australian assets and ways of life; and

(3) develop detailed theories and computational numerical models for the plasma physics concerned and for related astrophysical phenomena.

Theme P2P 'Plasma to Planets':

Developing a quantitative understanding of how Earth, the Moon, Sun, and other solar system bodies formed and evolved. The underlying strategic aims are to:

(1) explain the characteristics of Earth, with a focus on Australia and Antarctica, and its evolution on planetary timescales from the dusty solar nebula (linking with Themes RS and SSE);

(2) establish the effects of solar activity and evolution, cataclysmic collisions with space objects, and magnetism in the evolution of the atmosphere and biosphere (in association with SSE and LIFTS);

(3) predict the characteristics and evolution of exo-planets, with RS and SSE; and

(4) inform decision making on mining, environmental, climate, and relevant issues, linking with RS and LIFTS.

Theme RS 'Remote Sensing Australia, Earth and Other Bodies from Space':

Developing a quantitative knowledge of the atmosphere, oceans, and surface of the Earth, and of other solar system bodies (from planets to meteorites) based on space and ground observations and modelling. The underlying strategic aims are to:

(1) characterize and understand the present and past atmospheric, ocean and surface environments of Australia and Antarctica, with SSE and P2P;

(2) assess climate change and predict the consequences;

(3) provide new techniques and data for remotely sensing events and resources important to the nation;

(4) better manage Australia's natural and human environment; and

(5) develop theoretical and computational models, and test them with new data, for the evolution of Earth, planets, moons, and biospheres, linking with SSE, P2P, and LIFTS.

Theme LIFTS 'Life and Technology in Space':

Developing instruments and technology for space, understanding the effects of space on human technologies (from space to the ground), and quantifying how life developed on Earth and might exist elsewhere. The underlying strategic aims are to:

(1) provide instruments and technologies for Australian contributions to international and domestic space missions (linking with SSE, P2P, and RS), including the International Space Exploration Coordination Group;

(2) minimize the risks to Australian Government, industry, and society of space weather (linking with SSE and RS);

(3) maximize the economic and societal benefits of Australian investments in space research; and

(4) determine the constraints on, and likelihood of, life developing elsewhere in the universe.

III.3 Science Goals

The science goals and projects proposed for the Plan are specific but deliberately not proscriptive. This retains flexibility, so that the goals (and projects) can change as a result of future discoveries, changing circumstances, or evolving priorities for the nation and community. The current science goals are now described and related to Global Themes.

(1) Observe and model the drivers of space weather from the Sun to the ionosphere and surface of Earth, so as to predict their arrival and consequences at Earth and in space (Theme SSE).

(2) Understand the generation, propagation, and consequences of waves in space, including radar and radio signals in Earth's atmosphere and ionosphere (SSE, P2P).

(3) Understand reconnection of magnetic field lines, and associated heating and particle acceleration, with applications to solar activity and space weather at Earth (SSE).

(4) Observe and model the dynamics of Earth's ionosphere and the middle and upper atmosphere from the equator to the auroral regions and geomagnetic poles, including responses to space weather events (SSE, P2P, RS).

(5) Observe and model spatiotemporal variations in energy flow from the magnetosphere to the lower atmosphere, including the driving and propagation of ionospheric waves and changes in chemistry and other properties of the ionosphere and neutral atmosphere (SSE, P2P, RS).

(6) Develop, demonstrate, and sell Australian technologies for space, air, and ground use, including propulsion systems, advanced timing electronics, communication systems, and autonomous, multi-frequency, digital radars (LIFTS,SSE).

(7) Measure, model, and understand the influence of the upper atmosphere, ionosphere, and space on the lower atmosphere in order to contribute to improved understanding and forecasting of weather and climate (SSE,RS).

(8) Measure greenhouse gases and other atmospheric constituents from space, model climate change and its consequences, and provide independent verification of other measurements (RS, P2P, LIFTS).

(9) Develop and demonstrate remote sensing instruments that are either tuned to Australian conditions or have unique capabilities, and provide associated data and technology to Australian and other users (RS, LIFTS).

(10) Measure and model the self-assembly of plasmas and dust into solid bodies, possibly including experiments on the ground and International Space Station (P2P).

(11) Integrate measured chemical compositions of terrestrial and extraterrestrial materials with physical models to understand the timescales and mechanisms for planet formation, as well as the processes that create and allow persistence of distinct chemical and physical domains within planets (P2P, LIFTS).

(12) Measure and model the evolution of the Earth and solar system, based on observations of planetary atmospheres and surfaces, chemical composition measurements of terrestrial and extraterrestrial matter, and space weather effects (P2P, RS, SSE).

(13) Use unique Australian opportunities to delineate the origin and evolution of life, and life's interaction with its environment, in order to better understand and manage our environment and to contribute to the search for life elsewhere (LIFTS, RS).

(14) Measure and model the interaction of radiation with living cells, dosimeters (and associated inorganic analogues of living systems), and spacecraft systems, collaborate on changes of human physiology in space, and investigate the consequences for human medicine and the design of space structures and technology (LIFTS and SSE).

(15) Analyze, model, and integrate data from Australia, Antarctica, ocean vents, and elsewhere so as to constrain the timing, history, and persistence of life on Earth, in the solar system, and universe (LIFTS).

The Plan's research goals are challenging and represent significant steps towards achieving the Global Themes. These goals will be accomplished using a combination of new Structures (Section III.4), Research Projects and Infrastructure (Section III.5), Education and Training (Section III.6), and Public Outreach and Community Development (Section III.7). The space science community's priorities are listed in Section III.8.

III.4 Structures

The scientific Themes and Goals of the Plan require:

- active coordination and funding of the Australian space community, whether based in universities, government agencies, or industry;
- effective and strong connections to government; and
- the linking of the nation and its space community to international space efforts.

In addition, Australia would receive substantial national strategic benefits from having a well-recognized national space effort (Chapter I).

Figure III.4.1 shows a structure proposed by the Australian space science community to achieve these coordination and linkage goals. The structure involves a new entity, here called CASS (Coordination of Australian Space Science), but can also accommodate a new National Institute for Space Science (NISS) or a more general National Institute for Space Studies (again NISS). CASS is similar to Astronomy Australia Ltd (AAL) for astronomy, with NISS similar to the Anglo Australian Observatory for optical astronomy.

III.4.1 CASS (Coordination of Australian Space Science)

CASS is intended to be the national focus and unifying agent for space science and technology, as well as a government channel for dedicated new funding of the national effort (Figure III.4.1). It will provide access to space scientists and technologists for government, industry, foreign entities, and the public, as well as access vice versa.

The necessity of better management and governance of Australia's interest in space is argued in Chapter I.4(iii) above, resulting in Recommendation 3. Since Australia's interests in space are more general than space science alone, it is proposed below that government has an advisory entity for space as a whole (eg a Space Advisory Board or Council). However, an executive, community-based entity is appropriate for space science, since this would maximize innovation, capability and community development, engagement, and management efficiency, while keeping separate the roles of managing government projects and providing expert advice to government.

Recommendation 5: *The Australian Government should develop a Space Advisory Board or Council to provide it with expert advice across the gamut of Australia's national interests in space.*

Specific responsibilities for CASS regarding Australia's space science community are to:

(1) Help determine and then report the community's goals, needs, and priorities;

(2) Unify, link, and develop the community; and

(3) Represent the community in national and international settings.

It is proposed that CASS will work with government, especially the Space Policy Unit, space scientists, industry, and other Australian stakeholders to:

(1) coordinate, develop, and manage the strategic, large-scale, elements of Australia's national effort in civilian space science and technology (integrated over universities, government agencies, and industry);

(2) develop and manage an education and training program focused on space;

(3) develop Australia's space science capability for the nation's benefit;

(4) provide expert advice to government on civilian space matters; and

(5) if delegated suitable authority by the Australian Government, collaborate on space matters with foreign space agencies and domestic and international industry.

CASS will therefore have strong connections to all Australian stakeholders, as well as to international space agencies and both domestic and international industry.

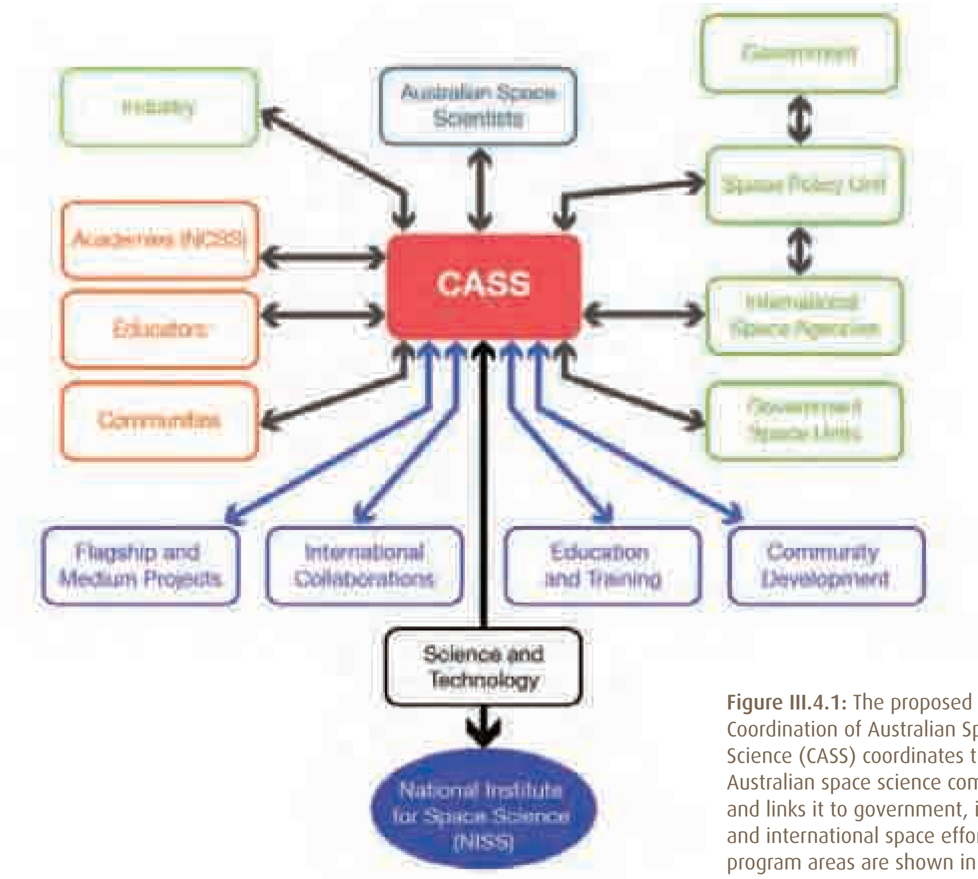


Figure III.4.1: The proposed entity Coordination of Australian Space Science (CASS) coordinates the Australian space science community and links it to government, industry, and international space efforts. CASS's program areas are shown in blue.

A corporate model is favoured for CASS. Ideally, this would involve[17]:

- a skills-based and task-focused Board of Directors, with recognizable expertise in space matters and fully delegated powers to act;
- a Board whose Chair and a majority of the Directors will be independent;
- a CEO subject to Board appointment and removal;
- CASS shareholders that are non-individual stakeholders in Australia's space effort, such as universities, corporations, government units with interests in space, the Federal Government itself, professional associations, and perhaps the Australian Academies of Science (AAS) and Technological Science and Engineering (ATSE);
- annual levies and an initial joining fee for approved shareholders; and
- government financial support for the operations of CASS.

The corporate model is believed to be 'best practice', since CASS will need to coordinate, link, and sometimes manage the research programs and assets of multiple entities (eg universities, corporations, and government units), and to manage both government and private sector funds.

CASS is intended to be primarily a coordination and management entity. As such it will receive inputs from government units with interests in space (eg AAD, BoM, CSIRO, DSTO, GA, and IPS), whether data, hardware, computational theoretical models (software), funds, or staff. These will be combined with inputs from universities, industry, and foreign sources in order to optimize the scientific, technological, political, economic, and societal benefits for Australia, as well as to improve predictions and services desired by government and industry. Put another way, existing and future assets owned by government departments will remain their responsibility but will be coordinated so as to improve the benefits for Australian space science and Australia as a whole, while providing improved utility, recognition, and kudos for the owners. The same model applies to assets of universities and industry.

CASS's program for space science and technology should address the goals of the present and future Decadal Plans with a balanced mix of research projects that range from pure science to mixed science/technology to demonstrators of technology. The proposed organization is into five areas: (1) Flagship and Medium Projects (Sections III.5.1 and III.5.3 below), (2) International Collaborations and Future Opportunities (Section III.5.2), (3) Science/Technology and the National Institute for Space Science (Sections III.4.2 and III.5), (4) Education and Training (Section III.6), and (5) Community Development, including Outreach (Section III.7). A minimum annual budget for the CASS CEO's salary and for administrative support is $200 K. The anticipated costs of the projects are described in Sections III.5 – III.8 below.

Figure III.4.2 illustrates the scientific and national benefits that are intended to follow from the creation of CASS and ensuing government support of the Decadal Plan and its major projects. It also shows how CASS will connect and leverage Australia's university, government agency, and industry interests and capabilities in space into a coherent national space effort that is connected to international space agencies and commercial entities. In short, CASS will provide access to space for Australian stakeholders, and links between Australian stakeholders and international civilian entities.

Recommendation 6: *The Australian Government should fund and support development of a coordinating entity for the space science community along the lines of CASS, in consultation with the space science community and other Australian stakeholders in space.*

17 J. Uhrig, Review of the Corporate Governance of Statutory Authorities and Office Holders, Commonwealth of Australia, June 2003.

Figure III.4.2: The proposed entity CASS (Coordination of Australian Space Science) works with government to connect and leverage Australia's space science interests and capabilities (universities, government units, and industry) into a national effort. Resulting national benefits are shown in gold text and the Plan's major reseach projects in white text, including SpaceShip Australis (SSA), Marabibi Constellation, International Collaborations and Future Opportunities (ICFO), and Sundiver. The link to the proposed National Institute for Space Science (NISS) is also shown. CASS will work with government to connect Australia's space effort to international space agencies and industry.

III.4.2 National Institute for Space Science (NISS): Years 2011-2019

Estimated Cost: $25 M ($14 M salary, $11 M infrastructure), 99 person-years training

CASS represents a minimalist approach to linking and coordinating Australia's space research into a cohesive national entity. A more dynamic and powerful approach to building a national capacity and capability in space is to establish a National Institute for Space Science (NISS). CASS might then be the governing entity of NISS. NISS would have strong similarities to the Anglo Australian Observatory (AAO) and CSIRO's Australia Telescope National Facility (ATNF) which have coordination roles for optical and radio astronomy, respectively.

The primary goal of NISS might be to provide a national, unifying, focus for Australian research on space science and technology. NISS might:

- build large-scale, strategically-focused research efforts directed towards the nation's space capability and the science goals and projects of CASS and the Plan;

- have a major focus on theory and modelling efforts since science is primarily motivated by the desire to understand, and understanding requires the development of theories and models that organize data;
- coordinate, and perform as required, research and technology development relevant to national strategic goals;
- develop the proposed SSAnet for space weather data (see Flagship 1: SpaceShip Australis below) into a general data network and repository for all space science data, with appropriate links to Earth observation repositories at BoM, GA, and elsewhere;
- provide the expertise necessary to evaluate research projects proposed to CASS;
- coordinate the education, training, and outreach programs proposed in the Plan;
- host the theory, computational modelling, operational, engineering, and networking personnel of Flagship projects like SpaceShip Australis and Marabibi Constellation;
- create and link already-funded informal or formal centres of excellence in areas of space science (eg astrobiology, planetary science, space weather, or theory);
- develop linkages with industry, government units with space interests and expertise, and international space agencies; and
- link individual research groups across the nation and internationally.

A recommended management structure for NISS, with program elements, is shown in Figure III.4.3, with CASS the governing body. A distributed, virtual model for NISS is most plausible, in which a small but growing group at a central location (eg Canberra or Sydney) coordinates, develops, innovates, and extends research efforts across Australia into a comprehensive national effort that addresses the goals of CASS, government, and other Australian stakeholders in space science.

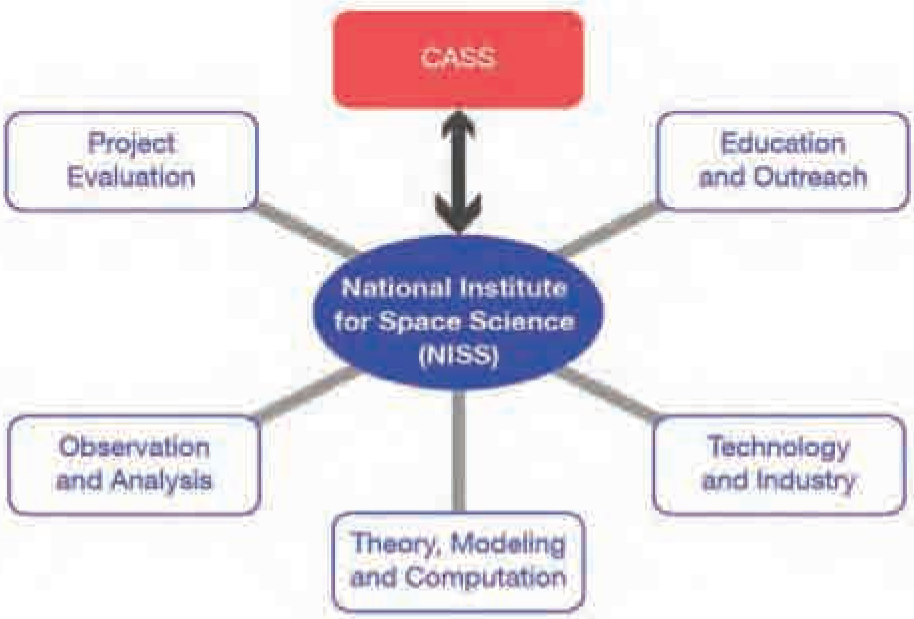


Figure III.4.3: NISS program elements and link to CASS.

The primary scientific and technological responsibilities of NISS would be to develop existing Australian expertise in space science into a sustainable, vibrant research effort of international excellence using large-overlap, strategic projects. Lower-level goals are:

- Develop existing expertise in theory, modelling and computing into an internationally recognized strength across space science that provides the theoretical underpinnings, links between, and interpretive framework for Australia's observational and technology development programs;
- Develop existing expertise in observation and the analysis, networking, and storage of data, including new areas required for CASS projects, and coordinate with government operational agencies, Defence, industry and other users;
- Coordinate the development of, and develop when necessary, advanced space instruments and technologies for national space projects and links with industry;
- Evaluate projects submitted to CASS and provide launch, orbit, operational, and technical advice for project development, selection, and management;
- Provide, coordinate, and manage education, training, and outreach programs to increase the numbers of scientifically trained and literate Australians; and
- Strengthen links to and capabilities of other scientific, government, and industrial groups that overlap with and depend on space science, including the low atmosphere/weather, astronomy, and Earth sciences.

A plausible initial setup for NISS involves eleven staff members with an associated salary budget of order $1.5 M per year. This includes:

- The NISS Director;
- Two Administrative assistants, one for finance and one for secretarial services;
- One scientist to develop and manage the Science portfolio;
- Three engineers, one to develop and manage the Technology portfolio and two for project evaluation and management;
- One scientist/engineer/industry professional to develop and manage links and relationships with industry and international space entities, including the International Space Exploration Coordination Group (ISECG);
- One educator/scientist to develop and manage Education and Training projects; and
- One educator/scientist/engineer to develop and manage the Outreach projects.

The NISS budget would require funds to cover rental of suitable office and work space, computer and other equipment, as well as costs of outsourced contracts for professional advice on space projects. A total budget of $25 M for the decade appears reasonable.

Recommendation 7: *A National Institute for Space Science should be developed along the lines proposed, with strong support from academia, government, and industry.*

III.5 Research Infrastructure, Science and Technology Projects

A flexible and balanced approach is required so that effective planning can proceed now but maximum advantage and leverage is obtained from new opportunities that will arise during the decade. The approach proposed has four classes of infrastructure, science, and technology projects (Education, Training and Outreach projects are in Sections III.6 and III.7).

(1) Three **Flagship Projects**, which target major research infrastructure and science goals for a large fraction of Australia's space science community, cost more than $10 M, and involve Australian leadership on research of international scale.

(2) The **International Collaboration and Future Opportunities (ICFO) Program** is intended to develop and fund (a) partial and entire scientific instruments, which enable Australia and its space scientists to take part in future international space projects, as well as (b) future projects in other areas (domestic or international) to which Australian space scientists can make vital contributions. This program is intended to provide, for the first time, the means and infrastructure for Australian scientists to take part officially in projects led by international space agencies.

(3) A small number of **Medium Projects**, which target medium-scale research infrastructure and science goals, involve a smaller fraction of the community, cost less than about $5 M, and involve leadership by Australian scientists.

(4) **Small Projects** proposed by individual Australian scientists and small teams for periods less than five years with total costs less than $3 M but usually about $150 K. No such projects are identified in the Plan due to its focus on community projects.

It is explicitly emphasized here that the specific Flagship and Medium Projects below, proposed on the basis of current knowledge and opportunities, should be expected to evolve after the Plan's completion (perhaps adding or removing significant initiatives) so as to maximize their benefits and outcomes. ICFO and Small Projects explicitly allow us to take advantage of future opportunities and successes.

The Flagship, Medium and Small Projects involve Australian leadership of complete projects. ICFO is essential for official Australian participation in international missions, including leadership roles, and for us to take advantage of future opportunities and unexpected events that will arise during the Plan's Decade.

Flagship Projects and ICFO have scales too large to be funded by the Australian Space Research Program (ASRP) or the standard programs of the Australian Research Council (ARC). Funding from the equivalent of NCRIS or direct from government will be necessary for them. Individual Medium Projects, as well as some individual ICFO projects, have appropriate scales for the ASRP or ARC Linkage, Linkage Infrastructure Equipment and Facilities (LIEF), Centre of Excellence (CoE), or Cooperative Research Centres (CRC) funding schemes. Small Projects are envisaged to be funded primarily by proposals to the ARC Discovery, ARC Linkage, and ASRP schemes.

18 The Cooperative Research Centre for Satellite Systems (CRCSS) resulted in 57 PhD and 11 Masters (Research) graduates during the government-funded period and the following year, all working on CRCSS research projects. The total government funding for CRCSS was $29 M over its 9-year life. Taking these figures, provided by Professor A. Parfitt (the CRCSS's final CEO), government funding of the Plan's space projects is expected to lead to 20 additional PhD graduates and 4 additional Masters graduates per $10 M than expected based on pre-2009 funding. These are conservative estimates for the rate at which new government funding of Plan projects will stimulate the creation of PhD and Masters graduands expert in space science and associated technology and engineering. Only the numbers for additional PhD graduands are stated above.

The costs estimated below for the Flagship Projects and ICFO total $110 M over 10 years and include advanced scientific, engineering or management training of over 1100 person-years for postdoctoral scientists, engineers, and technicians, assuming $100 K p.a. per person. Moreover, based on the exceptional track records for the CRC for Satellite Systems and FedSat satellite[18], which graduated at least one PhD student per $500 K of project funding, a minimum of 220 additional PhD student graduations are expected.

III.5.1 Flagship Projects

Three Flagship projects are proposed to simultaneously build capability, develop community-scale research infrastructure, and address broad-themed fundamental and applied space science. Each has large scale in terms of science and impact, though not in cost, and will provide Australia with specific strategic capabilities and long-term research infrastructure for space science. Together they address the Global Themes and Science Goals proposed, and so the major unsolved questions of space science. The Flagship Projects should have major impact and significance internationally, with concomitant benefits to Australian science, government, society, and industry. The first two Flagship projects are all achievable with current technology, although all will benefit from future instruments and systems developed during the design and building stages. In contrast, Sundiver, the third Flagship, is deliberately high profile, high risk, and high payoff.

Flagship 1: SpaceShip Australis, Years 2010-2019, 40 PhDs[18]

Estimated Cost: $20 M ($7 M assets, $13 M operations), 200 person-years training.

A large-scale combined capability, research infrastructure, and science project, SpaceShip Australis (SSA) is intended to be the world's first southern hemisphere equator-to-pole network of instruments and theoretical models that measure, monitor, model, and predict how energy from the Sun and space, including transient events:

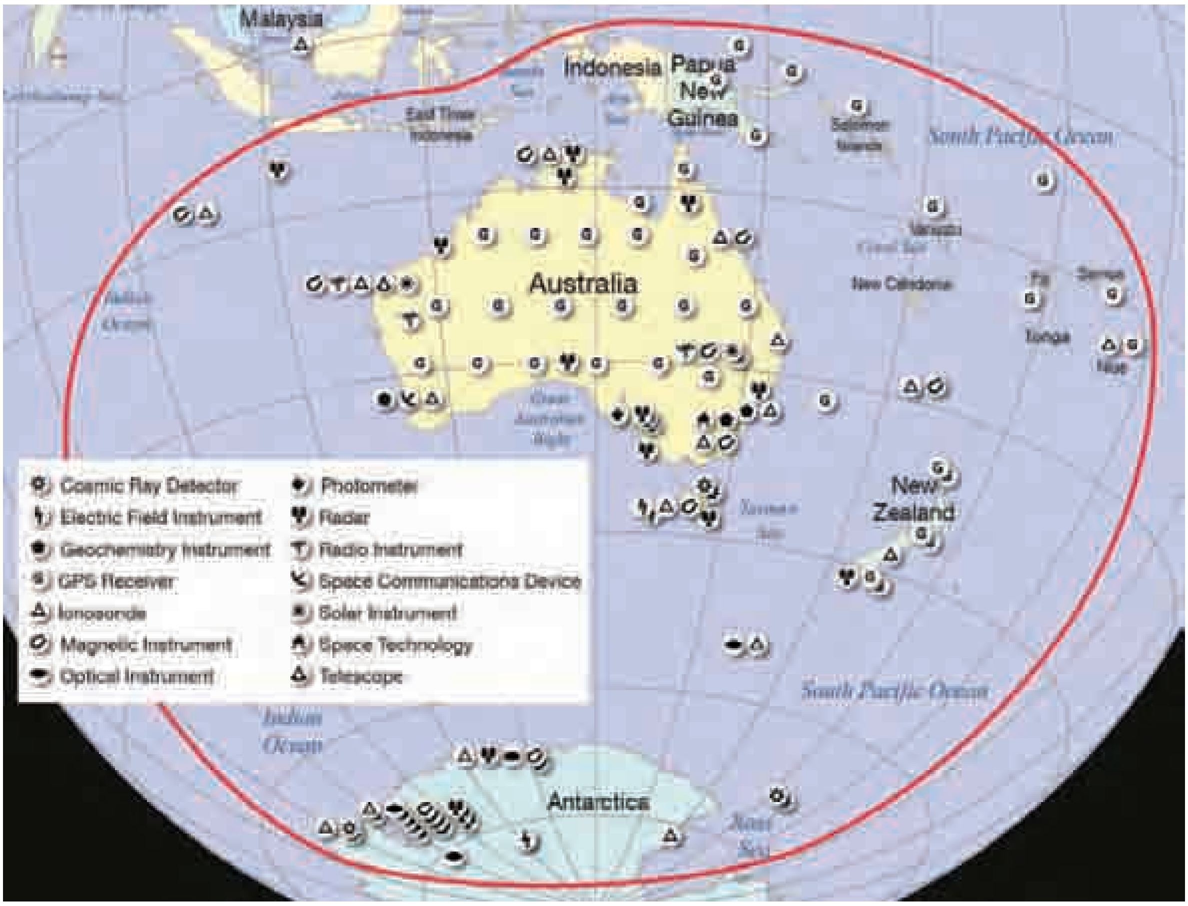
- travels through interplanetary space;
- couples through the magnetosphere, ionosphere, & atmosphere to Earth's surface;
- produces space weather; and
- affects Australian assets and society.

SSA will focus on the ⅛ of the globe for which Australia asserts sovereignity (including much of Antarctica) or has United Nations' responsibility (the southern oceans).

The scientific goal of SSA is to measure, model, and predict space weather from the Sun to the ground with Australian and international assets, focusing on the Australian region from pole to equator. This includes the equator-to-pole dynamics and coupling of the atmosphere, ionosphere, and magnetosphere over the Australian region (including Antarctica). SSA directly addresses Themes SSE, LIFTS, and RS and the associated Science Goals 1–7.

SSA involves linking existing Australian and international assets in new ways to greatly enhance returns, as well as developing new assets and theoretical tools such as a data-driven theoretical model of Australia's space environment.

The enduring national capabilities desired from SSA are thus in (1) space weather, (2) space technology, and (3) domestic and international space collaboration.



Existing & New Assets:

1. Ionospheric radars: TIGER and 3 DigiTigers
2. GPS arrays, including the Nat. Geospatial Ref. Syst. (AuScope)
3. Magnetometers of GA, SERC, IPS, & Newcastle
4. Solar radiotelescopes: IPS
5. Cosmic ray detectors: AAD
6. Atmospheric & meteor radars: Buckland, Katherine
7. Optical/UV: Fabry-Perot, lasers
8. DSTO ionosondes
9. AWSESOME VLF detectors
10. MWA & SKA

Science areas:

Sun-Earth coupling & space weather

Dynamic atmosphere and ionosphere

GPS tomography

Radar & wave physics

SKA & MWA

Sea state & climate

Space debris & meteorites

International Links:

SERC (Japan)

Cosmic Ray Net,

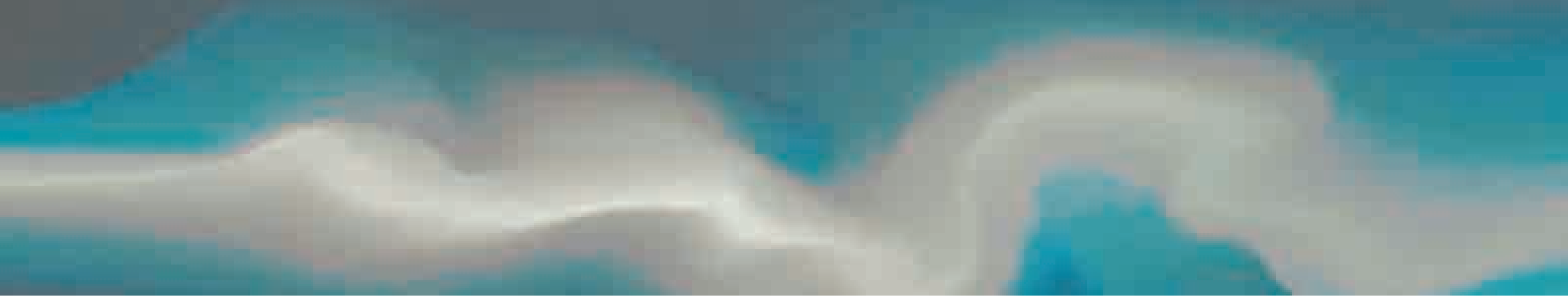
SAMBA and AWESOME (USA),

Meridian (China)

Australian Links:

Universities, AAD, BoM, CSIRO, DSTO, GA, IPS, industry

Figure III.5.1: The Flagship project SpaceShip Australis (SSA), showing the suggested types of instruments and observing assets, the science areas, and the international and Australian linkages to be built. Theory, modelling and computional aspects of the project are not shown but are vital.



Objectives of SpaceShip Australis

- Link and leverage into a new Australian space data network (SSAnet) existing and future Australian civilian space data, including those of GA, IPS, and the National Geospatial Reference System, some Defence products, as well as data from Japan's SERC magnetometers and New Zealand's GPS arrays.
- Develop, deploy, use and integrate new ground-based instruments from Australian and international collaborations (including radars, magnetometers, GPS arrays, and optical, VLF to GHz radio, and cosmic ray detectors) to optimally instrument Australia's ⅛ of the globe for space science research.
- Develop the capability, with selected DSTO sections and Defence contractors, to process digisonde ionospheric data continuously and release it to SSAnet.
- Develop a theoretical understanding and comprehensive models, based on theory and SSAnet data, for the middle and upper atmosphere, ionosphere, magnetosphere, and associated space weather in Australia's region.
- Create near real-time displays of SSAnet data and associated theoretical models that directly address scientific objectives and allow prediction and mitigation of space weather effects by real-time connections to government and industry.
- Provide ground-truth testing of space data (eg from the Flagship project Marabibi), with special relevance to climate change and atmospheric variations.
- Characterize the ionosphere, atmosphere, and space weather above the MWA and proposed Square Kilometer Array (SKA) sites, so as optimize Australia's chance to host the SKA and the science returns from MWA and SKA.
- Link with the proposed Chinese Meridian and North/South American assets (as well as with Indonesia, Malaysia, Papua New Guinea, and Singapore) to form a unique pole-to-pole space weather network over ¼-½ of the globe, thereby forming a very attractive focus for major international collaborations.

Rationales for SpaceShip Australis

- Science and Technology – SSA will perform fundamental world-class science, major technology development, and provide vital national services and infrastructure protection.
- Builds Critical Mass and Capability – SSA will link many Australian researchers and institutions with internationally-recognized expertise in space science into an intellectual critical mass that will power the community's expansion and enhance its capabilities.
- Education and Training – SSA will provide opportunities for instrument development, data analysis, theoretical modelling, simulation, data-theory comparisons, and international collaborations for Honours and PhD students and professionals (whether civilian of Defence), as well as training for information technology and operational workers.
- Timeliness – SSA will be ready for the next maximum in space weather (2011-2014).
- Uniqueness – SSA will have unique equator-to-pole coverage and be the only southern hemisphere national ground-based space system. No plausible competitor exists.

- Low Risk, Achievable, and Powerful – SSA involves integrating existing assets with new instruments into a powerful, real-time, data and modelling network that measures and predicts the space environment for Australia's region.
- National Research Priority Areas – SSA addresses NRP 3 via breakthrough science, frontier technologies, and smart information use, NRP 4 via safeguarding critical infrastructure from space weather, NRP 1 via the effects of the Sun and space on Australia's atmosphere and environment, and NRP 2 via prediction of space weather.
- Regional Dominance in Space – SSA will consolidate Australia as the dominant space nation in our region, with improved links to neighbours and other nations.
- International Good Neighbour and Linkages – SSA will exchange ground-based and other space data, model capabilities, services, and perhaps instruments with international partners, and will provide 'public good' space services to neighbours without space capabilities. Neighbours may link instruments into SSA.

Implementation and Budgeting

SSAnet will involve major extension of the IPS observing network, with existing assets of universities, government units, and international collaborators (eg Japan's SERC magnetometers) integrated in 2010-2012 and new assets added as built. It will be usable immediately. A plausible cost in 2009 dollars, in addition to current funding, is $250 K p.a. (for two full-time positions), not including instrument operating costs.

Development and deployment of new instruments to fully instrument SpaceShip Australis is envisaged to take until 2013, with immediate integration of new instruments into SSAnet. Plausible costs are $6 M plus land for three new DigiRadars, atmospheric and meteorite radars, $300 K for new magnetometer arrays, and $700 K for other instruments (including GPS receivers additional to the new NCRIS arrays, VLF detectors for the US global Atmospheric Weather Electromagnetic System for Observation Modelling and Education (AWESOME) and Fabry-Perot optical detectors). SSA's contribution to operating costs is assumed to be $225 K p.a. for 10 years.

Development of the capability to process Defence ionospheric data and release it to SSAnet is expected within two years. The annual cost is estimated at $150 K p.a. (mostly for one contractor employee), first for development and then for refinement and compliance.

The theoretical modelling effort will start in 2010 and continue for the decade. New staff are required for this, with an estimated annual cost of $375 K p.a. (for three staff positions).

Development of real-time displays of SSAnet data and theoretical models to address scientific objectives and to predict and mitigate space weather will be a major initiative. Based on the SSAnet and theory efforts, it will start in 2010. These capabilities will also allow ground-truth testing of remote sensing data and characterization of the ionosphere for SKA and MWA. The annual cost is estimated to be $250 K p.a. for two staff.

Linking SSA to Asian and American space weather efforts, such as Japan's MAGDAS and China's Meridian projects, will leverage Australia's investment and lead to the first truly global space weather network. This is expected to occur after 2014. Costs are estimated at $100 K p.a.

Summary

SSA should provide immediate results once funding and development starts, with increasing capabilities added with time. SSA is expected to be operational by 2012. The total cost for instruments and facilities is expected to be of order $7 M (excluding land), with average annual operational and staff costs of $1.3 M. Thus, for a total cost of approximately $20 M, Australia would obtain a globally state-of-the-art facility with major scientific, government, industry, and societal benefits, a respected place in the international space effort, and major opportunities for constructive international linkages.

Recommendation 8: *Australia should develop a state-of-the-art capability in ground-based space science and assorted services and technology via a research network along the lines of SpaceShip Australis, aiming to make Australasia the world's best instrumented and modelled region for predicting space weather from the Sun to the ground and mitigating its effects.*

Flagship 2: Marabibi Constellation, Years 2010-2019, 120 PhDs

Likely Australian cost $60 M, 600 person-years training.

It is proposed to build Australia a flexible, long-term, near-Earth space capability and associated infrastructure via the Marabibi Constellation project. Marabibi will be an Australian-led, low altitude (300–1000 km), constellation of nano (1-10 kg), micro (10-20 kg), and small (100 kg) satellites that is research-led but student-focused and has world-first capabilities in space weather, space technology, and Earth observation, and provides strong opportunities for education, training, and international collaboration. Named for the Wardaman aboriginal people's story about the Pleaides[19], there are close parallels in style and approach: two women (the small satellites) supervise and educate a group of young initiates (the nanosats and microsats) as they journey through their traditional lands, learning about the environment, laws, seasons, and cycles of life. Marabibi Constellation is an extension of the earlier Lightning concept.

Nanosats and microsats allow rapid development and launch cycles, strong involvement of students, focus on specific experiments and scientific/technological targets, multiple stages in evolution for Marabibi, and amazingly low cost (< $1 M for five nanosats designed, built, and launched in 1-2 years). Their use makes Marabibi highly flexible, adaptable, and responsive to changing circumstances, naturally extendable beyond 10 years, and able to use short lifetime and higher risk components. Deployment of nanosats and microsats in multiple tetrahedral deployments will allow local temporal and spatial variations to be separated with high scientific payoff, and allow testing of swarm concepts and control technology.

The primary themes of the Marabibi constellation are to:

- measure space weather and develop our understanding in unique ways;
- develop space technology; and
- develop Australian capabilities in Earth observation from space.

Marabibi naturally involves two coordinated sub-constellations, each with a small satellite and four or more nanosats, one in a closely equatorial orbit and one in a highly inclined orbit. This will allow almost complete global coverage, reliable calibration every 90 minutes, novel commandable orbital changes, and excellent overlap with SpaceShip Australis.

19 'Dark Sparklers', H.C. Cairns and Bill Yidumduma Harney, 2003 (accessible via http://www.darksparklers.com/Pages/contacts.html).

Proposed Instruments:

Electric and magnetic fields (waves, large scale, plasma parameters, & dust impacts)

GPS receivers

Ionospheric beacon detectors for DSTO

Gravimetric & magnetic gradient detectors

Climate change & remote sensing instruments

Plasma thrusters for propulsion

Science & Technology Goals:

Space weather , including ionospheric & atmospheric dynamics, & turbulence

Space debris: natural & human

Ionospheric tomography & beacon

Climate change

Remote sensing & ground-truth testing

Gravimetric & magnetic maps

Satellite GPS receiver technology

Spacecraft propulsion and new instrument demonstrator

Nanosat / swarm control

International Links:

Taiwan, Japan, USA, ESA, Ukraine, Russia

Australian Links:

Universities, AAD, DCCEE, BoM, CSIRO, DSTO, GA, IPS,

Industry

Figure III.5.2: The Flagship Project Marabibi Constellation: shown are equatorial and inclined sub-constellations of nano, micro, and small satellites. Proposed instruments, Science & Technology goals, and both the international and Australian links are listed. Theory, modelling and computional aspects of the project are not shown but are vital.

Goal 1: Measure and model the response to space weather of Earth's dynamical middle/upper atmosphere, ionosphere, and inner magnetosphere from equator to poles.

Goal 2: Demonstrate new Australian capabilities in space technology.

Goal 3: Leverage the strong overlaps with SSA, ground-truth testing, and international linkages to optimize the science, technology, strategic, and other returns to Australia.

Goal 4: Make Australian contributions to international observing and modelling programs on Earth observation and climate change.

Marabibi addresses Themes SSE, P2P, RS, and LIFTS, and Science Goals 1-10.

Unique aspects include the:

- combination of novel research with strong opportunities for student and industry involvement/development immediately and in a sustainable, evolving program;
- strong focus on equatorial and mid-latitude science from the ground to space (but from equator to poles) and the associated space weather;
- first equatorial/mid-latitude constellation mission in Low Earth Orbit (LEO) with large orbital change capability;
- ability to disentangle temporal and spatial variations in the upper ionosphere and inner magnetosphere using subconstellations of 4-5 closely spaced spacecraft, similar to recent ESA and NASA magnetospheric missions Cluster and Themis;
- reprise and extension of ionospheric tomography capabilities using GPS data, first pioneered by Australia's FedSat;
- reception of beacon signals for novel ionospheric radio propagation studies;
- first detection of LEO space debris of both natural (eg meteoritic) and human origin, via spacecraft antennas measuring the charge clouds of dust particles vapourized by collisions with a spacecraft, and correlation with ground data;
- opportunity to design, develop and fly Australian Earth observation instruments;
- testing on orbit of novel Australian technological capabilities in spacecraft thrusters, control software for constellations, inter-spacecraft communication, GPS receiver technology, and the construction of instruments and spacecraft;
- low risk approach using nanosats, microsats, and small satellites, with a development path possible from nanosat design/building in Australia (cf. UNSW's BlueSat) and small satellites designed here but built overseas, to all satellites designed and built in Australia;
- strong overlap with SSA and associated ground-truth testing; and
- strong potential for international collaboration with the proposed US-Taiwan Cosmic-3 project and Ukraine's proposed Ionsosat project.

Marabibi could fly Australia's first major experiments on climate change and remote sensing. However, presently the choice of specific goals and instruments is complicated by the following: (1) operational and scientific instruments have different foci, outputs, and requirements; (2) many climate change and remote sensing instruments are currently planned for launch before 2012, but cancellations and failures will leave gaps in capability; (3) Australia's Government is reviewing its operational needs, which may require increases in scientific capability; (4) development of a novel hyperspectral instrument (see III.5.2) might require $30 M and so significantly change the project cost. The approach adopted now is to include GPS, magnetic, and gravity field instruments relevant to Earth observation, but to defer choice of specific climate change and remote sensing instruments until the Design Study phase. It is assumed that an international partner will either donate an upgraded flight spare instrument or pay a major fraction of the cost; Japan is a very plausible partner.

Objectives for Marabibi Constellation

- Design the constellation, instruments, and mission plan and launch Marabibi to maximally achieve the science goals and leverage technology development.
- Develop and test Australian constellation control and communication software.
- Measure and model theoretically space weather effects associated with the dynamics, coupling from equator to poles, and response to solar activity of the ionosphere and atmosphere.
- Measure dust-sized space debris using wave receivers and correlate with possible sources and Earth-based data.
- Disentangle spatial and temporal variations in the plasma and electromagnetic fields using Marabibi, interpret, and correlate with space weather & GPS data.
- Develop the capability for real-time tomographic inversion of GPS data from multiple simultaneous spacecraft for atmospheric and ionospheric studies.
- Remotely sense the atmosphere, ocean, and surface (environmental, human, and mineralogical) of Australia's octant of the globe, with instrument innovation, and contribute to global programs on Earth observation and climate change.
- Obtain global gravimetric and magnetic maps for geodetic, scientific, & commercial uses.
- Demonstrate that plasma propulsion engines can alter spacecraft orbits on demand.
- Probe radio propagation from the ground to spacecraft and apply to JORN, MWA, SKA, and other users.

Rationales for Marabibi Constellation

- Science and Technology – Marabibi will enable world-class science, both fundamental and applied, stimulate major technology development and lead to improved national services and protection of vital infrastructure.
- Education and Training – Many students and workers will be educated and trained in science, engineering, and the space industry while they (1) design, build, and operate Marabibi's instruments and spacecraft, (2) analyze and interpret the data, (3) develop theoretical models, understanding, and predictive capabilities, (4) improve space services and infrastructure in Australia, and (5) interact with the space industry and government.
- Industry – Australian industry will benefit from opportunities to design and build components of Marabibi, as well as increased access to trained workers and future projects.
- Builds Critical Mass and Capability beyond SSA – Marabibi will enable Australian researchers and institutions with internationally-recognized expertise in space science to design, build, and use space instruments and vehicles to solve outstanding scientific problems.

- Timeliness – Marabibi will start during the next maximum in space weather (2011-2013) and strongly leverage SSA and multiple international space projects.
- Low Risk, Achievable, and Powerful – because most instruments will use existing technology in novel ways, multiple rapid-turnaround launches of inexpensive nanosats will complement a few more powerful small satellites, constellations amplify the scientific return by separating temporal and spatial variations, piggyback launches to low orbits are frequent and safe, and investment in Marabibi will strongly leverage and amplify the returns from SSA.
- National Research Priority Areas – Marabibi addresses NRP 3 via breakthrough science, frontier technologies, advanced materials, and smart information use, NRP 4 via safeguarding critical infrastructure from space weather and remote sensing, and NRP 1 via remote sensing of climate change and Australia's environment.
- Regional Dominance in Space – The combination of SSA and Marabibi will give Australia strong credentials as a space nation and significantly improve links with regional neighbours and international space partners.
- International Good Neighbour – In situ ionospheric, remote sensing and other data from Marabibi, as well as data and model products from SSA, will be exchanged with international partners, especially those without space capabilities.
- International Linkages – Marabibi can become part of international missions and international partners can contribute whole or partial instruments or other technology, especially in the areas of climate change and remote sensing. Taiwanese and Japanese scientists have already inquired about providing instruments for Marabibi.

Implementation and Budgeting

A plausible implementation plan for Marabibi involves launch of three separate groups of four or more nanosats (Years 3, 5, and 8) and two small satellite launches (Years 4 and 6) for maximum flexibility and adaptability. The initial design of the overall project is expected to take one year (nominally ending in late 2011), with a cost of order \$1 M. This includes definition of the nominal instruments, spacecraft systems, propulsion systems, and orbital requirements for launch. During this time suitable launch providers (assumed to be via piggy-back launches) and builders for the small satellites, both expected to be outsourced, will be identified.

Each group of nanosats is budgeted at \$1.4 M, with \$0.2 M each of two years before launch, \$0.4 M for the launch year (including launch), and \$0.3 M of dedicated funding for each of two years after launch. This costing assumes strong reliance on Australian students and either simple or donated instruments, or instruments funded from other sources. The design launched will be refined from designs in two previous years.

The design and building of the instruments for the two small satellites is expected to take three years (ending in late 2013 and 2015, respectively) and cost approximately \$5 M each. The spacecraft builders and launch providers will be contracted and start work in 2012 and 2014, respectively.

The integrated theory, modelling, and computation efforts for Marabibi will start in Year one (nominally 2010) and continue, joined by data analysis and interpretation efforts after launch, until Year 10 (2019). The nominal budget is $1 M per year. The instrument teams for the two small satellites will be funded at $4 M and $3 M total for the six and four years after launch until 2019, respectively. This will allow detailed analysis of the data, in combination with the integrated theory, modelling and computation efforts, and applications for separate ARC funding.

The two Marabibi small satellites are expected to be built, integrated and ready for launch by the end of 2013 and 2015, respectively, with launch in the next year. The indicative cost of these services is expected to be $14 M including a piggy-back launch: two leading international corporations have stated prices of US$12 M to design, build, instrument, integrate, and launch a 100 kg small satellite into Low Earth Orbit for us.

When required, flight testing of instruments is envisaged via NASA's balloon science campaign, out of central Australia, or sounding rockets. Estimated costs are much less than $1 M. In general, it is expected that the Marabibi spacecraft will be launched by foreign providers.

Summary

The exciting scientific, technological, educational, training, and other benefits of the Marabibi Constellation project are expected to be achievable for $60 M, with almost all funding for science and engineering. This exceptional value for money will include advanced scientific training for approximately 300 person-years of Australian postdoctoral scientists, engineers, and technicians, assuming $100 K p.a. per person. Based on the exceptional track record of the FedSat satellite, a minimum of 120 PhD student graduations is expected, a conservative estimate based on the increased scientific payloads and return envisaged for Marabibi relative to FedSat.

Recommendation 9: *Australia should develop a long-term near-Earth space capability by funding a multiple spacecraft project along the lines of the Marabibi Constellation, so as to build the required research infrastructure, perform world-first, student-focused, research on space weather, space technology, and Earth observation, and provide opportunities for strong education, training, outreach, and international collaboration.*

Flagship 3: Sundiver Design Study, Years 2011-2014, 10 PhDs

Budgeted Australian cost $10 M, 100 person-years training.

Go/NoGo Decision in 2015 with subsequent budgeting as appropriate.

This Flagship involves the initial steps for developing an Australian capability for deepspace interplanetary and planetary projects via a detailed design study of an innovative and challenging mission concept, Sundiver. Involving both research infrastructure and exciting broad-based science and engineering, Sundiver is a visionary mission to send humanity's first spacecraft into the Sun, in order to solve two of the holy grails of space science: how the Sun's corona is heated to over a million degrees and what mechanisms form and propel outwards the Sun's supersonic solar wind. Reaching the Sun requires shedding much of Earth's orbital speed of 30km/s, an extremely difficult task. Sundiver will do this by using Australia's uniquely advanced propulsion technology, complemented by gravitational swing-by manoeuvres at planets and perhaps the Moon which will enable new planetary science research. This enables research across the full gamut of space science and all four Global Science Themes.

Sundiver involves unique, extremely high profile, science with immense payoff. The technical challenges are similarly huge: keeping a spacecraft cool and instruments operating within a few solar radii of the Sun (when the nominal surface temperature will exceed 3000 degrees); retaining communications, data transfer and command capability; and attaining the required orbit and changes in velocity. The opportunities for international collaboration are great, with this pathfinder mission likely to attract ESA, NASA and other international teams. Sundiver will greatly elevate the profile of Australia and Australian space science on the world stage. The great potential rewards and technical difficulties require that Sundiver be regarded as a Grand Challenge to Australia, the Australian scientific community, industry, and their global counterparts. It should galvanize these entities into concerted effort, with great benefits.

The essential and unique elements of Sundiver from an Australian perspective are:

(1) It is a one-way mission, so that long mission lifetimes will not be planned for, simplifying the engineering and lowering cost.
(2) Fundamental, high-impact research across space science and astronomy.
(3) Its unique orbit into the Sun will be enabled by an Australian propulsion system and gravitational swing-by manoeuvres.
(4) A high publicity mission for Australia in international space science.
(5) A highly attractive and advantageous mission for international collaborations, giving access to state-of-the-art international instruments at nominal cost for Sundiver, with associated entries into international space missions and instrument teams for Australian scientists and technologists.

Objectives of Sundiver

(1) Discover the heating mechanism and source of the solar corona and solar wind, two of the fundamental unsolved questions of space science and astrophysics.

(2) Measure the properties of coronal mass ejections, shocks, and transient solar phenomena in the inner solar wind and outer corona and compare these with observations near the orbit of Earth.

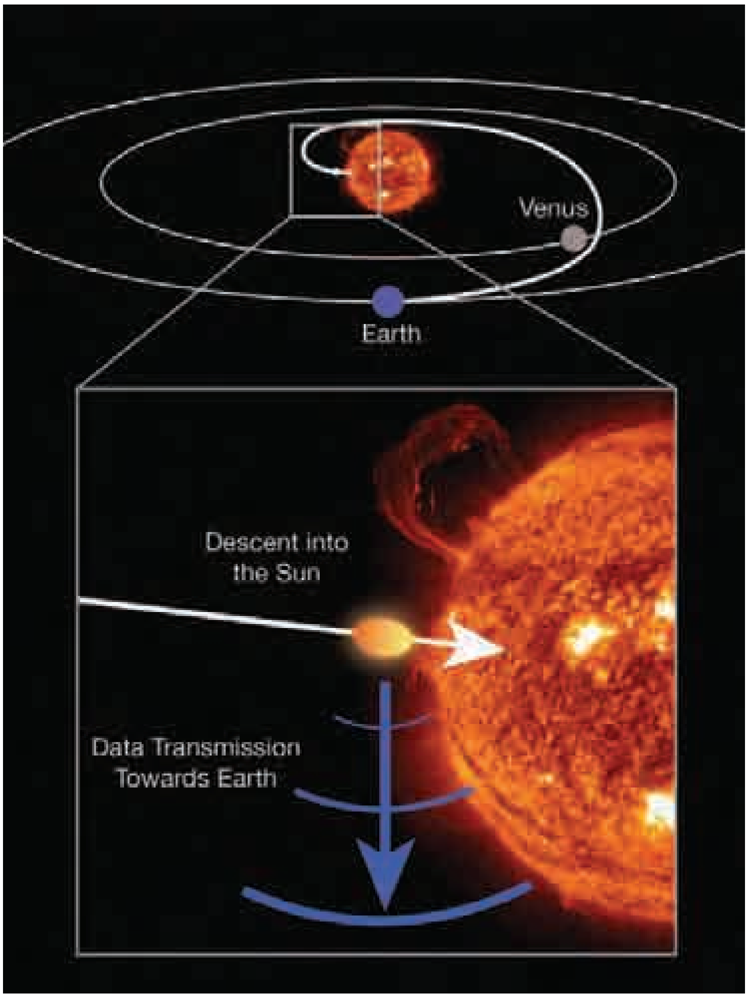
(3) Establish how the composition, magnetic field, velocity, temperature, and other characteristics of the solar wind evolve with heliocentric distance (including turbulence), and compare with Earth- and space-based observations near 1 AU.

(4) Perform the first in situ composition and spectroscopic observations of dust near the Sun (the 'zodiacal dust' that comes from comets and asteroids), with similar observations of the Moon, Earth and Venus in transit.

(5) Obtain maps of the mass distribution and magnetic fields of Venus and the Moon with unique sensitivity and resolution due to close swing-by manoeuvres.

(6) Measure the atmospheres of Venus, Earth, and the Moon (very small) to test atmospheric circulation and composition models, and ground-truth remote data.

(7) Demonstrate an Australian spacecraft propulsion system.



Science & Technology Goals:

Heating of the solar corona
Origin of the solar wind
CMEs, flares and space weather
Composition of corona and solar wind
Zodiacal dust distribution
Remote sensing of Venus & Moon
Venusian greenhouse modelling
Gravimetric maps of Venus & Moon
Magnetic maps of Venus & Moon
Spacecraft propulsion demonstrator
Instrument development
International collaboration

Proposed Assets and Instruments:

1 or 2 spacecraft (redundancy)
Thermal plasma (electrons and ions)
Local electric and magnetic fields
Plasma waves and radio waves
Energetic particles
Solar wind composition
Dust experiment
Atmospheric composition
Spectral imagers for remote sensing
Gravimetric gradient detectors
Magnetic gradient detectors
Plasma thrusters for propulsion

Figure III.5.3: Schematic of the Flagship Project Sundiver, including the proposed assets, instruments, and science and technology goals.

Implementation and Budgeting

The project has two phases, a four year Design Study followed by a Go/NoGo decision in early 2014 and, if selected, a six-year building, launch, and mission phase:

- Years 1-2: Perform orbit and mission calculations and establish thruster capabilities;
- Years 2-4: Detailed spacecraft, instrument, and mission design;
- Year 5 (2014): Go/NoGo decision;
- Years 5-7: Build instruments and spacecraft and prepare for launch; and
- Years 7-10: Launch and 3-year mission.

Detailed costing of Sundiver is not possible without knowing the outcomes of the research and design study proposed for years 1-4, which is budgeted at $10 M. It also requires consideration of whether one or two spacecraft should be built: two spacecraft are favoured for reasons of redundancy, multiple datasets and vantage points, and much greater scientific return. The additional cost is likely to be much less than a factor of two. A strong emphasis on international collaboration should lead to foreign teams proposing instruments with Australian co-investigators for nominal cost to Australia.

Assuming piggy-back or donated launches, costs are estimated to be $35 M to build, instrument, and launch one spacecraft and $3 M/year for operations thereafter. The total is estimated to be of order $50 M. However, only $10 M is requested at this time for the detailed research and design study.

Recommendation 10: *Australia should start to develop a capability and associated research infrastructure for interplanetary and planetary space projects by approving a detailed design study for a combined solar, planetary, and interplanetary project with exciting science goals and challenging engineering requirements, along the lines of Sundiver.*

III.5.2 International Collaborations & Future Opportunities (ICFO) - 40 PhDs

Timing: 2010-2019, proposed budget: $20 M, 200 person-years training.

The goal of the ICFO Program is to enable official Australian participation in international missions and future opportunities (domestic or international) that will arise during the Plan's decade, so as to take advantage of future successes and unexpected events. This involves the development of our space capability, research infrastructure, and ability to collaborate on international science, engineering, and technology projects. The Program should develop and fund:

- partial and entire scientific instruments and technical systems, which enable Australia and its space scientists to take part in future international space projects, as well as
- future projects in other areas (domestic or international) to which Australian space scientists can make vital contributions.

The rationale for ICFO is that current Australian funding schemes (eg NCRIS, ARC Discovery, Linkage, and LIEF, and the ASRP) cannot accommodate the usual requirements for international space projects: funding proposals for instruments etc. must often be written and accepted in less than 6-12 months yet involve funding for five or more years at more than $1 M per year. Thus ICFO needs a significant yearly budget that can accumulate, and the ability to commit funds for periods of at least five years.

International space projects in which Australian space scientists are well-placed to make significant contributions to instruments and associated technology include:

- **the International Space Exploration Coordination Group (ISECG)**, formerly the Global Exploration Strategy (GES). Australia is a full partner in this 14-member group, which has developed a conceptual framework for internationally coordinated exploration of the Moon, Mars, and beyond (see http://www.csiro.au/files/files/pev1.pdf). As ISECG moves from conceptual framework to mission scenario planning, joint projects with international space agencies are expected. Possibilities for the space station include experiments on complex/dusty plasmas (ESA and NASA) and biology (such as apiary pollination in microgravity with JAXA). Additional projects include dietary mitigation of radiation damage of biological systems (NASA), Mars Analog Sites in Australia (NASA), and laser induced breakdown spectroscopy for mineral characterization of lunar surfaces (Canada). The focus is on mature Australian research and development that lends itself to space-based application.
- **Hayabusa-II**, a Japanese mission to sample an asteroid and return it to Earth, will rely on Australian expertise in cosmochemistry (ANU and Curtin) to analyze the results. It has already benefited from sample-return-capsule ground-testing and simulations by the Australian hypersonics community. Investments in laboratory geochemical equipment, for use in analyzing meteorites and lunar samples, will be required.
- **Meridian (China)**. Once SpaceShip Australis is operational, Australia will be in an excellent situation to propose combining it with the Chinese Meridian project in order to instrument almost one quarter of the world (from north to south pole between longitudes 90 and 180 East) for space weather research. This would be an exceptional combination with the Marabibi Constellation.
- **Orbitals** is a Canadian mission to study the injection, acceleration, and loss of energetic protons in Earth's radiation belts, as part of the International Living With a Star (ILWS) Program. University of Newcastle scientists are involved in designing a magnetometer to study electromagnetic waves that scatter and accelerate the particles, contributing to space weather events.

- **MWA** is a US-Australia radio telescope project near Murchison, WA, to study the early universe, coronal mass ejections and other solar/space weather events in transit from the Sun to Earth, and transient radio sources. Although early phases are funded by the US National Science Foundation and Australia's NCRIS program, full development may require additional funding.

Possible future opportunities which would lead naturally into either Australian (eg Marabibi Constellation) or international space projects include:

- **Hyperspectral imaging instruments**: Development and provision of such an instrument for remote sensing purposes, on a future international or Australian government or commercial spacecraft would be an excellent way to revitalize and develop Australia's well-known expertise in this area (cf. the AATSR instrument on ESA's Envisat). Collaboration with Japan and other Asian neighbours would have additional strategic benefits.
- **Advanced photonic approaches to instruments and communications**: Integrated photonic circuits result from coupling optical physics with integrated circuits, with dramatic decreases in size of optical elements. Similarly, bundles of optical fibres allow efficient transmission of light within instruments. Combining fibre bundles with integrated photonic circuits may offer a powerful way to simplify and enhance many optical Earth observation instruments. Similarly, laser systems have some benefits for spacecraft communication and telemetry. Both approaches could be usefully pursued for distinctively Australian contributions to Earth observation and other space projects.

The budget proposed for ICFO is \$20 M over the decade, corresponding to \$2 M per year on average. Provision of an additional \$10 M after five years should be considered if the program is very successful. These amounts of \$20–30 M are of sufficient scale to fulfill the aims of the ICFO and allow Australian space scientists to make major contributions to international space projects, while still retaining the Plan's primary focus on Australian-led and demonstrably Australian projects. The space science community attaches great importance to ICFO, as shown by ICFO being prioritized as the third of its large projects (Table 2 in Section III.8 below).

A fascinating scenario, outside the proposed scope of ICFO due to the current exclusion of operational Earth observation systems, would be for Australia to fund an extra spacecraft for a future Earth observing constellation that is an element of GEOSS (the Global Earth Observation System of Systems). This would likely cost in excess of \$50 M but would establish Australia's commitment to GEOSS. Discussions in 2008 and 2009 indicate that this would have widespread appeal within the Australian Earth observation community and the more general Australian space science community.

It is proposed that ICFO is managed directly by CASS and (once formed) NISS. Short expressions of interest to propose to ICFO, describing the Australian contributions to the project and associated justifications, would be submitted to CASS. Those projects deemed of sufficient interest would be asked to submit detailed proposals, which would be reviewed comprehensively by suitable Australian and international experts and a decision made by CASS on a suitably rapid timescale.

***Recommendation 11:** Australia should develop its capability and infrastructure for collaborating on international space projects through an official program, along the lines of the proposed International Collaborations and Future Opportunities (ICFO) program, to support official Australian participants in international space missions and future opportunities (domestic or international) that arise during the next decade.*

III.5.3: Medium Projects

DigiRadar

Timing 2010-2012, likely cost: $2 M, 20 person-years training; 4 PhDs[18]

High frequency (HF) ionospheric radar is an excellent technique for probing large areas of the ionosphere simultaneously. Explosive development in digital techniques, particularly in signal processing, make current HF radars much more adaptable and allow tailoring of operational modes to address specific scientific questions. DigiRadar will be one of the first fully digital radars designed. It will use digital pulse transmitters and receivers and advanced digital processing techniques. Each antenna element will have its own transceiver and its signal will be recorded independently. This provides enormous flexibility since different beams can be formed during post-processing to study different phenomena using the one set of data, analogous to MWA and SKA.

Industry (eg BAe and Raytheon) and DSTO are strongly interested in DigiRadar. During the decade the international SuperDARN collaboration's 19 radars will all need to be made fully digital based on DigiRadar, leading to continued industry sales, technical development, and scientific innovations.

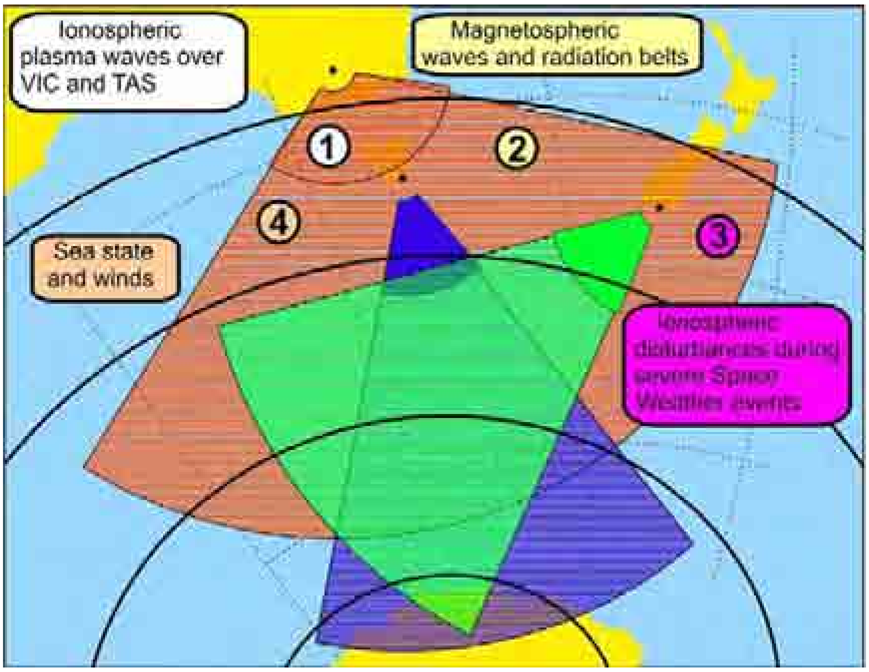


Figure III.5.4: Schematic of a DigiRadar located in Victoria.

DigiRadars will investigate phenomena listed under SpaceShip Australis and Science Goals 1-6. DigiRadar might be deployed at southern latitudes near Adelaide, to cover south and east over the TIGER footprint (Figure III.5.4). A very exciting opportunity is for a DigiRadar at mid-latitudes, near Newcastle. It should look to the west, north and south, thereby naturally covering the entire Australian continent from the equator to Melbourne. This would cover the domains of the SKA, MWA, and the JORN radars and link naturally with SpaceShip Australis and Marabibi Constellation.

Plasma thrusters for spacecraft propulsion

Timing: 2010-2012, likely cost: $2 M, 20 person-years training, 4 PhDs[18]

As described in Section II.4, Australia currently has two types of plasma-based thrusters being evaluated for space propulsion by ESA and Europe's largest space company (EADS-Astrium). Another type is also being developed. This research program involves laboratory experimentation and testing, theoretical modelling, and construction. The goal is to develop a well-understood thruster ready for use in space by ESA and also Australia. Specifically, the first demonstration of this thruster technology in space is a major goal of the Marabibi Constellation and this technology is expected to be essential for Sundiver.

Figure III.5.5: HyShot ready for launch

Hypersonic technologies for scientific access to and return from space

Timing: 2010-2014, likely cost: $5 M, 50 person-years training, 10 PhDs[18]

All the Global Science Themes and Science Goals described in this Decadal Plan depend critically upon access to space. Furthermore, space science often depends on planetary atmosphere entry capability – whether for exploring other planets, or for returning crew, experiments, or samples to Earth. Long term we plan to develop this capability for access to and return from space. In particular, to translate Australian expertise in hypersonic propulsion (both scramjet and rocket) and aerothermodynamics into a vehicle to launch small scientific payloads into low-Earth orbit, and then de-orbit and successfully return the payload to Earth. Applications include returning satellites to Earth for repair and upgrading, as well as significant Australian participation in planetary exploration. Research on two aspects is proposed.

First, safe, economical and ecologically responsible access to space is a major technological challenge of the 21st century for space-dependent nations. The most promising approach is to extend aeronautical technology to hypersonic vehicles powered, at least partially, by supersonic combustion airbreathing engines (scramjets). Scramjets can be combined with rockets to produce a more fuel-efficient hybrid system with better performance. (As they burn atmospheric air, they do not need to bring oxidiser with them.) With the work performed by our domestic hypersonics community, including universities, industry and DSTO, Australia is internationally recognized as a world leader in this field (Figure III.5.5). Current ground-based and flight programs conducted in Australia (for example, HyShot and HIFiRE) address low to midrange technology readiness levels for scramjet-powered atmospheric flight, at Mach 8. The ultimate aim however is to reach high technology readiness levels for access to space, and this requires scramjet vehicles that can operate at much higher Mach numbers.

Second, research that pushes the state-of-the-art in hypervelocity aerothermodynamic phenomena is needed in order to design safer and more efficient concepts for planetary entry, as evidenced by the demise of the Space Shuttle Columbia and the Beagle II Mars lander. Launching a satellite into orbit and successfully returning it will enable us to design and build a reliable re-entry vehicle, reducing the likelihood of failed planetary exploration missions. The Australian hypersonics community has a proud heritage of leading the world in such research and is extremely well equipped to pursue this goal.

The research proposed here is an essential stepping stone to realising the desired long term capability. Building on our ground-based research experience and HyShot and HIFiRE hypersonic flight experiments, it is a focused program of fundamental research that addresses low technology readiness levels for hybrid scramjet/rocket-powered access to space, coupled with fundamental research into key aerothermodynamic phenomena and technologies for both the ascent and re-entry. In particular, using our world-class experimental facilities and modelling capabilities, we will:

- Conduct the necessary experiments and computer simulations to validate and optimize novel Australian concepts for small hybrid rocket/scramjet vehicles for ascending to space - scramjet inlet design, fuel injection, combustion efficiency improvement, drag reduction, positive thrust over wide Mach number ranges, flight instrumentation, materials for thermal management, and trajectory optimization;
- Conduct the necessary experiments and simulations to design and validate a small, heavily instrumented re-entry capsule for safe return to Woomera from orbit – aerothermodynamics, thermal protection, recovery system, and instrumentation; and
- Couple these developments together to design a complete hybrid rocket/scramjet (Figure III.5.6) with a re-entry capsule for future flight testing at Woomera.

Figure III.5.6: A concept hypersonic vehicle.

The outcomes will represent a crucial step in ultimately developing and flying an Australian vehicle, including onboard instrumentation and control systems, for launch, ascent, re-entry and recovery of small satellites or payloads.

Planetary Data and Image Analysis Facility (PDIAF)

Timing: 2011-2013, likely cost: $1 M, 10 person-years, 2 PhDs[18]

Australia has expertise in processing and interpreting extra-terrestrial planetary data and terrestrial remote sensing data from NASA, ESA, and other foreign missions. While these datasets are generally accessible free via direct link to NASA and ESA data repositories, the lack of local data places important limitations on the types of analysis possible in Australia. This proposal is to create a planetary data network and image analysis facility that ‘powers up’ Australia’s existing expertise and capabilities. The facility will mirror the overseas datasets so as to make feasible more sophisticated and novel analyses by Australian scientists. It will also make available and process planetary and remote sensing data (both in their raw and processed form) for researchers, educators, and the informed public in Australia and in the broader southern hemisphere/Oceania region, which currently does not have this type of facility. This facility would link naturally to NISS and associated data networks. It will build significant Australian capacity for planetary science, Earth observation, and astrobiology.

The facility will require an advanced server with at least 10 TB storage, four or more workstations for processing, four or more PCs for processing and web-based dissemination of information, and advanced imaging and GIS software. Anticipated costs for 2 years are of order $0.4 M for the hardware ($0.1 M) and software ($0.15 M p.a.), plus $0.4 M for 2 IT experts ($0.1 M p.a. each) and $0.1 M for admin support. An additional $0.1 M is budgeted for hardware and software at network sites across Australia. Subsequent operating and upgrade expenses would be sought after the 2-year setup period.

Australian spacecraft telemetry, ground support, and tracking capability

Timing: 2012-2019, likely cost: $5 M, 50 person-years training, 10 PhDs[18]

The University of Tasmania’s two existing and three future (ideally in 2010) radio antennas could be extended beyond the NCRIS AuScope project to give Australia an indigenous telemetry, tracking, and ground support capability for its space program. This would leverage NCRIS’s AuScope geodetic investment (for program ‘Structure and Evolution of the Australian Continent’) and the University of Tasmania’s strong record of providing downlink/uplink and tracking services for NASA, ESA, and JAXA, as well as industry. It would also provide abundant training opportunities for students.

The required technical upgrades are modest and will provide a new Australian spacecraft control capability while respecting the existing AuScope geodetic and astronomical commitments. The proposed system would be able to service the proposed Australian projects Marabibi Constellation and Sundiver (III.5.1), as well as foreign space agencies. Having this indigenous capability would remove the risks of depending on the generosity of NASA and ESA or on future renegotiations of existing tracking treaties. The project is very cost-effective, leveraging existing infrastructure worth over $30 M to provide a new space capability at an additional estimated cost of $5 M for the decade: yearly operational costs of $0.5 M and new technical upgrades and infrastructure of $1 M.

Mass Spectrometer Centre for Cosmochemistry (MASPC)

Timing: 2013-2018, likely cost: $4 M, 40 person-years training, 8 PhDs[18]

Modern cosmochemistry requires measurement of the chemical abundances and isotopic proportions of trace constituents in very small samples to ultra-high precision. Most Australian cosmochemical research occurs in shared facilities or multi-purpose geochemical laboratories that are currently among the best equipped in the world. However, hardware has a finite lifetime and its performance degrades below world-best standards after several years of continuous use. Moreover, use of shared facilities inevitably requires trade-offs between different applications. Accordingly, over this next decade new investment in next-generation instrumentation, upgrades to laboratory infrastructure, and a commitment to skilled technical support is needed to maintain and improve Australia's participation at the highest level of planetary science.

Mass spectrometers are the instruments of choice for most cosmochemical research. The most pressing need for new instrumentation over the coming decade will be for solid sample analysis using thermal ionization or plasma source ionization mass spectrometry.

Immediate applications will include measurement of (1) long-lived and extinct radionuclides to determine the timing of nebular evolution and planetary evolution (Science Goals 12, 13) and (2) heavy stable isotopes as tracers of nebular environments, water-rock interactions, and the development of hydrospheres and biospheres (Science Goals 14, 15). The cost for a next generation mass spectrometer will be approximately $3 M for instrument and laboratory hardware, and an additional $0.2 M annually for technical support and consumables. It should be based in a new Centre at the ANU that leverages the expertise, heritage, and investments at ANU and Curtin among others.

Recommendation 12: *Medium Projects represent important combined infrastructure, science, and technology projects that will develop, extend, and support Australia's new space capabilities across the gamut of space science, are vital for a strong and integrated space science community, and should be funded strongly via ARC, ASRP and NCRIS programs.*

III.6 Education and Training

Space science is an excellent field for inspiring people to undertake additional education and training, as argued in Section I.4. The projects proposed in this section, as well as the research-led but strongly student-focused projects in III.5 (especially SpaceShip Australis and Marabibi Constellation), offer tremendous opportunities for education and training in the enabling sciences, engineering, and management. These opportunities are required by future space scientists, technologists, and related experts in industry and government, as well as to educate and train people who will contribute in other ways to Australian society.

These education and training projects aim to:

- reduce the large shortages of trained scientific and technological personnel anticipated to arise in Australia by 2013 (and to worsen with time if not remedied);
- increase the attractiveness and efficacy of science, mathematics, and engineering education in Australia, including practical experience on large space projects; and
- encourage a greater appreciation, awareness, and understanding of science by the Australian public, industry, and government.

Four initiatives are proposed that use space science to educate and train increased numbers of workers with advanced scientific and technical knowledge. These are in addition to the increased opportunities provided by the foregoing projects in Section III.4. These initiatives could be managed primarily by CASS and universities with funding from government, industry, and other sources.

(1) **Space Science and Engineering Student Scheme:** 20 Honours year scholarships of $4000 each, 20 Vacation Scholarships of $3000 each (for at least six weeks), and 10 Postgraduate Topup Scholarships (each for three years) of $5000 per year will be awarded via an annual competition organized and managed by CASS (or NISS longterm). Each award will involve joint research between a university and a partner that is either a government unit or an industrial entity. The research may involve any combination of space science, technology, and related engineering. There will be a requirement for substantial (more than 10%) presence at the partner institution. The partner is able to enhance the scholarship once awarded.

    The Scheme aims to (1) improve the linkages between universities, government laboratories, and industry, (2) increase the number of students and academics working at partner institutions, and (3) develop better career pathways into government and industry of highly trained scientists, technologists, and engineers.

    Funding could be provided by donations from interested government and industry entities, with the option of sponsors naming specific awards. The primary award criterion would be academic excellence, with the secondary criterion being overlap between the desires and attributes of the students, academics, and partners institutions.

    Full funding of the scheme would be $290 K per year and $3 M for the decade.

(2) **Assessing Education and Public Outreach Programs:** There is little research on whether high school curricula actually produce scientifically literate citizens, or whether programs aimed at increasing the appreciation or awareness of science in the wider public community are effective to any degree. In other words, much funding, time, and effort is spent on programs without knowing whether they work.

    A 2009 study by Maltese and Tai[20] into what first engaged scientists and graduate science students with science found that ‘space’ was the most commonly mentioned topic. This is consistent with the huge surges in the number of engineering and physical science PhD enrolments that started with Sputnik and then the Apollo and Space Shuttle programs[21]. Therefore, the inspirational nature of space offers an unique opportunity to engage students and the public with science, and to study when that engagement is effective. The initial institutions involved are envisaged to be the Australian Centre for Astrobiology (ACA), the Victorian Space Science Education Centre (VSSEC), the Australian Centre for Field Robotics (ACFR), and several member teams of the NASA Astrobiology Institute (MIT and Arizona State University), with initial support and engagement with CASS.

Funding for this effort could come from multiple sources, including DIISR and DEEWR but also programs currently in place for use by universities and high schools. An example is the Australian Schools Innovation in Science, Technology and Mathematics fund that was available as of February 2008. Initial annual funding of $200 – 500 K would be appropriate, with extension as the program develops.

(3) **Virtual Reality Field Trips (VRFTs) for high schools students:** Australia has a world-recognized expertise in the development of VRFTs, specifically in the area of astrobiology. The aim of the VRFT technology, developed by the Australian Centre for Astrobiology (now at UNSW) in partnership with NASA and others, is to engage students in scientific field trips with a gaming-technology feel. Users are able to travel kilometers over the landscape with scientists, who are debating the evidence in the field. In this way users learn that science is about discovery, probability, and predictability. The first VRFT was finished in 2007 and launched in the Australian science magazine *Cosmos*. In the first two years the associated wiki webs attracted nearly six million hits. New VRFTs are planned, the first with the ACA and the MIT NASA Astrobiology team in early 2010 to astrobiology sites in the Flinders Ranges of South Australia. These VRFTs are intended as a resource for all interested users. Future applications are envisaged across space science and related subjects (eg the enabling sciences and mathematics) at high schools and universities. Initial annual funding of $50 K to CASS is appropriate, with extension as the program develops.

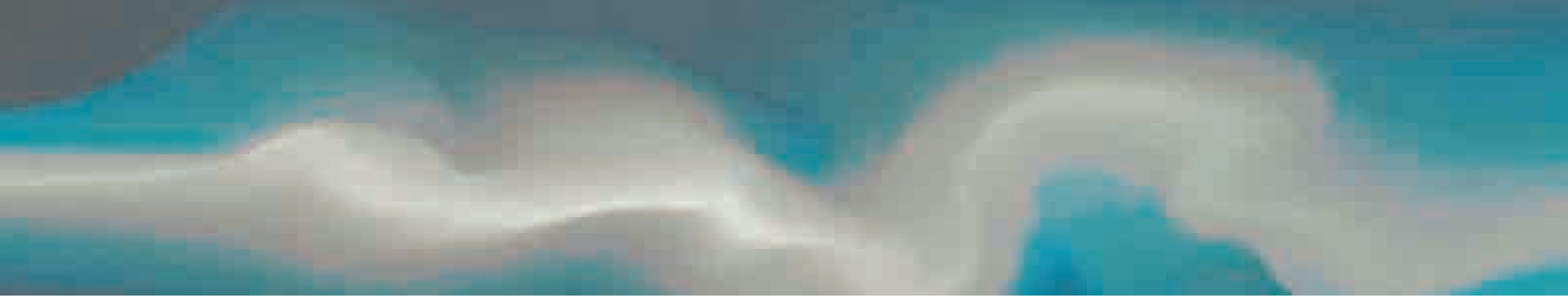
(4) **Collaborative Postgraduate Degrees by Coursework and Research** across disciplines and universities: At present almost all postgraduate degrees in space science at Australian universities are narrowly focused on one scientific or engineering discipline, are within one faculty and one university, and are primarily by research and directed towards academic careers. There are no opportunities for students to develop a broad education across space science, engineering, business, law and government by course work. Similarly, taking courses at more than one university requires multiple enrolments and lacks a unified degree structure.

Developing a flexible, multiple institutional, multiple discipline Masters program in space science would address these deficiencies, provide concomitant opportunities for tuition fees, and provide a means to broadly educate and train increased numbers of workers in fields relevant to space. Moreover, these workers would have skills in advanced science, engineering, and associated business and government that should be widely transferrable. While students should have access to Fee-Help for enrolment fees, funding from government, industry and universities should be pursued to reduce the costs. This would demonstrate longterm commitment to space beyond the 2009 Super Science Initiative.

Recommendation 13: *Government, industry, and the science and education communities should strongly support the Education and Training projects since they directly address crucial national needs and questions on the efficacy and methods of education, and also support the long-term development of Australia's human capital, educational infrastructure, space capability, and stakeholders in space.*

20 'Eyeballs in the Fridge: Sources of Early Interest in Science', A.V. Maltese and R.H. Tai, Int. J. of Science Ed., 31, 1-17, 2009.

21 'US doctorates in the 20th Century', L. Thurgood, M. Golladay, and S. Hill, US Nat. Sci. Found. (NSF) Special Report 06-319, 2006.



III.7 Community Development and Outreach

Australia's professional space science community has only recently organized itself into a cohesive whole. It is thus both vital and very timely to plan how to develop and optimize it for maximal scientific and national benefits. More generally, 'community development' refers to the development of an explicitly cooperative approach between the professional space scientists and engineers, universities, the Academy of Science, the Academy of Technological Sciences and Engineering, government units, industry, public interest groups, and the public that encourages stronger links between one another and develops a national space community with broad public, government, and industry support. This development involves outreach activities that stimulate and educate members of these groups, and motivate them to engage with and join the broader space science community for mutual benefit. The projects proposed are as follows:

(1) **Annual Space Science Conference or Forum:** An annual professional-level conference that brings together all parts of the professional space science community (from solar physics to cosmochemistry to space technology) is required. It should also attract space engineers, industry, government, educators, and public 'space advocacy' groups. No such conference presently exists, although the Australian Space Science Conference (ASSC) and Australian Space Development Conferences (ADSC) provide a base. Related conferences include those of the Australian Institute of Physics, Geological Society of Australia, and Australian Remote Sensing and Photogrammetry community. The first steps to develop this have taken place: the 2007 to 2009 ASSC meetings were organized jointly by the National Committee for Space Science (NCSS) and the National Space Society of Australia (NSSA), with a major effort to make the conference professional level and to invite and attract the above constituencies. Funding of less than $10 K p.a. from CASS should be required.

(2) **Link Organizations Interested in Space:** Multiple high-level 'space' committees exist in Australia, but they act independently and have little overlap. These include NCSS, the National Committee for Space Engineering of Engineers Australia, the Australian Government Space Forum, the Australian Industry Chamber of Commerce, and the Australian Defence Information and Electronic Systems Association, among others. These need to be linked more efficiently to produce results. The proposed CASS (Section III.4.1) is the natural linkage mechanism and organization. This is also the right high-level group to develop and coordinate the space science community. It is proposed that CASS organize regular one-day meetings, approximately twice per year, to consult with and coordinate the above groups and to inform them of recent progress. Funding of less than $10 K p.a. from CASS should be required.

(3) **Speakers Bureau:** Space science experts with advanced educational skills and media training are needed to effectively present science to the media and public, and to provide comment and advice at short notice to the media, industry, and public. The project involves establishing a 'Speakers Bureau', with approximately 10-20 trained, media-friendly speakers available across space science and technology. This addresses 'public good' and education goals, as well as outreach. An extension would for the Bureau to moderate an on-line forum and associated Wiki pages, providing expert feedback in a guaranteed time. CASS, NISS or other qualified organizations would provide the training. Speakers' costs would be borne by requesters for talks and media events and by the speakers' organization for Wiki and forum pages.

(4) **Science Meets Parliament Day:** Scientists and members of Parliament attest to the value of this annual meeting. The space science community must better communicate its vision, potential and needs to government (including ministers, members of Parliament, and public servants). High priority thus needs to be placed on sending an effective delegation of space scientists to each Science Meets Parliament Day.

(5) **International Space Week, Amateur Space Groups, and Industry:** The UN's International Space Week (4-10 October), which contains the 4th October anniversary of Sputnik's launch and the dawn of the Space Age, is an excellent opportunity for raising the public's interest in space and for bringing together professional and amateur space groups and industry. It is proposed that these groups, led by CASS, develop an annual program in International Space Week that includes:

- public-level talks on the new scientific results and technology of Australia's space effort, and on Australia's role in the international space effort;
- scientific, engineering, and business competitions for university and school students; and
- open-day visits for the public and media to institutions with space science and technology facilities, including VSSEC, SpaceShip Australis instruments, and museums.

As well as increasing interest and therefore student inflow into space-related studies, these events should enhance the public profile and reputation of organizations involved. They will also provide opportunities to distribute information on Australian space science, technology, and industry, and to capitalize on Australian participation in international projects. Requisite funds could be provided by CASS's public outreach program, industry, and government funds for popularizing science at less than $10 K p.a.

Recommendation 14: *Oureach and community building are vital to the development of Australia's space capability, human capital, and society, and should be actively performed and supported by all Australian stakeholders in space.*

III.8 Priorities

The priorities decided by the Australian space science community for Structures, the Flagship and ICFO Projects, and the Medium Projects are listed separately in Tables 1, 2, and 3, respectively.

The prioritization of Medium Projects is determined within two tranches, the first from 2011 to 2012, and the second from 2012 to 2013. Thus, DigiRadar is ranked first for tranche one and the Telemetry and Tracking Capability is ranked first for tranche 2. The latter is partly determined by strategic considerations regarding the initial launches for the Marabibi Constellation: having a strong indigenous telemetry and tracking capability would limit Australia's dependence on ESA and NASA for these services.

Tables 1-3 also show the timelines and estimated total budgets for projects, as well as priorities. They therefore provide a good overall summary. Note that the costs of Medium Projects are expected to come primarily from ASRP and ARC Linkage and LIEF funding schemes. Only the Flagship, CASS, NISS and ICFO Projects need funding from new government funding schemes and so represent 'new' funding.

Table 1: Coordinating infrastructure for Australian Space Science

Name	Priority	Budget	Time
CASS (Coordination of Australian Space Science)	1	$200 K p.a.	2010-2019
NISS (National Institute for Space Science)	2	$25 M for decade	2011-2019

Table 2 – Priorities and Timelines for Flagship Projects and ICFO

Project	Priority	Budget ($M)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
SpaceShip Australis	1	20	D,C,O,M	C,O,M	C,O,M	C,O,M	O,M	O,M	O,M	O,M	O,M	O,M
Marabibi Constellation	2	60	D,M	D,M	D,C,M	D,C,M	C,O,M	C,O,M	D,O,M	D,CO,M	O,M	O,M
ICFO	3	20	D	O	O	O	O	O	O	O	O	O
Sundiver - Design	4	10	D,M	D,M	D,M	D,M						

D = Design, C = Construction, O = Operational, M = Modelling/Theory,
ICFO = International Collaboration and Future Opportunities, and
NISS = National Institute for Space Sciences.

Table 3 – Priorities and Timelines for Medium Projects

Tranche	Project	Priority	Budget ($M)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	DigiRadar	1	2	D,C	D,C	C,O							
1	Thrusters	2	2	D,C,M	D,C,M	C,O,M							
1	Hypersonic	3	5	D,C,M	D,C,M	D,C,M	D,C,M	D,C,M	D,C,M				
1	PDIAF	4	1	C,O	C,O	C,O							
2	Telemetry/ Tracking	1	5			D,C	D,C,O	O	O	O	O	O	O
2	MASPC	2	4					D,C,O	O	O	O	O	O

PDIAF = Planetary Data and Image Analysis Facility, MASPC = Mass Spectrometry Centre for Cosmochemistry.

Chapter IV
Conclusions

Chapter IV

Conclusions

(1) Space Science is inspirational and well suited to education and training in the fundamental sciences, mathematics, engineering, and commerce.

(2) Space science produces vital discoveries and services for modern society.

(3) Space science naturally promotes a global view, increasingly crucial for a finite world with a strongly coupled economy and ecosystem, and links Earth science to the distant cosmos.

(4) Space science has strong national and international benefits for Australia and a natural focus on Australasia and Antarctica.

(5) Space science and technology have strong potential for productively linking Australian universities, government units, domestic and international industry, educators, other professions, professional societies, and the public.

(6) Australia has world-leading space scientists doing visionary, state-of-the-art, innovative science and technology research.

(7) The proposed research effort is very high value, low expense, and has a high multiplier benefit. Over the next 10 years it involves:

   (a) Investment into new large projects that build capability, develop research infrastructure, and pursue exciting, broad-themed, fundamental and applied science at an estimated cost of less than $140 M[22], which is less than $1 per Australian per year.

   (b) Development of a real, active, presence in space for Australia (Figure IV.1), with multiple strong international collaborations and links:

   - A new entity CASS Ltd (Coordination of Australian Space Science) to manage investment and link Australian stakeholders.
   - A new National Institute for Space Science (NISS) that builds capability, computation and theory skills, and data networks across space science.
   - New science themes and specific (but not proscriptive) goals determined and agreed by Australia's space science community.
   - A ground-based state-of-the-art network (SpaceShip Australis) to make Australasia the world's best instrumented and modelled region for predicting space weather from the Sun to the ground.

Figure IV.1: The proposed entity CASS (Coordination of Australian Space Science) works with government to connect and leverage Australia's space science interests and capabilities (universities, government units, and industry) into a national effort. Resulting national benefits are shown in gold text and the Plan's major reseach projects in white text, including SpaceShip Australis (SSA), Marabibi Constellation, International Collaborations and Future Opportunities (ICFO), and Sundiver. The link to the proposed National Institute for Space Science (NISS) is also shown. CASS will work with government to connect Australia's space effort to international space agencies and industry.

- A flexible, long term, indigenous space capability, built via the novel Marabibi Constellation of nano, micro, and small satellites, that pursues world-first, student-focused, research on space weather, space technology, and Earth observation.
- A new program (ICFO) to fund Australian participation in future international space efforts (eg human medicine & exploration).
- Major education, training, and outreach programs that build new capabilities and leverage existing capabilities.
- Medium-sized collaborations that build capability and infrastructure while pursuing major research innovations from digital radars to image analysis laboratories to propulsion.
- Development of a capability for interplanetary and planetary spacecraft projects, via a design study of a concept (Sundiver) with multiple novel capabilities and visionary science goals.

22 In 2009 dollars with September 2009 exchange rates. This sum does not include funding from the Australian Space Research Program and Australian Research Council for medium and small projects.

Chapter V
Recommendations

Chapter V

Recommendations

Recommendation 1: Australia should invest in a strong capability in space science and engineering in order to grow its own economy and industry, develop its scientific and technical infrastructure, increase the long-term opportunities available to its citizens, and build stronger international relationships with other nations.

Recommendation 2: Australia should invest in an enhanced Australian space capability in order to manage more effectively the risks of dependence on foreign space assets and to ensure Australia's long-term economic security.

Recommendation 3: Over time government and its Space Policy Unit should work with stakeholders in Australian space science and engineering to coordinate space efforts across government and the nation in a strategic way that:

- develops a demonstrably Australian capability in space science and industry;
- maximizes the scientific and innovation benefits;
- gives consideration to government's broader objectives in national security and foreign affairs, public-good services, telecommunications, and economic policy;
- empowers Australian stakeholders in space science to achieve agreed goals; and
- develops and supports executive structures (eg CASS) to accomplish agreed goals and boards/ councils (eg a Space Advisory Council) to provide advice.

Recommendation 4: An innovative and invigorating Australian program in space science should be pursued as one government approach to reverse current educational trends and better position Australia's economy and citizens in global society.

Recommendation 5: The Australian government should develop a Space Advisory Board or Council to provide it with expert advice across the gamut of Australia's national interests in space.

Recommendation 6: The Australian Government should fund and support development of a coordinating entity for the space science community along the lines of CASS, in consultation with the space science community and other Australian stakeholders in space.

Recommendation 7: A National Institute for Space Science should be developed along the lines proposed, with strong support from academia, government, and industry.

Recommendation 8: Australia should develop a state-of-the-art capability in ground-based space science and associated services and technology via a research network along the lines of SpaceShip Australis, aiming to make Australasia the world's best instrumented and modelled region for predicting space weather from the Sun to the ground and mitigating its effects.

Recommendation 9: Australia should develop a long-term near-Earth space capability by funding a multiple spacecraft project along the lines of the Marabibi Constellation, so as to build the required research infrastructure, perform world-first, student-focused, research on space weather, space technology, and Earth observation, and provide opportunities for strong education, training, outreach, and international collaboration.

Recommendation 10: Australia should start to develop a capability and associated research infrastructure for interplanetary and planetary space projects by approving a detailed design study for a combined solar, planetary, and interplanetary project with exciting science goals and challenging engineering requirements, along the lines of Sundiver.

Recommendation 11: Australia should develop its capability and research infrastructure for collaborating on international space projects through an official program, along the lines of the proposed International Collaborations and Future Opportunities (ICFO) program, to support official Australian participation in international space missions and future opportunities (domestic or international) that arise during the next decade.

Recommendation 12: Medium Projects represent important combined infrastructure, science, and technology projects that will develop, extend, and support Australia's new space capabilities across the gamut of space science, are vital for a strong and integrated space science community, and should be funded strongly via ARC, ASRP, and NCRIS programs.

Recommendation 13: Government, industry, and the science and education communities should strongly support the Education and Training projects since they directly address crucial national needs and questions on the efficacy and methods of education, and also support the long-term development of Australia's human capital, educational infrastructure, space capability, and stakeholders in space.

Recommendation 14: Outreach and community building are vital to the development of Australia's space capability, human capital, and society, and should be actively performed and supported by all Australian stakeholders in space.

Appendices

Note that Appendices F – O predate completion of the Decadal Plan. Accordingly the recommendations and information in these Appendices are extended and superceded by those in the Decadal Plan itself.

Appendix P, the standalone joint Academies strategic plan for Earth observation from space, is provided here for convenience.

Appendices F – P are available on the accompanying CD.

Appendix A

The National Committee for Space Science (NCSS)

NCSS is the committee of the Australian Academy of Science for space science (see www.science.org.au/natcoms/nc-space.htm and www.physics.usyd.edu.au/~ncss) The members of NCSS during the Decadal Plan's development and finalization were:

Prof. Iver Cairns, Chair	University of Sydney	(2005 – 2010)
Dr Charlie Barton	Australian National University	(2005 – 2008)
Prof. Russell Boyce	University of Queensland	(2009 – 2010)
Dr Graziella Caprarelli	University of Technology Sydney	(2009 – 2010)
Dr David Cole	IPS Radio & Space Services	(2005 – 2007)
Prof. Peter Dyson	La Trobe University	(2005 – 2010)
Prof. Brian Fraser	University of Newcastle	(2005 – 2008)
Dr Alex Held	CSIRO and its Office of Space Science and Applications (COSSA)	(2005 – 2010)
Prof. Fred Menk	University of Newcastle	(2009 – 2010)
Dr David Neudegg	IPS Radio & Space Servives	(2008 - 2010)
Prof. Andrew Parfitt	University of South Australia	(2005 – 2007)
Prof. Robert A. Vincent FAA	University of Adelaide	(2005 – 2010)
Prof. Malcolm Walter FAA	University of New South Wales	(2005 – 2010)

Appendix B

Steering Committee for the first Decadal Plan for Australian Space Science

The members of the Steering Committee and their connections are:

Prof. Iver Cairns, Chair	NCSS and University of Sydney
Dr Miriam Baltuck	CSIRO (from 2008)
Mr. Brett Biddington	Independent consultant, Australian Space Industry Chamber of Commerce (Chair), and Cisco Systems, Inc.'s Global Defence & Space Group (formerly)
Prof. Rod Boswell FAA FTSE	Australian National University (from 2007)
Prof. Russell Boyce	University of Queensland
Dr Graziella Caprarelli	University of Technology Sydney (UTS) and Geological Society of Australia
Dr Jon Clarke	Mars Society of Australia
Dr David Cole	NCSS and IPS Radio & Space Services
Prof. Peter Dyson	NCSS and La Trobe University
Prof. Brian Fraser	NCSS and University of Newcastle
Dr Alex Held	NCSS, CSIRO, and its Office of Space Science and Applications (COSSA)
Dr David Morton	COSSA (2008 only)
Dr Marc Norman	Australian National University and Geological Society of Australia
Dr Carol Oliver	University of New South Wales
Prof. Andrew Parfitt	NCSS and University of South Australia
Prof. Chris Rizos	University of New South Wales (from 2008)
Prof. Anatoly Rozenfeld	University of Wollongong
Prof. Robert Vincent FAA	University of Adelaide
Prof. Malcolm Walter FAA	NCSS and University of New South Wales
Dr Phil Wilkinson	IPS Radio & Space Services (from 2008)
Prof. John Zillman FAA FTSE	Australian Academy of Technological Sciences and Engineering

The dates of involvement are 2005 – 2010 except where otherwise noted.

Appendix C

Working Groups

(1) Ground Working Group

Prof. Peter Dyson, Chair	La Trobe University
Dr David Cole	IPS Radio and Space Services
Prof. John Devlin	La Trobe University
Dr Marc Duldig	Australian Antarctic Division
Prof. Mervyn Lynch	Curtin University of Technology
Prof. Fred Menk	University of Newcastle
Prof. Andrew Parfitt	University of South Australia

Others consulted included:

Mr Brett Biddington	Independent Consultant, Australian Space Industry Chamber of Commerce, and Cisco Systems Inc.
Dr Laurie Burgess	BAe
Dr Jon Clarke	Mars Society of Australia
Dr John Foster	Haystack Observatory, Massachusetts Institute of Technology, USA
Dr Roger Franzen	Auspace Limited, Earthspace, and KaComm Communications Ltd
Prof. Brian Fraser	University of Newcastle
Dr Alex Held	CSIRO and COSSA
Dr David Jauncey	CSIRO
Dr Frank Lind	Haystack Observatory, Massachusetts Institute of Technology, USA
Dr Marc Norman	Australian National University
Dr Murray Parkinson	La Trobe University
Prof. Iain Reid	University of Adelaide
Dr Joe Salah	Haystack Observatory, Massachusetts Institute of Technology, USA
Dr Don Sinnott	IEEE
Dr Ian Tuohy	BAe

(2) Planetary Sciences Working Group

Dr Marc Norman, Chair	Australian National University
Dr Vickie Bennett	Australian National University
Dr Graziella Caprarelli	University of Technology Sydney
Prof. Brad Carter	University of Southern Queensland
Dr Jon Clarke	Mars Society of Australia
Dr David Nelson	Curtin University of Technology
Dr David Stegman	Monash University
Prof. Ross Taylor FAA	Australian National University
Prof. Sergey Vladimirov	University of Sydney
Prof. Malcolm Walter FAA	University of New South Wales

With submissions from:

Dr Jeremy Bailey	Macquarie University
Dr Trevor Ireland	Australian National University
Prof. Robert Pidgeon	Curtin University of Technology

(3) Public Outreach Working Group

Dr Carol Oliver, Chair	University of New South Wales
Dr Jonathan Clarke	Mars Society of Australia
Mr Michael West	National Space Society of Australia
Ms Kerrie Dougherty	Powerhouse Museum
Dr Naomi Mathers	Victorian Space Science Education Centre (VSSEC)
Dr Larisa Lindsay	200 Labs

(4) Remote Sensing of Earth and other Planetary Environments Working Group

Dr Alex Held, Chair	CSIRO and COSSA
Dr Peter Woodgate	CEO, CRC for Spatial Information
Dr Stuart Phinn	University of Queensland
Dr Richard Smith	WA Department of Land Information
Dr Tony Wheeler	Sinclair-Knight & Merz
Prof. Tony Milne	University of New South Wales

Others consulted included:

Dr Sue Barrell	Bureau of Meteorology
Dr Adam Lewis	Geoscience Australia

(5) Space Technology Working Group

Prof. Iver Cairns, Chair	University of Sydney
Prof. Rod Boswell FAA FTSE	Australian National University
Dr Roger Franzen	Auspace Limited, Earthspace, and KaComm Communications Ltd
Dr Alexey Kondyurin	University of Sydney
Dr Wayne McRae	Gravitec Instruments and University of Western Australia
A/Prof. Sam Reisenfeld	University of Technology Sydney
Prof. Don Sinnott	Institute of Electrical and Electronics Engineers (IEEE)
A/Prof. Salah Sukkarieh	University of Sydney
Prof. Michael Tobar	University of Western Australia

Others consulted included:

Dr Miriam Baltuck	CSIRO and COSSA
Dr Grant Griffiths	CSIRO, Industrial Physics
Dr Joe Khachan	University of Sydney
Dr Phillip Teakle	CSIRO and University of Queensland
Prof. Pavel Trivailo	Royal Melbourne Institute of Technology

(6) Space Weather and Industry Working Group

Dr David Cole, Chair	IPS Radio and Space Services
Mr Bill Barrett	Asia Pacific Aerospace Consultants, Australian Space Industry Chamber of Commerce (former Chair), and ComDev
Mr Brett Biddington	Independent Consultant, Australian Space Industry Chamber of Commerce (Chair), formerly Cisco Systems, Inc.
Wing Commander Nicholas Clarke	Satellite Operations, Dept of Defence
Colonel Michael Collie	Strategic Development, Dept of Defence
Mr Chris Deacon	Deacon Communications Pty Ltd
Dr Marc Duldig	Australian Antarctic Division
Prof. Peter Dyson	La Trobe University
A/Prof. Yanming Feng	Queensland Institute of Technology
Dr Roger Franzen	Auspace Limited, Earthspace, and KaComm Communications Ltd
Captain Dr Ian Getley	QANTAS and University of New South Wales
Prof. Fred Menk	University of Newcastle
Prof. Andrew Parfitt	University of South Australia
Dr Gordon Pike	Optus Communications
A/Prof. Jinling Wang	University of New South Wales

Others consulted included:

Dr David Neudegg	IPS Radio and Space Services
Dr Phil Wilkinson	IPS Radio and Space Services

(7) Sun to Earth Working Group

A/Prof. Colin Waters, Chair	University of Newcastle
Dr Ildiko Horvath	University of Queensland
Dr Roman Makarevich	La Trobe University
Dr Ray Morris	Australian Antarctic Division
Dr Murray Parkinson	La Trobe University
Prof. Peter Robinson	University of Sydney

(8) Theory, Computation, Modelling, and Data Working Group

Prof. Peter Robinson, Chair	University of Sydney
Dr Rowena Ball	Australian National University
Dr Charles Barton	Australian National University
Dr John Bennett	Monash University
Dr Jorgen Fredericksen FAA	CSIRO
Dr Murray Parkinson	La Trobe University
A/Prof. Colin Waters	University of Newcastle
Dr Phil Wilkinson	IPS Radio and Space Services

(9) New Instruments and Mission Working Group

Prof. Brian Fraser, Chair	University of Newcastle
Prof. Iver Cairns, Deputy Chair	University of Sydney
Dr Roger Franzen	Auspace Limited, Earthspace, and KaComm Communications Ltd
Dr Zdenka Kuncic	University of Sydney
Dr Wayne McRae	Gravitec Instruments & University of Western Australia

Others consulted or who submitted materials:

Prof. Rod Boswell FAA FTSE	Australian National University
Prof. Peter Dyson	La Trobe University
Mr Daniel Faber	Heliocentric Pty Ltd and Heliocentric Technologies Inc.
Dr Noel Jackson	University of Southern Queensland
Dr Phillip Teakle	CSIRO and University of Queensland

(10) Demographics Working Group

Prof. Brian Fraser, Chair	University of Newcastle
Mr Brett Biddington	Independent consultant, Australian Space Industry Chamber of Commerce (Chair), & Cisco System, Inc.'s Global Defence & Space Group (formerly)
Prof. Iver Cairns	University of Sydney
Dr Jon Clarke	Mars Society of Australia
Dr Marc Duldig	Australian Antarctic Division
Dr Alex Held	CSIRO and COSSA
Prof. Andrew Parfitt	University of South Australia

With submissions from:

Prof. Rod Boswell FAA FTSE	Australian National University
Prof. Russell Boyce	University of Queensland
Prof. Iver Cairns	University of Sydney
Dr Hilary Cane	University of Tasmania
Dr Graziella Caprarelli	University of Technology Sydney
Prof. Paul Cally	Monash University
A./Prof. Brad Carter	University of Southern Queensland
Dr David Cole	IPS Radio and Space Services
Dr Marc Duldig	Australian Antartic Division
Prof. Peter Dyson	La Trobe University
Professor Brian Fraser	University of Newcastle
Dr Alex Held	CSIRO (COSSA)
Mars Society of Australia	
Mimix Broadband	
Dr Marc Norman	Australian National University
Dr Ray Norris	CSIRO (Tracking and communications facilities)
Prof. Robert Pidgeon	Curtin University of Technology
Dr Anthony Rea	Bureau of Meteorology
Dr Ravi Sood	University of New South Wales
A./Prof. Robert Stening	University of New South Wales
Prof. Mike Tobar	University of Western Australia
Prof. Robert Vincent FAA	University of Adelaide

Appendix D

Comments and Inputs on the Decadal Plan

In addition to the members of the National Committee for Space Science (Appendix A), the Steering Committee for the Decadal Plan (Appendix B), the members of the Plan's Working Groups and associated consultees (Appendix C), comments on or inputs to the Decadal Plan were received from at least the following people and institutions:

Dr Thomas Barlow[23]	Thomas Barlow Advisory Services
Dr Chris Boshuizen[23]	NASA/Ames Research Center and Space Generation Advisory Council
Prof. Jim Peacock FAA	Chief Scientist of Australia
Dr Chris Pigram	Deputy CEO, Geoscience Australia
Prof. Sue Rowley	Deputy Vice-Chancellor and Vice-President (Research), University of Technology Sydney
Dr Tony Press	Director, Australian Antarctic Division
Mr Michael Pakakis	Director, Victorian Space Science Education Centre (VSSEC)
Dr Kim Reitman	General Manager, Bureau of Rural Sciences
Dr James Moody	General Manager, CSIRO International
Dr Phil Wilkinson	General Manager, IPS Radio & Space Services
Dr Vaughan Beck	Technical Director, Australian Academy of Technological Sciences and Engineering (ATSE)
Mr David Cooper	President and Board of the Mars Society of Australia
Ms Anntonette Joseph	President of the National Space Society of Australia
Dr Takumi Abe	JAXA, Japan
Dr Ian Allison	Australian Antarctic Division
Dr John Bell	ATSE
Prof. Joss Bland-Hawthorn	University of Sydney
Mr Gordon Briggs	Australian Defence Force Academy
Prof. Paul Cally	Monash University
Prof. Matthew Colless FAA	National Committee for Astronomy
Prof. John Dickey	University of Tasmania
Dr Simon Ellingsen	University of Tasmania
Dr Brian Embleton	(retired – former Director of CRC for Satellite Systems)

23 Some inputs and comments were provided as part of contracted services.

Prof. Matthew Colless FAA	National Committee for Astronomy
Prof. John Dickey	University of Tasmania
Dr Simon Ellingsen	University of Tasmania
Dr Brian Embleton	(retired – former Director of CRC for Satellite Systems)
Dr Roger Gifford	National Committee for Earth System Science
Dr Tetsuya Kodama	JAXA, Japan
Dr John LeMarshall	Bureau of Meteorology
Mr Mark McAuley	Astronomy Australia Ltd.
Prof. Michael Manton	ATSE and Monash University
Dr Naomi Mathers	VSSEC
Dr Frank Mills	Australian National University
Prof. Tony Milne	University of New South Wales
Prof. Brian O'Brien	(retired in Perth – former Apollo experimenter and Professor of Rush University, Houston, USA)
Prof. Koh-ichiro Oyama	National Central University, Taiwan
Dr W.K. (Bill) Peterson	NASA Headquarters and University of Colorado, Boulder, USA
Prof. Stuart Phinn	University of Queensland
Dr Sean Tuttle	EADS Astrium Satellites

Appendix E

Decadal Plan Presentations

The Decadal Plan, its process, and its content have been presented, discussed, and approved at many workshops, conferences, and venues during the Plan's development. Some of these presentations are available from www.physics.usyd.edu.au/~ncss.

The purposes of these presentations include (1) obtaining input to and feedback on the Plan's content and motivations, (2) educating and developing Australia's space science community and related communities, and (3) obtaining formal approval of the Plan from stakeholders in Australian space science. The list of presentations and approvals include:

February 2006
Workshop on Applications of Radio Science (WARS), Leura, NSW;
approval of the Plan's process and outlines.

November 2006
Forging a National Remote Sensing Strategy, Canberra, ACT;
positive feedback; no request made for approval.

December 2006
Solar-Terrestrial and Space Physics (STSP) Group, Australian Institute of Physics Congress, Brisbane, QLD; approval of the Plan's process and content to date.

September 2007
Australian Space Science Conference (ASSC), Sydney, NSW;
approval of the Plan's process and content to date.

May 2008
Australian Government Space Forum, Canberra, ACT;
positive feedback; no request made for approval.

July 2008
Committee on Space Research (COSPAR) Congress, Montreal, Canada;
positive feedback; no request made for approval.

July 2008

Australian Space Development Congress, Adelaide, SA;
approval of the Plan's process and content to date.

July 2008
Australian Space Development Congress, Adelaide, SA;
approval of the Plan's process and content to date.

July 2008
Space Based Remote Sensing meeting, Canberra, ACT;
approval of the Plan's content and the separate development of what
became the Joint Academies *Australian Strategic Plan for Earth Observations from Space*.

September 2008
ASSC, Canberra, ACT; approval of the Plan's process and content to date.

September 2008
Joint videoconference of ASSC and the Australasian Remote Sensing and Photogrammetry
Conference (Darwin, NT); approval of the Plan's process and content to date.

December 2008
STSP Group, Australian Institute of Physics Congress, Adelaide, SA;
approval of the Plan's process and content to date.

September 2009
ASSC, Sydney, NSW; unanimous approval of the Decadal Plan.

Notes

2010 - 2019

Decadal Plan for Australian Space Science

Building a National Presence in Space

National Committee for Space Science
Australian Academy of Science