New Horizons

A Decadal Plan for Australian Astronomy 2006 – 2015

Prepared by the National Committee for Astronomy of the Australian Academy of Science November 2005

Editorial Note

This document is Volume I of the Decadal Plan. It is the culmination of over one year's effort by the Australian astronomical community. The Plan is based on the reports of nine Working Groups, comprising over 100 astronomers, engineers and educators from over 30 Australian institutions. The Working Group reports are published on CD (included with the printed copy of Volume I) as part of Volume II. The Decadal Plan was edited for the National Committee of Astronomy by an Editorial Board comprising Brian Boyle (chair), Chris Tinney (vice-chair), Charles Jenkins, Elaine Sadler and John Storey.

Cover images:

The Southern Milky Way

© Anglo-Australian Observatory/David Malin Images

This wide-angle picture covers the part of the Milky Way between Sagittarius and Norma that makes up the dusty body of "The Emu in the Sky". It was made with colour film and an ordinary camera attached to the Anglo-Australian Telescope.

Warlu Time

© 2003 Charmaine Green

This painting, Warlu Time, was commissioned by the ATNF for an international SKA workshop that was held in Geraldton, Western Australia, in July 2003. The original painting is acrylic on canvas.
Charmaine Green is a member of the Marra Art collective in Geraldton.

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Australian Astronomy
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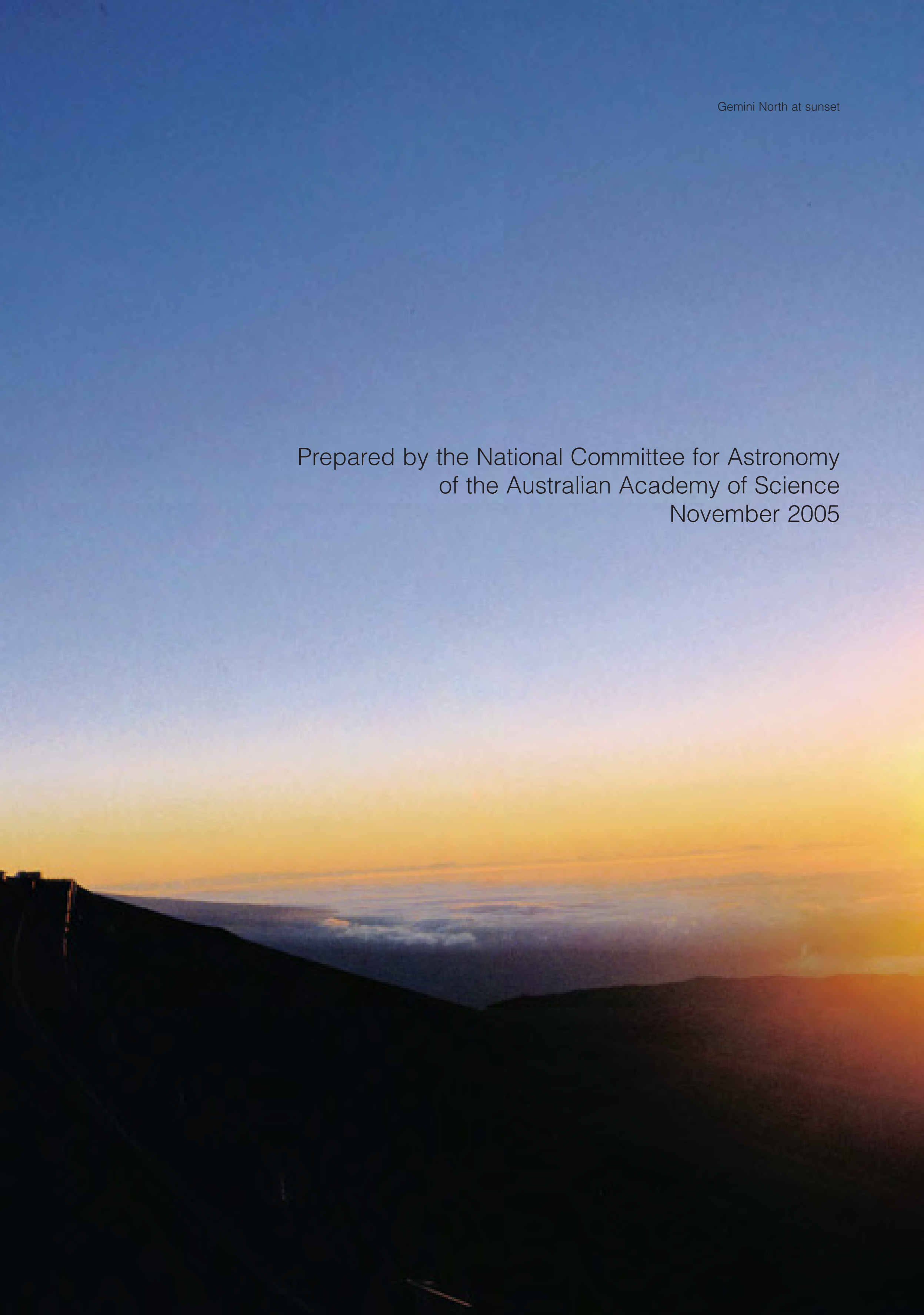

Gemini North at sunset

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Executive Summary

We live in a truly remarkable time.

We live in a truly remarkable time. As our understanding of the Universe deepens, we are seeing connections emerge between many formerly disparate fields of research. Astronomy targets some of the biggest questions it is possible to ask. It explores the structure of nature on scales and in realms too extreme to examine in any laboratory. Ultimately, it is through astronomy that we will understand the emergence of life within the tapestry of planets, stars, dust clouds and galaxies of our Universe. It is through astronomy that we will understand how this emergence is linked to the fundamental laws governing the origin, evolution and final fate of the Universe itself.

Astronomy, and Australian astronomy in particular, can boast some of the most remarkable discoveries in recent years, including the detection of planets orbiting other stars, the discovery of a unique double pulsar, and the detection of a mysterious "dark energy" that pervades our Universe and opposes the relentless pull of gravity.

Australian astronomy's outstanding track record has been, and must continue to be, based on a suite of strategic investments in both national and international infrastructure, and in the people who turn such facilities into research outcomes. The nation's areas of internationally acknowledged strength—as measured by capability, global impact and natural resource—are therefore targeted as high priorities: ground-based astronomy at optical/infrared wavelengths, astronomy at radio wavelengths, and theoretical astrophysics.

This Decadal Plan presents the Australian astronomical community's strategic vision for our continued engagement with this great adventure. It maximises astronomy's benefit to the nation by:

- continuing and enhancing our capacity to undertake world-leading research;
- stimulating our capacity for innovation in science and engineering;
- training a new generation of graduate and postgraduate students in science and engineering;
- and, perhaps most importantly, inspiring and educating the public at large.

Over the coming decade, 2006 – 2015, international astronomy will continue a trend toward increasingly global projects and collaborations. These include the Square Kilometre Array program and the development of Extremely Large Telescopes. Australia must be an effective partner in the international consortia building these highly sophisticated next-generation facilities. To do so, the nation must build on the research base of its strong national facilities and continue to strengthen support for its internationally renowned research community. It must invest in innovative research and development into new facilities, new sites and new technologies.

Stephan's Quintet

To achieve these goals we propose an interlocking "pyramid" of required investments in people and facilities over the coming decades. Partnership in the Square Kilometre Array (SKA) and an Extremely Large Telescope (ELT) form the apex and long-term goal of this pyramid, supported in the nearer term by continued partnership in international 8-m class telescopes, and investment in national facilities such as the Anglo-Australian Observatory, Australia Telescope and a planned 2-m Antarctic telescope. The foundations of this pyramid will be secured by continued support of university-run facilities and experiments, together with the observational and theoretical research programs that motivate the entire structure. This foundation is essential to training and developing the generation of scientists and engineers who will build and exploit the major facilities at the pyramid's apex.

Looking beyond the astronomy sector, maximum return to Australian industry comes through early engagement in the relevant technologies. Creating the best training environment and career structure in the "enabling sciences" of physics and mathematics in turn provides the essential underpinning of national innovation. Communicating the results of astronomical research to the public—especially children—in an exciting and accessible way is an effective approach towards raising the scientific literacy of our nation.

Significant prioritisation has been required in developing the goals outlined in this Plan. A nation of Australia's size cannot compete on every playing field in international astronomy. Major international developments like the Atacama Large Millimeter Array and space astronomy missions like the James Webb Space Telescope are just a few of the many projects that we have decided not to participate in directly, in order to focus on the pyramid of interlinked investments most critical to Australian astronomy's future.

Because the coming decade's major astronomical facilities will be truly global in scope and membership, Australia must develop a model of governance and executive authority for astronomy that allows it to negotiate effectively with international partners and manage participation in these projects to maximum national benefit. These next-generation facilities will be built at the world's best sites—in some cases, these sites will be on Australian territory.

The development of new radio astronomy infrastructure in Western Australia, leading to the start of construction of the SKA Phase 1 at the end of this decade, will be an effective way for Australia to engage in the SKA at the 10% level. In the optical/infrared domain, 10% membership of an Extremely Large Telescope project is also required. The path to this ELT engagement will require completing and maintaining Australia's 20% access to an 8-m class telescope, as well as developing key Extremely Large Telescope technologies and exploring the opportunities associated with our Antarctic sites.

During the first five years of this plan the required level of new investment in major facilities is approximately A$50M[1], rising to a total of approximately A$125M for the full decade. New investment over the next 10 years will be supported by the reprioritisation of A$50M from existing operational funds to meet investment goals in new infrastructure.

To parallel this investment in facilities and fund research activities across the foundation of the astronomy pyramid, similar levels of growth must be achieved in the funding won by astronomers through the National Competitive Grants Program operated by the Australian Research Council. This should result in the level of competitive grant support being, on average, A$3M per annum higher than current levels in the first five years of this plan and A$6M per annum higher in the second half of the decade.

Over the past decade the Australian astronomical community has demonstrated the ability to formulate a strong vision, prioritise its goals and deliver on its promises. This Decadal Plan is an extension of our vision to 2015 and is an expression of our commitment to deliver the best possible outcomes for Australian astronomy and the nation.

School students visit a university observatory

Audience and Intent

This Plan sets out large-scale goals.

This Decadal Plan presents the Australian astronomical community's strategic vision for the ten years 2006–2015. It follows on from the previous Plan *Australian Astronomy: Beyond 2000*.

Australian astronomy is funded, managed and executed in a variety of ways. Most astronomical research takes place in universities, and is funded by the Commonwealth (both directly, and via the Australian Research Council), State governments, industrial partners and overseas research organisations. Other organisations and agencies, including DEST, CSIRO and the AAO, have important and distinct roles, both performing and supporting astronomical research.

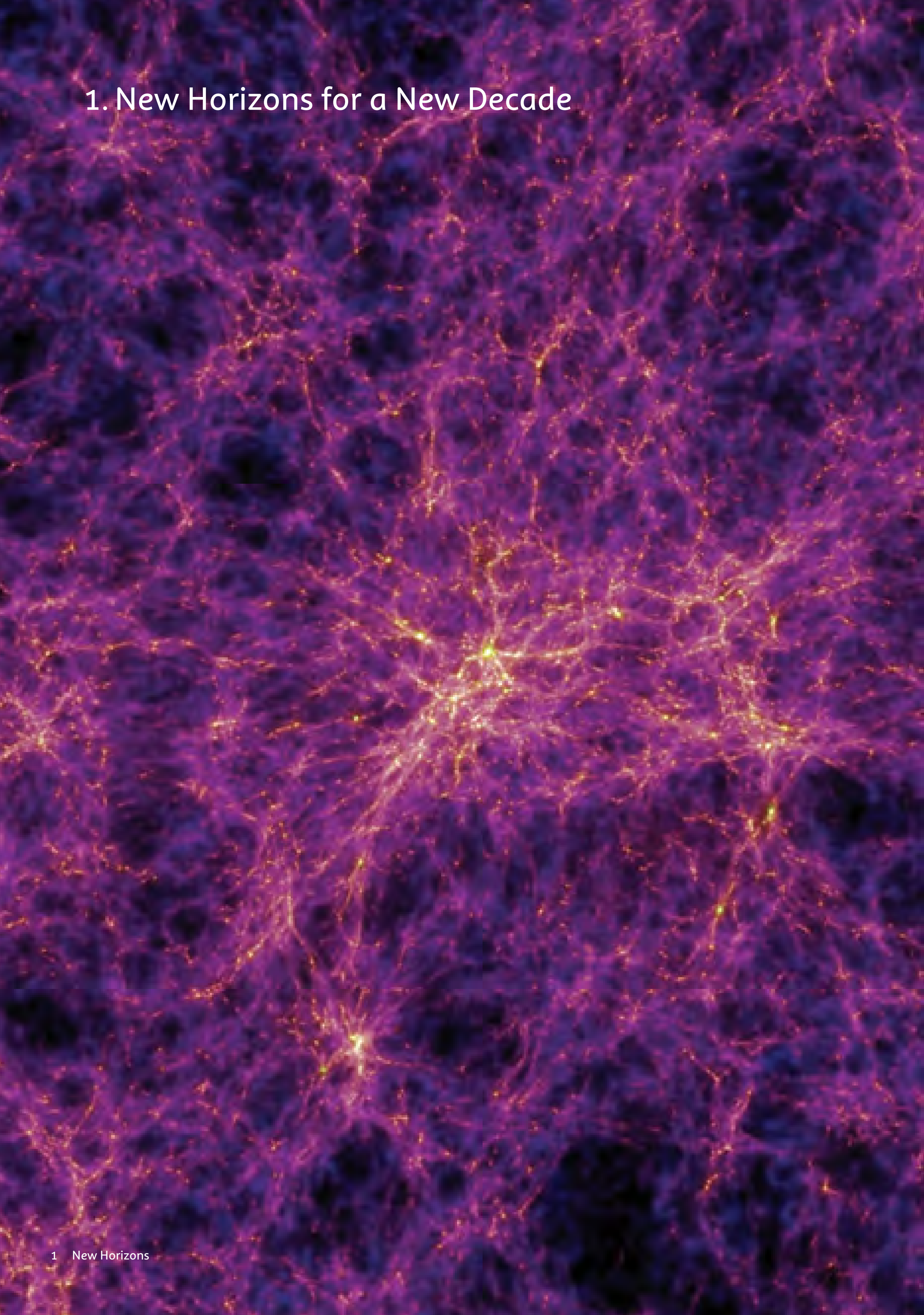
Together, these bodies are the audience for this Plan. The Plan emphasises those areas of research policy where the astronomical community has a unique voice, and for which direct government funding is essential. Recommendations in a broader context that contribute to a wider debate on the resourcing and future direction of universities and other research institutions are also made.

This Plan sets out large-scale goals. To reach these goals will require much detailed work and planning as funding opportunities become clearer over the decade. This detail will be the subject of a set of implementation plans, developed and regularly revised by the community.

With this Plan, Australian astronomers also speak to each other. The Plan is built upon detailed discussions in a series of Working Groups, whose reports appear in Volume II. These analyse the scientific opportunities and strengths in the community, map out research directions and priorities for the next decade, and are the solid basis for the development of this Plan. The community has worked together in the formulation of a strategy for investment that is in the best national interest.

Australia Telescope Compact Array

1. New Horizons for a New Decade



The questions that astronomers seek to answer are amongst the biggest it is possible to ask.

Astronomy is a profound expression of humanity's need to understand how the Universe works. We are living through a remarkable era of discovery in astronomy. For the first time we have found clear evidence for planets orbiting other stars, for massive black holes occupying the centres of our own Galaxy and many other galaxies, and for a dark energy component to the Universe whose origin and nature we have yet to fully understand. As the full complexity of the cosmos becomes apparent, today's astronomers require cross-disciplinary skills in fields as diverse as computer modelling, chemistry, fluid dynamics, statistics and even biology.

Over the coming decade, astronomers in Australia and around the world will undertake basic and fundamental research into the laws of physics on scales and in realms too extreme to examine in any laboratory. The questions that astronomers seek to answer are amongst the biggest it is possible to ask.

What is the nature of the dark energy and dark matter?

One of the great puzzles of modern cosmology is that up to 95% of the Universe apparently consists of dark matter and dark energy, whose physical nature is unknown, and which we can only observe indirectly by measuring their effects on visible stars and gas. Determining the nature of these dark components of the Universe is an important problem in fundamental physics.

The existence of dark matter was first suggested more than 20 years ago, but the presence of dark energy has only recently been deduced from the observation of distant supernova explosions, which shows that the expansion of the Universe is speeding up. There are many possible forms this dark energy could take, and detailed studies are needed to distinguish between competing theoretical models. Over the next decade, measurements of very large numbers of standard candles (e.g. supernovae) or standard rulers (e.g. the scales on which galaxies cluster) in the early Universe are needed, and new wide-field optical and radio facilities have been proposed to tackle this problem.

How and when did the first stars form in the early Universe?

The very early Universe, as revealed by study of the relic radiation from the Big Bang, was almost completely uniform in density. This is in complete contrast to the Universe we see today, which is complex, inhomogeneous and full of stars and galaxies. At some point in its first few million years, the Universe must have undergone a fundamental transition in structure powered by the first star-like objects to be formed. When, where and how did the first stars form? Were magnetic fields involved in their formation? How massive were these stars? And how did they subsequently influence the evolution of the Universe?

Simulation of the early Universe

How are galaxies assembled and how do they evolve?

There is growing evidence that large galaxies like our own Milky Way are assembled over cosmic time by successive mergers of smaller galaxies. Their history is therefore likely to be complex, with bursts of star formation associated with the swallowing of each small galaxy or gas cloud rather than a smooth transformation of gas into new stars over time. Much progress has been made in tracing the global rise and fall of star formation in galaxies over the last 90% of the history of the Universe, and a general “cold dark matter” framework exists for understanding the growth of structures. However, critical uncertainties remain. In particular, how do the interactions of galaxies affect their eventual shape and brightness? How do the small, clumpy galaxies we see in the early Universe evolve into the highly-structured systems seen today?

Is our understanding of gravity correct?

Nature's most accurate clocks are pulsars—the rapidly rotating collapsed remnants of massive stars. Pulsars have enormously strong gravitational fields, and provide a unique laboratory for testing theories of gravity under conditions that are impossible to probe in Earth-based laboratories. Nobel prizes for Physics in 1974 and 1993 underline the importance of pulsars as a link between fundamental physics and astronomy. Some of the most stringent tests of gravitational theories will come from research into pairs of pulsars that orbit each other, and especially from as-yet undiscovered binary systems in which a pulsar orbits a black hole. These systems are rare, but provide crucial tests of general relativity and the fundamental nature of gravity.

How do the super-massive black holes in the cores of galaxies work?

Black holes are the most exotic prediction of Einstein's general theory of relativity. The accretion of material onto a black hole taps into the most efficient energy conversion mechanism in the Universe. The result is an intense radiation spanning the entire electromagnetic spectrum from radio waves to gamma rays, and in some cases thin, magnetised jets of plasma moving at close to the speed of light. But why do some black holes have jets, while most do not? How do the black holes at the cores of galaxies form so early in the Universe? And how does the energy they produce affect the evolution of galaxies?

What is the origin and evolution of cosmic magnetism?

Magnetic fields permeate the Universe and span an enormous range in strength, from the weak magnetic fields in interstellar space to the extremely strong magnetic fields of pulsars. They play a key role in the physics of star formation, control the density and distribution of cosmic rays within our Galaxy, and collimate the powerful radio jets that emerge from super-massive black holes at the centres of radio galaxies. Although magnetic fields are intimately involved in astrophysical processes on many scales, the origin and growth of magnetism in the Universe is poorly understood at present. When and how did magnetic fields form in the early Universe, and how does this relate to the formation of galaxies and large-scale structure at the same epoch?

How do stars and planetary systems form?

Stars form when regions of the interstellar gas clouds in galaxies become gravitationally unstable, and collapse to densities and temperatures sufficient to ignite nuclear fusion. Key to this collapse are accretion disks—churning maelstroms that swirl around forming stars, transporting gas and dust inwards from the extended gas cloud onto the young star's surface. Inside these accretion disks, agglomerating dust particles grow into the rocky nuclei of terrestrial and gas giant planets. While this general picture is accepted, the discovery of planets as they are forming has stimulated new examinations of the details of this process. For example, how do dust particles grow into the rocky cores that build planets? What determines the rate at which a galaxy's gas and dust are turned into stars?

How common are planetary systems and conditions suitable for life?

The detection over the last decade of numerous planetary systems outside our Solar System has been one of the most significant astronomical results of the last 100 years. We now know that gas giant planets are reasonably common. We also know that the "ecologies" of planetary systems are many and varied. So far, few planetary systems are known that look even remotely like our own. Most critically, then, in the next decade astronomers will seek to understand how common planetary systems are in all their diversity. In particular, how common are systems in which rocky, terrestrial planets are suitably placed for the evolution of the types of life we see on the surface of our own home—that is, how many Earths can we detect orbiting nearby stars?

How do stars produce and recycle the elemental building-blocks of life?

Understanding the life and death of stars, and the birth of the subsequent generations from the ashes of stars that have gone before, is a fundamental part of the quest to understand the processes that generate life. As Sun-like stars approach the final stages of their lives, the elements created by internal nuclear reactions are transported to their surface and ejected back into space. Stars more massive than the Sun, and certain types of binary stars, undergo more violent deaths as supernovae explosions. In both cases, the enriched material from each star's core becomes available for the formation of new generations of stars and planets. Understanding this cycle in detail is fundamental to understanding the frequency with which habitable planets can form throughout the Universe.

2. Australian Astronomy 2005

Melbourne Planetarium

Australia has a long and proud tradition in astronomy. For the past 50 years, Australian astronomers have been at the forefront of their field. Today, it is one of the nation's highest impact sciences[2] and its impact relative to the rest of the world's astronomers continues to increase (see Figure 2.1). Australian astronomers have pioneered some of the most important technological advances in astronomy of the past two decades, including the use of fibre optics and robotics in astronomy and advanced signal-processing techniques.

In order to understand the physical processes occurring throughout the Universe, it is essential to use a wide variety of tools. A "cosmic symphony" of signals spans the spectrum from low-frequency radio waves to high-energy gamma rays. These signals cannot be decoded by looking at sections of the symphony in isolation. The study of cool, low-energy processes is best done at long wavelengths, while hot, energetic objects including stars are more accessible via the short wavelengths seen by optical/infrared or even X-ray telescopes. Every successful nation in astronomy exploits a range of observing facilities across the electromagnetic spectrum. Particle astronomy and gravitational wave physics contribute additional important elements to a complete picture of the Universe.

Australia has been successful as a result of significant investments in world-class and innovative research infrastructure that have been made since the 1960s. These investments have made it possible to attract and retain excellent researchers. Our most powerful facilities result from visionary funding decisions made by the Commonwealth Government in four separate decades: the single-dish radio telescope at Parkes, the Anglo-Australian Telescope (AAT), the multi-antenna Australia Telescope, and the Gemini 8-m telescopes in Chile and Hawaii. Combined with university-operated observatories, supercomputing facilities and an effective national information technology network, Australia has a solid base from which to develop its capabilities into the next decade.

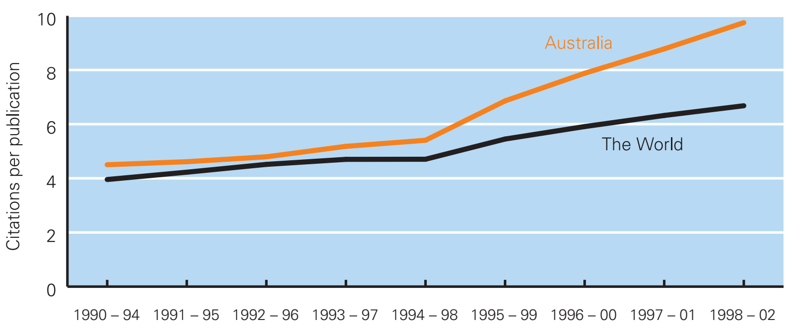


Figure 2.1 Impact of Australian astronomical research as measured in citations per publication from 1990 to 2002. Australia has not only remained ahead of the rest of the world in research impact in astronomy, but improved its relative standing significantly (adapted from ANU Capabilities & Performance Statement 2004).

Parkes radio telescope

Australia has a long and proud tradition in astronomy.

Australian astronomers ... are the most important component of the national astronomical enterprise.

The Australian astronomers who use and exploit these facilities are the most important component of the national astronomical enterprise, because it is they who are responsible for turning data and theoretical models into scientific outcomes. The number of Australian astronomers has remained approximately constant over the past decade[3] in contrast to the decline in other branches of physics[4] and this has been a major factor in maintaining Australian astronomy's international impact.

An estimated A$60M is invested annually by Australia in astronomy-related activities[5]; around two thirds is used to fund university activities, including teaching. Just over 30% is used to fund the Anglo-Australian Observatory (AAO) and Australia Telescope National Facility (ATNF) as providers of national astronomy facilities, and a further 5% funds Australian 8-m telescope access and SKA activities.

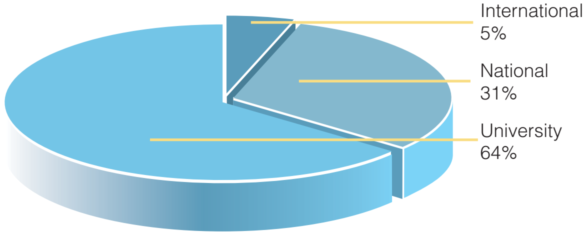


Figure 2.2 The Australian annual astronomical investment in people and facilities for 2005. The breakdown is categorised by scale and measured as a percentage of the estimated A$60M total: "International" comprises expenditure on Gemini, 8-m and SKA activities; "National" comprises expenditure on AAO and ATNF; and "University" is the estimated expenditure on infrastructure, salaries and facilities operated by university-based groups engaged in astronomy[5].

In addition, overseas investment in Australian astronomy has grown by 20% per annum over the period 1999 – 2004[6]. In 2003/04, A$10M was invested in Australian astronomy by international partners. This includes the United Kingdom contribution to the operation of the AAO, and overseas instrumentation contracts won by the AAO, ATNF and Australian National University (ANU).

Astronomy is a scientific field in which forefront science can only be done in cooperation and collaboration with scientists from around the world. The benefits that accrue from such linkages are substantial[7] and include access to cutting-edge data and technologies, leveraging the scientific funding of larger nations, and increased international collaboration. Australian astronomy has a strongly developed culture of international linkage—it leads the nation in the fraction of publications it produces with international collaborators[8], its on-shore facilities are in high demand from international users[9], and almost all its next-generation facilities will be built with international partners.

Australia's key observational strengths lie in the radio and the optical/infrared domains. Optical and radio astronomy account for over three quarters[10] of the total citations gathered by Australian astronomers over the past decade. Approximately half of the optical and radio citations derive from Australia's national facilities, and a quarter each from Australian university-run facilities and overseas facilities funded by other countries.

A university training in astronomy develops critical skills that are highly valued in the commercial and industrial sectors, with the result that astronomy-trained graduates can be found in many senior positions in information technology, banking, industry and defence. One fifth[11] of Australia's astronomy honours graduates move into commerce and teaching, where they make an important contribution to the nation.

Astronomy plays a crucial role in inspiring young people. Astronomy is seen by educators as offering an attractive context within which students can be taught a range of scientific subjects. Victoria and NSW have both recently introduced astrophysics into their senior high school physics curriculum. Vigorous astronomy groups at our universities and national observatories are working to ensure that more of our best young people develop an interest in and an understanding of science, without which the nation cannot hope to remain technologically competitive.

Astronomy has always received the strong support of the general public. Fundamental research at the frontiers of science is an essential cultural element of any technologically advanced nation and is an important expression of our identity. Australians are justifiably proud of our position as one of the world's most successful nations in astronomy.

Case Study: An Astronomer in Industry—Dr Paul Brooks

Dr Paul Brooks is the Technology Director and one of the founders of Consultel BWP Pty Ltd. Paul graduated from the University of Adelaide with an Honours Degree in Physics and Computer Science, and went on to study astrophysics at the University of New South Wales, where he obtained his PhD. For the past 15 years he has played a major role in the planning and development of data networking for Australia. Paul's training at undergraduate and postgraduate levels has equipped him not only to be a high flier in the Australian telecommunications sector, but has left him with a passion for astronomy that he enjoys passing on to school children through volunteer talks and presentations.

As Director of Asia-Pacific Network Engineering for Global One (now Equant/France Telecom), Paul provided strategic technical leadership in the planning, design and deployment of Internet backbone networks and associate infrastructure throughout the Asia-Pacific region.

Paul's reputation as a senior consultant is recognised internationally through his design of global Internet connectivity for Australian service providers. For the past year Paul has been heavily involved in bringing the next generation of broadband connectivity to Australia. These new high-capacity broadband technologies will dramatically alter the way we live, work and entertain ourselves over the next decade, and help Australia to stay competitive with other economies in an increasingly broadband-connected world.

Paul is also involved in a long-term project with potentially very significant implications for rural health care, through a pilot program in the Eastern Goldfields area of Western Australia. This study will assess the costs and benefits arising from widespread use of broadband and permanent secure networked capabilities linking doctors' practices, specialists, hospitals, health authorities, and even doctors' homes.

3. The Foundation of Astronomy: Education

Astronomers play an important role in public education.

Astronomy, like other sciences, is directed at the discovery of new knowledge about the Universe, and the dissemination of this knowledge amongst both astronomers and the public. Because astronomy's scope is so large—addressing questions that are fundamental to our existence—it is one of the most popular and accessible sciences. The teaching of astronomy, and the general diffusion of astronomical knowledge, are important contributions that astronomers make to society at large and to the health of science and technology in particular. Australia's citizens learn about astronomy at various levels and in various ways. Any level of exposure to an exact science is valuable in maintaining a scientifically literate society and in encouraging young people to persist with study in scientific subjects. Education in its widest sense is a life-long endeavour to which astronomy makes an important contribution.

Astronomers play an important role in public education, mostly as volunteers during open days or viewing evenings, or by giving public lectures to clubs and societies. Over the past five years, on average a public lecture has been given by an astronomer once a fortnight and 750,000 people a year have attended a public astronomy event or facility. An additional half a million people per year visit Australian planetariums[11]. This clearly demonstrates the high degree of public support for the field and the commitment of members of the astronomical community to public outreach activities.

Astronomy is part of the school curriculum (both primary and secondary) across Australia, and because of its exciting content is often used to stimulate interest in science. However, a declining proportion of teachers is qualified in any area of the natural sciences. Astronomers cannot solve this nationwide problem on their own, but the maintenance and development of programs of public outreach, especially those that support teachers, is an important activity for astronomers. Much of what is done at present is unfunded and voluntary, and would benefit from more coherent support within national and state programs.

Currently, competitive research grants cannot be used to enhance outreach activities. This is an issue wider than just astronomy. Our experience suggests a mechanism is required to reward teaching and research success with an additional funding component to ensure that the latest research results are promptly and effectively communicated to the public.

Pictured left: three winners of the "Sport in Space Competition" take a ride on the Parkes radio telescope; right: Robert Hollow (centre) with teachers at a workshop at the Parkes Observatory.

Case Study: Astronomy Outreach in Action—Robert Hollow

Robert Hollow is the ATNF's Education Officer, and is responsible for managing the facility's education program. That program's goals are to attract young people into science and to provide astronomy resources for school students and teachers. Robert was previously a physics teacher and has almost 20 years of teaching experience and involvement in syllabus development for physics and cosmology. His current role involves providing workshops for high school teachers, writing an education newsletter, writing content for the ATNF outreach and education website, organising and giving public talks, running competitions for school students and liaising with teachers, educational authorities and the public.

Teacher Workshops—Because many high school teachers have little training in astronomy, Robert organises regular workshops to support teachers in the necessary knowledge and skills. These workshops allow Robert, together with other tutors, to introduce teachers to current research topics in astronomy, as well as providing the background theory necessary to teach the astronomy in the current syllabus. Teachers also participate in practical activities and are given a wide range of resources that they can use in their classrooms. Robert also provides regular sessions across Australia at other science teacher professional development events.

Web-based Outreach—The ATNF outreach and education website (www.outreach.atnf.csiro.au) provides in-depth educational resources and syllabus content in astronomy for high school students and teachers. The site also provides resources for teachers, information about the facility and its history, feature articles, visitor information, live webcam images and movies and links to public astronomical facilities. In its first year of operation the site received more than a million hits. Feedback shows that teachers and students find it to be a valuable resource.

The PhD program is the backbone of professional astronomical training.

At the undergraduate level, many universities now teach astronomy modules to both science and non-science majors. For many students, the astronomy they take will be their only exposure to science at university. Within physics, astronomy sets a useful and attractive context for the study of topics such as gravitation, radiation transfer, and computational physics. Twelve Australian universities offer honours degrees in astrophysics, and most graduates of these programs progress to a research degree in astronomy. Because of the importance of a physics degree to a broad range of scientific and analytical careers, the astronomical community must continue its strong commitment to undergraduate teaching. It is important to ensure that our best researchers are able to teach undergraduates, while maintaining internationally competitive research careers.

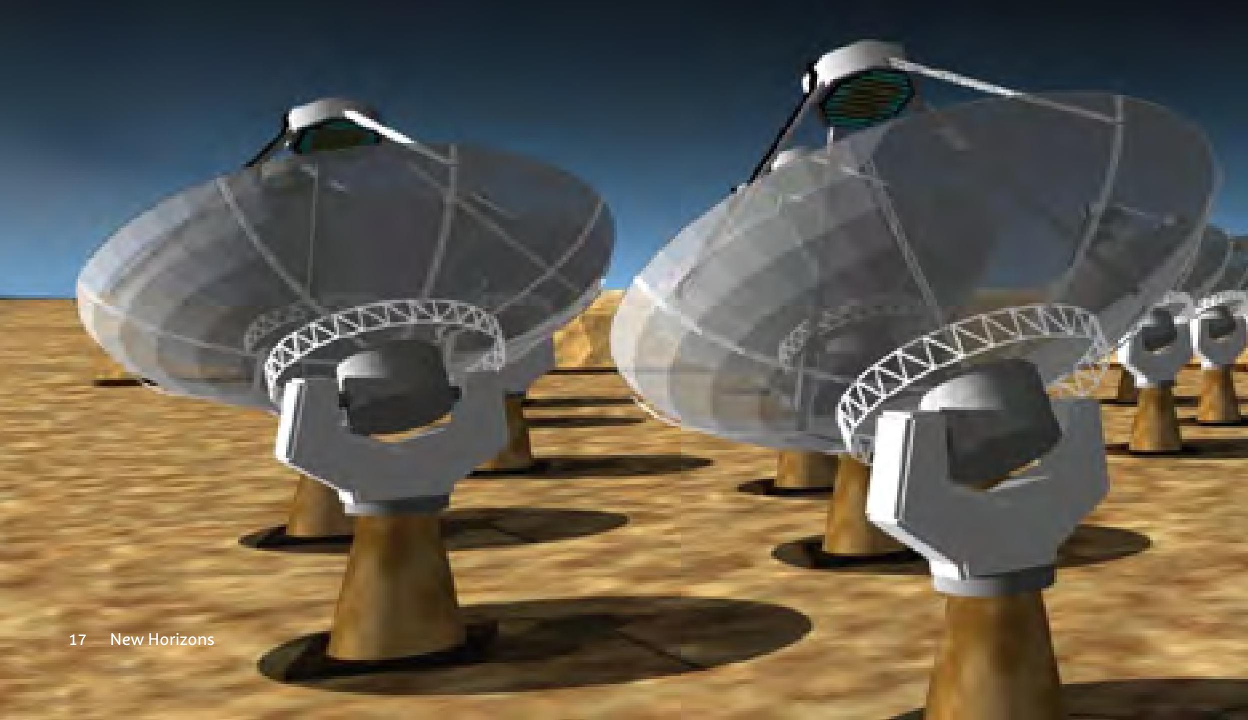
Astronomy is a growing component of science education in countries in our region, especially southeast Asia. Undergraduates tend to be extremely well trained in these countries and can make excellent and productive PhD students at Australian universities. Currently the number of fee-exempt awards for such students is small, and could be increased to the benefit of both Australia and the region.

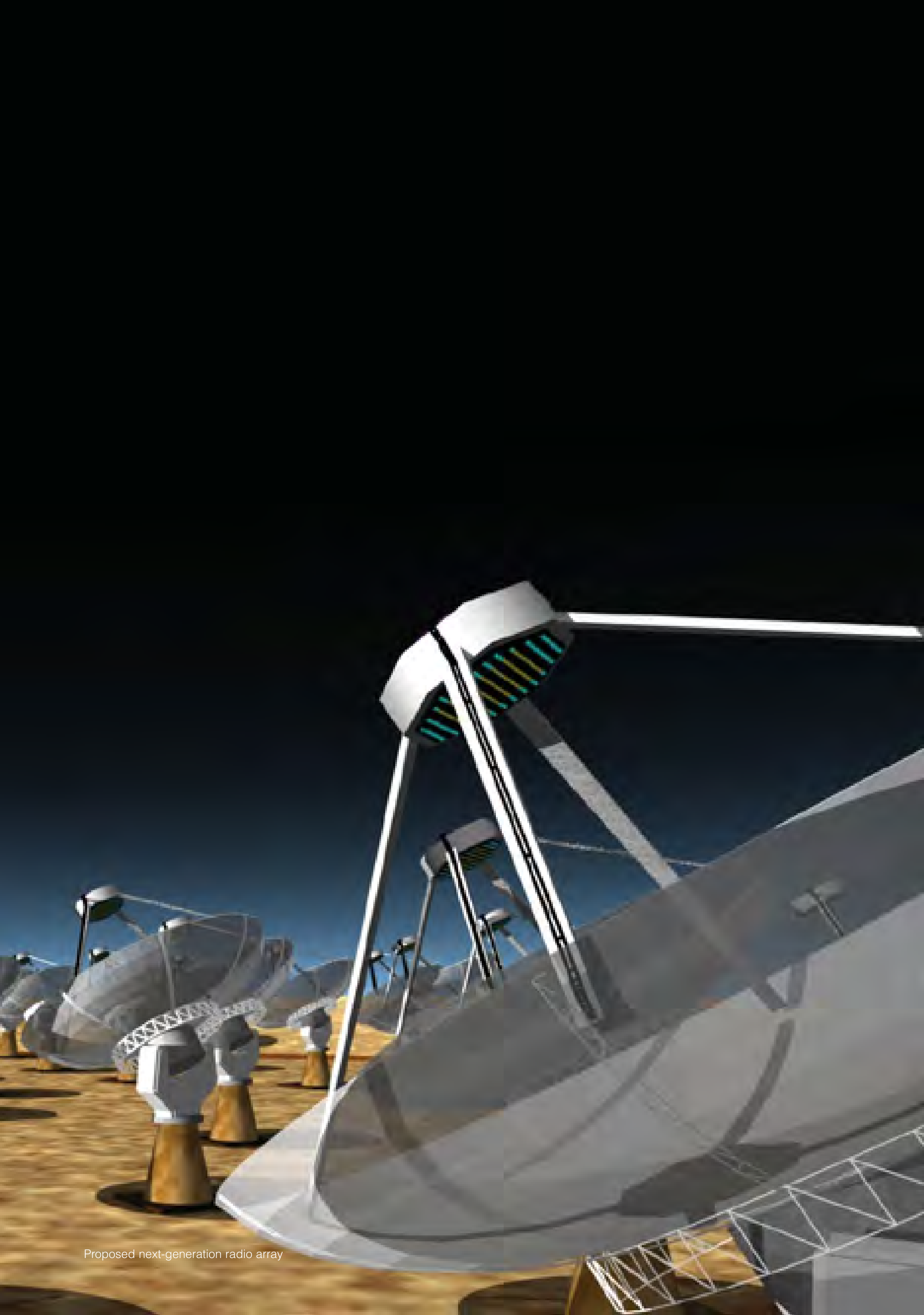
The PhD program is the backbone of professional astronomical training in Australia with about 20 doctorates awarded per year. About one sixth of PhD graduates go on to careers outside academia, with the remainder taking up postdoctoral research appointments in Australia or overseas. At present, the number of PhD students is a steady and reasonable proportion of the research community (about a quarter) and should not be allowed to decline. As new facilities become available during the decade, there should be an associated increase in the number of research astronomers in Australia, with a proportional increase in PhD places. At the same time, the development of these new facilities should include a vigorous involvement of Australian industry, and as a consequence a greater proportion of PhD graduates may be expected to find their skills in demand in this sector. Both effects should see the total number of PhD students increase over the next decade. The national facilities also have a role to play through the increased joint supervision of PhD students.

In an increasingly competitive world, it is vital that Australian graduates are trained to the highest possible standards. The development of high-bandwidth communications will make the virtual classroom a reality. This would allow graduate lectures to be provided by the national expert in any given subject. Although there are practical and administrative difficulties to be overcome, attaining this goal should be an objective for astronomy educators within the decade.

Attendance at workshops and conferences is a vital part of the interaction between Australian and international researchers, and formal programs to support these interactions need to be developed.

4. A Strategic Plan for the Next Decade





Proposed next-generation radio array

The current health of Australian astronomy represents the dividend of far-sighted investments.

4.1 Introduction

A remarkable breadth of opportunities lies ahead of us. Astronomy now spans the entire electromagnetic and particle spectrum, allowing areas of astronomical research to be set by their intrinsic physics, chemistry or biology, rather than by earlier delineations due to accidents of technology, geography or the transparency of our planet's atmosphere. At the same time, astronomy has become a truly global endeavour.

These developments pose challenges for Australian astronomy. To retain its world-class position, Australia will have to strengthen further its domestic research capacity while continuing its transition into a world of major international programs, agreements and commitments. Our astronomers have long worked internationally, and are increasingly successful in collaborating with overseas scientists[12]; the time has now come for similar internationalism on the scale of inter-government and inter-agency agreements.

Australia is currently unique amongst the major industrial nations (US, Canada, Europe, Japan) in that it has no space program and has chosen not to participate in the Atacama Large Millimeter Array (ALMA), the major ground-based astronomical build project of the present decade. Despite this, Australian astronomers should be able to win time competitively on these facilities, because of the quality of the science conducted on their own front-rank facilities.

The current health of Australian astronomy represents the dividend of far-sighted investments—many made a decade and more ago. For similar future success it is essential that comparable investments are planned for and made over the next decade. Otherwise, Australia faces the threat of losing ground to other nations in access to state-of-the-art telescopes and experiments.

4.2 People—Australia's Most Valuable Scientific Asset

Major radio and optical telescopes only come about as the result of many years of work by many people. While much of the emphasis of this Decadal Plan is on projects, it must be recognised that proper support of the people involved and the processes of research management are essential. While the nation has geographical advantages in its natural resources like the radio quietness of inland Australia and the excellent observing sites in the Australian Antarctic Territory, these are of little value without the expertise of its astronomers and engineers, both students and professionals. This expertise allows Australia to be disproportionately successful in gaining access to many facilities funded by other countries, winning overseas instrumentation contracts, and participating as intellectual equals in projects involving much bigger players.

Integrating a new infrared imager

It is vital for education and training in astronomy to be ambitious and effective.

The total number of people involved in astronomical research in Australia has remained roughly constant over the past decade, but there has been a significant shift from continuing positions to short-term ones. The trend is particularly marked in the university sector, where an increasing number of researchers at all levels (including senior scientists) are now employed on fixed-term positions, including Australian Research Council (ARC) fellowships. In 1995, only 18% of astronomers and instrument scientists were employed on fixed-term contracts. By 2005 this had doubled to 37%, reflecting a trend in the wider community towards employment flexibility. This trend does, however, pose particular challenges for astronomy, since those in continuing positions play a key role in setting the research agenda and providing continuity over the timescales relevant to the planning and operation of new facilities.

University Vice Chancellors and facility Directors need to ensure there are sufficient continuing positions to maintain the corporate memory and continuity necessary for effective innovation, research and training.

The gender balance of Australian astronomy has improved over the past decade, with 20% of positions being held by women in 2005, up from 11% in 1995. Currently 37% of postgraduate students are female, up from 15% in 1995.

It is vital for education and training in astronomy to be ambitious and effective. It is also important that human resources are efficiently used. The great majority of research in astronomy is carried out in universities. Over the span of this decadal review, there will be at least one, and perhaps several, quality assurance initiatives in publicly-funded research and education. The prudent spending of public money requires that scarce resources should be used to greatest effect, and any assessment of the quality of scholarly outcomes should also ask explicitly whether there is an appropriate balance between teaching, research, administration, and the securing of funding. These are systemic issues in which the decisions of the most powerful stakeholders in research—government and universities—can have profound influence.

The international-scale projects planned for the next decade will require dedicated teams to provide the scientific direction to their development and operation. Attached to these major projects, therefore, there must be an adequate number of research support positions, comprising first-class scientists who apply their research-based experience to the practical support of the facility. These could be constituted as fixed-term postdoctoral fellowships and non-continuing staff positions, along the lines of the model that has been so successful in the operation of the AAO and ATNF. Some of these positions should be implemented as high-prestige named fellowships tenable at any institution in Australia. To further enhance and support the research carried out by the wider astronomical community with these facilities, provision should be made for facility support of computing and travel requirements for users.

Theorists pose many of the questions that drive the next generation of large facilities.

The majority of the research enabled by these facilities will be carried out by university-based astronomers, employed either in university teaching positions, or as externally funded researchers. In the latter category, researchers funded by the National Competitive Grants Program (NCGP) operated by the ARC are vital. The NCGP currently funds a significant fraction of the university-based staff actively engaged in research and technical support[13]—an average of A$6.9M per annum over the period 2003 – 2005[14].

The Government has recognised through its Backing Australia's Ability (BAA) initiatives that expansion of the NCGP is critical for the maintenance of and growth in impact of Australia's research, both nationally and internationally. Over the period 2001 – 2007 these initiatives will see NCGP funding grow at an average rate of A$69M per year, doubling NCGP funds in 2006/07 relative to 2001/02 levels[15]. This creates a welcome opportunity for Australian astronomers to increase funding for university-based research through competitive applications. Continued expansion of NCGP funding after 2011 will be important to all Australian science.

In addition to maximising the research outcomes made possible by BAA's increased support of science, it is also important to ensure that as many of our undergraduate students as possible are taught by the nation's best research scientists. Achieving this joint objective becomes more challenging as academic staff find their administrative and operational responsibilities growing. Changes to the funding models for universities, together with changes in the way those funds are distributed within universities, are needed to ensure that science-based faculties have sufficient resources to maintain international competitiveness.

Theory is an important area where the role of people is pivotal. Theorists pose many of the questions that drive the next generation of large facilities, and often lead the interpretation of results. Successful teams of theorists have tended to emerge from an indirect process, such as a cluster of teaching appointments, successful grant applications and the like. A more strategic approach to planning for theory will be required over the next decade as Australia moves increasingly into very large infrastructure programs on international scales. These projects will contain experimentalists and technologists who should also interact with strong theory groups both inside and outside the facility. These theorists should play an important role in guiding the development of the scientific specifications. The distinctive analytical skills of theorists can be of benefit to the solution of the many intricate design problems (e.g. adaptive optics, optical interferometry) that the next generation of projects will entail.

Australia must remain internationally competitive as a destination for top researchers. While this is an issue with much broader scope than just astronomy, experience in the astronomical community suggests a number of improvements to current arrangements that would enhance our international competitiveness. The ARC fellowship system should offer the potential for a long-term career path for our best researchers, rather than terminating in mid-career as at present. Almost half of

Australian PhD graduates in astronomy take up postdoctoral positions overseas. The nation needs to "close the loop" on the young researchers it has trained by attracting these excellent researchers back to Australia. This requires an increase in the number of Australian Research Fellowships offered by the ARC—currently these are too few to attract enough of our mid-career Australian-trained researchers back. The interval between application and award of ARC fellowships at all levels is much longer than that for similar schemes in other countries, making it difficult to recruit high-profile international researchers through this system. This interval must be shortened, and phased with international employment calendars.

4.3 Governance—Managing Australian Astronomy

At present there are no established mechanisms by which Australia can make commitments on the scale that the coming generation of international astronomical facilities require, or provide an executive body with the authority to implement that commitment. The funding and evaluation mechanisms in Australia are primarily bottom-up, depending on the success of individuals or groups in securing grant-based funding through a variety of routes. The funds available are usually short-term and are rarely, in any one grant, sufficient for participation in projects of the scale expected in the next decade. As a result, current procedures mean that Australian astronomy, despite its potential collective strength, has difficulty in operating internationally with great weight or authority, and continually has to deal with the difficulties imposed by funding horizons of just a few years.

The scope and duration of the next decade's projects require that Australia develop mechanisms for negotiating and committing, both nationally and internationally, over time scales of five to 10 years. These are the lead times for the staged development of the giant telescopes that will be completed in 2015 – 2020, and they are the time scales over which the health and productivity of Australian astronomy can only be assured by access to the leading international collaborations and facilities. Short-term arrangements inevitably lead to Australia's marginalisation by international partners who are prepared to accept full levels of commitment and risk.

A peak body to coordinate Australia's astronomical activities and to represent it in international partnerships would streamline decision making, allow Australia to be more responsive to opportunities as they arise, and maximise the benefits achieved through partnership agreements. Such a body may not necessarily have formal authority over all the diverse elements that comprise Australian astronomy, but it can provide an effective governance mechanism if its members are widely respected, accountable to the community, and appointed in a transparent way. The ability to seek and administer funds will also be a key element in the effectiveness of such a body. Several models for such a peak body exist internationally.

Solutions required for astronomical applications create opportunities for industry.

Executive structures must also be in place to manage the major astronomical initiatives of the next decade. In their capacities as national observatories for optical/infrared and radio astronomy respectively, the AAO and ATNF are well placed to deliver this service. These existing national facilities can do so with only a small additional administrative load, while remaining strongly consensual in their mode of operation. Both aspects are essential given the nature and size of the Australian astronomical community.

4.4 Astronomy and Industry—Maximising Our Investments

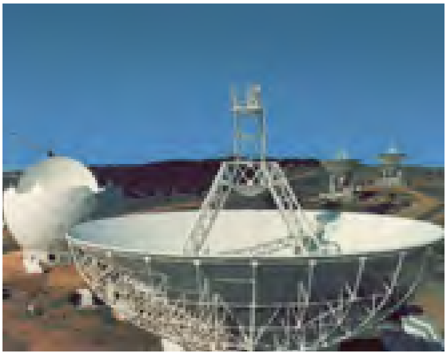
Astronomy has historically been a challenging customer for industry, extending capability in commercially valuable ways. The technological solutions required for astronomical applications create opportunities for industry to transfer new ideas to existing products, and to create whole new commercial products. At present, around 15% of PhD astronomers move into industry where the value of their astronomical training is demonstrated by their ensuing successful careers.

Examples of companies that have developed new business as a result of their work for astronomy in Australia include Altium, Auspace, AUSSAT, Austek, Connell Wagner, EOS, Interscan, Lake Technology Corp, Poseidon Scientific Instruments, and Radiata. The freedom to publicise project outcomes, and to use this publicity as an attractor for other (non-astronomy) contracts and personnel, is an additional benefit to industry.

Closer industry links need to be established for the next generation of astronomical facilities. In optical astronomy, these links are important for the development of Extremely Large Telescope (ELT) technologies within Australia such as precision servo-control systems. In radio astronomy, the large volume of components required for large-scale distributed antenna systems necessitates a shift in philosophy towards adapting Commercial-Off-The-Shelf components. Industry interest in these developments is reflected in the endorsement of the Square Kilometre Array (SKA) project in Australia in July 2005 as a key project within the Electronics Industry Action Agenda, having received significant support from the Australian Electrical & Electronic Manufacturers' Association.

The Australian Astronomy Industry Network (AAIN) was initiated in 2003 by Australian astronomers with a view to encouraging knowledge diffusion and exposing Australian businesses to the highly-networked, international astronomy endeavour. Specific resources must be associated with the major projects of the forthcoming decade to expand on such initial contacts, to maintain databases of relevant industries, to keep industrial and astronomical stakeholders informed of each other's relevant activities, and to identify and nurture opportunities for commercial exploitation.

Australian engineers build a new telescope



Connell Wagner 26-m antennas under construction in Geraldton, WA

Case Study: Industrial Partnership in Action—Connell Wagner

Radio astronomy dishes share basic technologies with those used in communications. A key design goal for the Australia Telescope was to develop shaped parabolic antennas with high efficiency in the microwave part of the spectrum. Connell Wagner Pty Ltd (previously MacDonald Wagner) partnered with CSIRO in the development of these new antennas.

The innovative antenna technology was developed in the early 1980s as a part of a design study for what was to become the Australia Telescope. "We are delighted that the CSIRO has given Connell Wagner much credit for the development of the technology that enabled Australia to succeed in delivering the Australia Telescope. While there is a larger array in New Mexico, the dish technology and the structural and mechanical systems used were well in advance of the technology of the day." (Anthony Barry, NSW Regional Manager and Director of Connell Wagner Pty Ltd)

Connell Wagner was presented with a copy of the Sir Ian McLennan Achievement for Industry Award made to Dr Bruce Thomas in 1995 for "contributions to and development of the antennae design industry in Australia", in recognition of Connell Wagner's role in that development.

Connell Wagner has subsequently won contracts for numerous national and international communications antenna projects:

- 18-m antennas for OTC Australia (nine in total in Perth, Sydney, HoChiMinh, Hanoi, and Phnom Penh)
- 7.5-m antennas for OTC Australia
- 20-m antenna for OTC Australia (Perth)
- 27.5-m antenna for OTC Australia (Perth)
- 26-m antennas for Department of Defence (four in Geraldton)
- 11-m antenna for Department of Defence (Canberra)
- upgrade of the Parkes radio telescope
- upgrade of the Narrabri Compact Array.

Today Connell Wagner provides a range of management, design and consulting services for communications network providers. Much of today's expertise and many of the antenna design contracts won can be traced back to the skills developed and relationships forged during the development of the Australia Telescope.

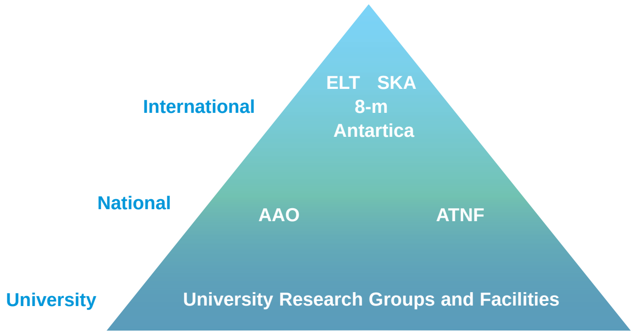


Figure 4.1 The Astronomical Pyramid[16]. The split in 2005 between funding at the International:National:University levels is approximately 1:6:12 (see Figure 1.2).

4.5 Current and Future Facilities—An Astronomical Pyramid

Australia's current and future suite of facilities can be viewed as a pyramid. At the apex are the small number of major international programs in which Australia collaborates with other nations to build and operate facilities too large for any one country. Forming the next level of the pyramid are the national facility organisations that operate major facilities based in Australia, and have the capabilities to manage Australia's access to large-scale international programs. Forming the critical foundation level of the pyramid are university research groups that run a broad suite of smaller, innovative facilities, as well as supplying most of the researchers who actually implement the research exploitation of national-level and international-level facilities.

The levels of this pyramid are tied together by a complex network of inter-linkages between the members of the Australian astronomical community. University groups provide innovation, training and the majority of the research activity. Facility managers and scientists contribute innovative instrumentation and research technologies that open up next-generation research areas, as well as contributing to research and training with those facilities. Research collaborations span all levels of the pyramid.

4.5.1 Current Facilities: Universities

University research groups and facilities span a comprehensive range. They are important for training, for the development of technologies, and for long-term or exploratory observing programs[17]. They produce a wide range of research, which is funded largely through competitive, peer-reviewed grants including the ARC's National Competitive Grants Program. Over the next decade, astronomers will continue to compete for funds to enhance established research programs and develop new ones. These funding options give Australian astronomers the flexibility to both participate in and lead new programs as opportunities arise. For example, Australia has an excellent record of achievement in fields such as solar astrophysics, optical interferometry and the study of very high energy cosmic rays. Projects like these are supported by competitive grant programs, and have a large international dimension.

A major issue in the coming decade will be the effects of grant funding on the operation of university facilities. While the competitiveness of such funding guarantees research excellence, current mechanisms are episodic and oriented towards short-term outcomes, rather than long-term operational or development costs. This can cause serious continuity problems for astronomical experiments and facilities, most of which are operated on time scales of more than just a few years. The resulting inefficiencies are a drain on the community financially and a significant opportunity cost for some of the nation's most productive scientific facilities.

Consider one specific example of the problems facing universities—the Siding Spring Observatory (SSO). This ANU-operated site is home to several telescopes identified as key for the next five to 10 years (AAT, Skymapper, and the ANU 2.3-m) and in addition a number of telescopes operated by other universities. The telescopes on the SSO site are widely used by Australian astronomers and students. As with other university facilities, however, funding mechanisms to support the site have become problematic.

One way to address these problems—and which is already used effectively in other countries (e.g. UK)—would be to change some fraction of existing grant arrangements to a "rolling grant" model for university astronomical infrastructure with appropriate critical review at least 12 months before the renewal of each grant. This would permit robust planning on longer timescales, while still allowing for on-going reprioritisation as existing facilities become uncompetitive. Such an arrangement would have broader implications, including the support of other university infrastructures identified as key for the next decade.

4.5.2 Current Facilities: National

The 3.9-m AAT is currently funded jointly by Australia and the UK. It is located at Siding Spring Observatory, providing added emphasis to the need to develop a viable long-term plan for that site.

By 2007 the AAT, and its parent organisation, the Anglo-Australian Observatory (AAO), will be 87% Australian-funded, while by 2010 it will be wholly Australian-owned. The telescope will continue to be a world leader in survey astronomy for at least the next five years, and beyond that will be critical as the single biggest source of optical/infrared observing time for Australian astronomers. During the decade, at least one more major instrument will be needed to maintain the telescope's scientific competitiveness. It is clear that by the end of the current decade the role of the AAT will have changed considerably, though the operational lifetime of the telescope will depend on the extent to which Australia achieves its goals of maintaining 8-m class telescope access and joining an ELT partnership.

The future of the AAO is a separable issue from that of the AAT. The observatory will have a clearly defined role while the AAT remains operational. Beyond that, it will continue to play an essential yet evolving role. The instrumentation program at the AAO is one of the very best in the world and it should be retained and developed as a national asset. Together with technology development in university instrumentation groups like the Research School of Astronomy & Astrophysics Advanced Instrumentation Technology Centre, it will be a key factor in allowing early engagement and influence in the next generation of telescopes.

Telescopes at Siding Spring including AAT & 2.3-m

The telescopes on SSO are widely used by Australian astronomers and students.

SKA is the highest priority new program for Australian radio astronomy.

Moreover, during the next decade, the scale and complexity of Australia's external involvement in major international facilities will grow (e.g. Gemini, Antarctica, and ELTs). In an expanded role as the optical/infrared national observatory, the AAO would be able to work with international partners in developing the next generation of optical/infrared facilities, and would ultimately manage Australia's access to these facilities.

In the radio domain, the telescopes of the ATNF continue to be highly productive in addressing a wide range of astrophysical problems. The extent to which these telescopes can be replaced and resources redirected to new infrastructure will largely depend on progress made with the prototypes for the SKA, the highest priority new program for Australian radio astronomy.

Continued operational support for the existing ATNF telescopes (Parkes, Mopra and Compact Array) is seen as important throughout the next decade. Nevertheless, over this period, resources from these telescopes will increasingly have to be reprioritised into the development and operation of infrastructure on the roadmap to the SKA if Australia is to maintain its world-leading position in radio astronomy. This will ultimately restrict the range of operational modes offered by the Compact Array and Parkes to a smaller number of areas where they can still offer world-class performance by the end of the decade.

CSIRO, the managing organisation for the ATNF, is well placed to act as the managing body for Australian SKA activities. As the radio national observatory, the ATNF will manage Australia's access to the international SKA Phase 1 and eventually to the SKA itself.

Just as new telescopes give us new perspectives on the Universe, so new generations of supercomputers bring increasingly detailed and higher resolution simulations of complex astrophysical problems within our grasp. Continued investment in computing infrastructure and associated personnel underpins both theoretical and observational astronomy.

Astronomers will be best served in the next decade by a mix of general use and dedicated astrophysical supercomputing facilities. General use facilities such as the Australian Partnership for Advanced Computing (APAC) will ensure Australian astrophysicists maintain access to an internationally competitive supercomputer. Dedicated astrophysical facilities will provide a focus for clusters of computational astrophysics expertise, as well as housing the petabyte (10^{15} bytes) scale databases generated by new observations and theory. The SKA and its prototypes will require tens of teraflops of dedicated computer power.

Increased bandwidth between computing facilities and observatories (up to and beyond 100 gigabits per second) is essential for the SKA, and will also greatly enhance collaborative activities across the research community. Astronomy will push the limits of any national capacity, providing sophisticated end users and leading-edge applications to maximise the scientific exploitation of any national and international network. As shareholders, the universities and CSIRO can look to the

Eight-metre telescopes will be the front-rank optical/infrared research tools worldwide.

Australian Academic Research Network (AARNet) to facilitate much of this infrastructure; however, further innovative solutions—including private–public partnerships between the research community and telecommunication companies—may also be explored as a means of providing and supporting this infrastructure, particularly in the more remote regions of Australia.

Australia will continue to participate in the International Virtual Observatory Alliance, a worldwide facility that aims to collect the archives of the world's major observatories into one distributed database. This activity will increase the worldwide impact of data taken with Australia's own telescopes and provide Australian astronomers with access to data from other telescopes worldwide.

4.5.3 Current Facilities: International

Over the coming decade 8-m telescopes will be the front-rank optical/infrared research tools worldwide. They will be critical to addressing many of the big scientific questions set out by this Decadal Plan.

Australia currently participates in the twin 8-m Gemini telescopes at a 6.19% level, equivalent to 12.4% of a single 8-m class telescope. Support from the present MNRF program is yielding additional 8-m telescope time over the next two years, temporarily bringing the total up to 20% of an 8-m class telescope. Excellent research is being done with these 8-m facilities, and Australians have been extremely successful in winning instrumentation development contracts from Gemini. There is, however, a need to streamline Gemini funding arrangements. The current funding mechanism is a combination of MNRF, LIEF and University contributions, an arrangement that is awkward, time-consuming and may not be sustainable over the lifetime of the Gemini partnership.

The astronomical community considers it essential that Australia maintain its 2006/07 level of 8-m access (i.e. equivalent to 20% of an 8-m telescope) throughout this decade. This will enable Australia to exploit the new science opportunities made possible by instrumentation being built by the Gemini partnership. It will also increase the community's access to a broader suite of instruments on a variety of 8-m telescopes in addition to those of the Gemini partnership. With all the relevant 8-m class telescopes operated by active international partnerships, attaining these objectives will require a more strategic and streamlined method of negotiating and contracting internationally. Any new governance model must be able to provide this.

4.5.4 Future Projects

Internationally, there are many major astronomical projects now in the planning and design stage. Some of the largest are space missions, predominantly being undertaken by NASA and the European Space Agency. On the ground, the largest new astronomical program is ALMA, a collaboration between the USA, Europe and Japan. Australia is not contributing financially to these, but, with proper investment in our areas of strength, we will continue to contribute to, and benefit from, these missions as valued collaborators with international astronomers[18].

Astronomers worldwide have plans under way to develop Extremely Large Telescopes.

Two of the pillars of Australia's present reputation are its radio and optical/infrared observatories[19]. On an international scale, both of these areas will see the development over the next decade of very much larger telescopes than are presently available to any astronomer.

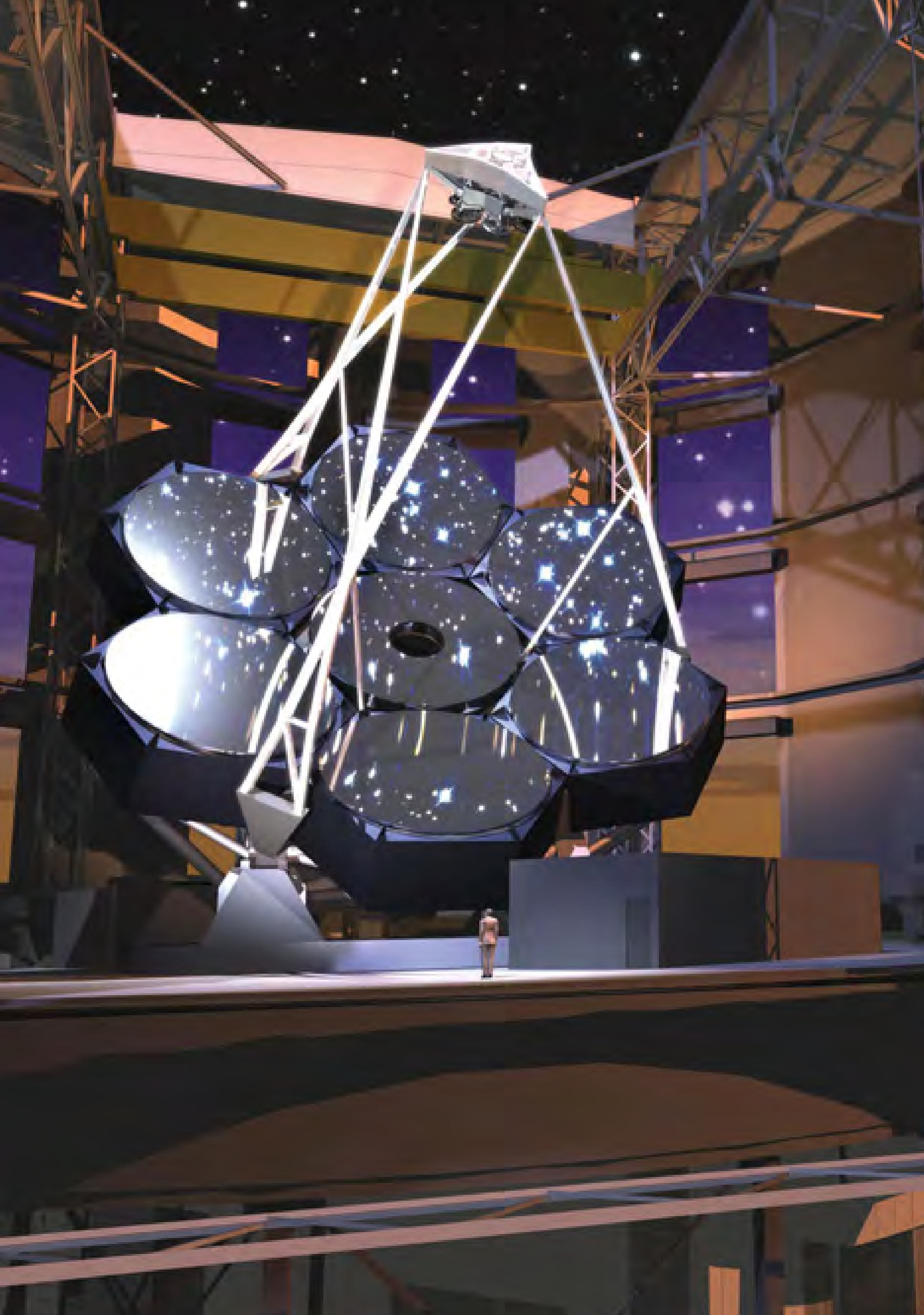
At radio wavelengths, astronomers worldwide are planning a staged progress towards the SKA, which will have a very much larger collecting area and sensitivity than any present-day telescope. Because the SKA is a technically challenging project, its staged development includes various national prototyping projects (in Australia, NTD, xNTD and SKAMP) and an internationally-funded SKA Phase 1 which is planned to follow on from the national efforts. This staged process, each stage resulting in a unique scientific capability in its own right, is part of a comprehensive risk mitigation approach to the SKA program. Over the decade, increasing amounts of operational resources for current infrastructure will be reprogrammed into the development and operations of these SKA prototypes. By the time the SKA is commissioned, most operational resources for the current national radio astronomy infrastructure will have been re-directed into the SKA, meeting in full Australia's long-term SKA operational commitments.

In the optical and infrared, astronomers worldwide also have plans under way to develop Extremely Large Telescopes—generically known as ELTs. These will be large enough to tackle fundamental questions such as the existence of Earth-like planets or the nature of dark matter and energy. The European OWL is the most ambitious ELT project, aiming at the construction of a telescope of 100 m diameter. Likely to be completed sooner are two projects based in the US, the Thirty Meter Telescope (an association of North American organisations) and the Giant Magellan Telescope (GMT: a consortium of major US universities). Australia currently has observer status within the GMT project and aspires to full membership and participation.

A smaller project, but of considerable long-term significance, is the Australian-led PILOT consortium, which aims to operate a pathfinder telescope on the high plateau in the Australian Antarctic Territory (Dome C). There are compelling indications that the Antarctic plateau is the best optical/infrared astronomical site on the planet by a significant margin. Looking further ahead, it may be possible to place a large telescope there that will out-perform any other. The PILOT project, while scientifically important in its own right, also points the way to this long-term objective and offers the opportunity for Australia to leverage additional scientific value from its Australian Antarctic Territories.

At the present time, the SKA and ELT projects are in their preliminary design stages. The site choices for the telescopes have not yet been made, and the partnerships are fluid. In addition there are considerable technological challenges attending the design and construction of such large telescopes. However, solving these challenges is also the lifeblood of innovation.

Proposed Giant Magellan Telescope



Because of the compelling science case for these telescopes, Australian astronomy has set an ambitious yet achievable target of participation in both the SKA and an ELT. Over the coming decade, Australia must continue its active engagement with both the SKA and an ELT, participating in the refinement of science cases, design and prototyping, with the intention of being at least 10% partners in both as they come to maturity. This level would ensure that Australia has an effective voice at the international table, and thus fully benefit from engagement in these partnerships. Australian astronomers could effectively utilise greater access made possible by even higher partnership levels, but note that the costs involved are significant and should not come at the expense of investment in people required to exploit this infrastructure.

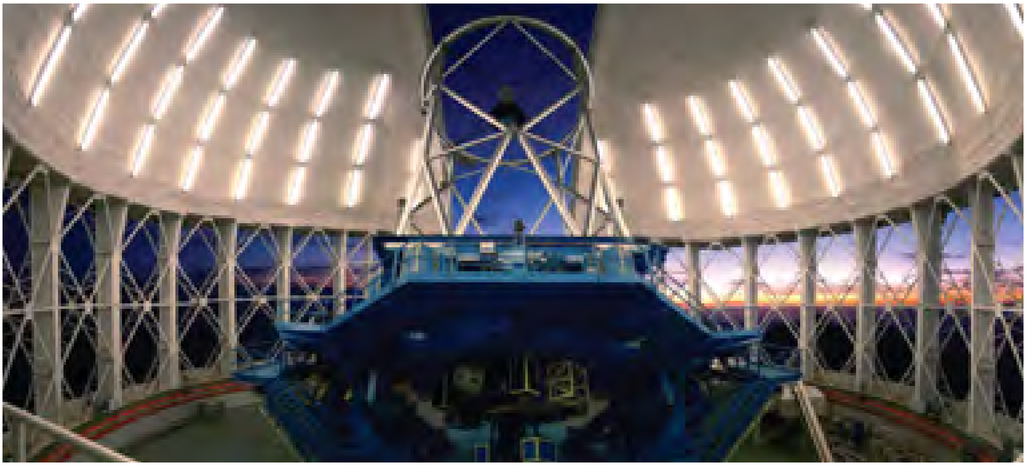
Radio and optical/infrared astronomy, and the associated areas of astrophysical research, are a key strength of the community; it is the combination of a range of observational technologies that has built Australia's reputation for astrophysics, and leverages access to other international projects, including space missions.

This engagement offers great opportunities, not only for pure research, but also for the involvement of Australian industry at an early stage in developments. It is possible that the SKA will be built in Western Australia, offering opportunities for diffusion of the investment in science into yet wider economic benefits. Because an ELT will be sited overseas, early membership of an ELT partnership is necessary to maximise the opportunity for Australian industry to construct components of the instrument and participate in actual construction.

Gravity-wave astronomy is identified as being of potentially enormous significance, but until gravity waves are detected they remain in the realm of experimental physics, rather than astronomy. Australia's role in the international gravity-wave observatory is best supported through Australia's subscription to the international Advanced LIGO program. The Australian Consortium for Interferometric Gravitational Astronomy (ACIGA) is developing and testing techniques for next-generation advanced gravity-wave interferometers, and is well-placed to make a significant intellectual contribution to Advanced LIGO.

There are compelling indications that the Antarctic plateau is the best optical/infrared astronomical site on the planet by a significant margin.

Gemini telescope at dusk



Case Study: **World-leading Innovation in Instrumentation**

Australia has demonstrated an outstanding capacity to develop innovative new instruments for use on some of the world's largest telescopes, including the ESO Very Large Telescope (Europe), the Subaru telescope (Japan) and the Arecibo radio telescope (USA). Most recently, Australian success in this field has been demonstrated within the Gemini partnership, through winning two major contracts (NIFS and GSAOI) and the development of an instrument concept for the largest instrument ever built for a ground-based telescope (WFMOS).

NIFS has been designed and built at the ANU's RSAA at a cost of US$2.4M under contract from the Gemini partnership. At the heart of this revolutionary instrument is a highly advanced set of tiny mirrors that will segment the Gemini field so as to send many spectra simultaneously to its infrared detector.

GSAOI will enable astronomers to obtain infrared pictures as sharp as the Hubble Space Telescope but it will do it from the ground, with a telescope 16 times larger, and at a fraction of Hubble's cost. Also under construction at the RSAA and funded by Gemini, this US$3.3M instrument will be installed on the Gemini South telescope in Chile and used in concert with the Gemini MCAO system which will correct for the turbulence of the Earth's atmosphere to deliver images of unprecedented quality over a wide field of view, revealing previously unseen vistas to Australian and international astronomers.

WFMOS—The AAO has been leading an effort by a team of Gemini partners to develop a wide-field, highly-multiplexed spectrograph for the Gemini Observatory. This massive project will represent a quantum leap in capability for one of the world's largest telescopes. It will be built around the AAO's revolutionary "Echidna" optical fibre positioning technology, which will feed light to banks of spectrographs mounted off the telescope. With a total projected cost of US$60M, it will represent the largest investment ever made in an instrument for a ground-based telescope.

4.5.5 Addressing the Big Astronomical Questions

Fundamental questions will drive astronomical research around the globe in the next decade, and beyond. The various elements of the astronomical pyramid outlined above will form an interlinked system in which observers and theorists together will address these key questions, placing Australia in a strategic position to take maximum advantage as ELTs and the SKA come on line.

The Big Questions	Facilities and their Investigations					
	University	National		International		
		Optical	Radio	8-m	ELT	SKA
Dark energy & dark matter	•	••	•	••	••	••
First stars	•	•	•	••	•	••
Galaxy assembly & evolution	•	••	•	••	••	•
Pulsars & gravity			••			••
Origin of magnetism		•	••	•		••
Supermassive black holes	•	•	••	•	••	••
Making stars and planets	•	•	•	•	•	•
Planetary systems	•	••		••	••	
Building blocks of life	•	•		••	••	

Legend: •• Key Investigation • Supporting Investigation

Table 4.1 How the Big Questions map onto the astronomical pyramid.

The table summarises how these facilities and their associated observational and theoretical investigations may address the "Big Questions" posed in Chapter 1. Most of these questions are comprehensive in their scope, requiring observations across the spectrum and engaging all levels of the astronomical pyramid. This research will be conducted by astronomers based at universities, national and international facilities, and overseas. For example, investigations probing the equation of state of the Universe and dark energy will require both the innovative radio facilities being developed on the road to SKA, and the new 8-m WFMOS instrument to be built in collaboration with our Gemini partners. The best strategies for these new observations will be determined by pilot studies carried out with the Anglo-Australian Telescope, and eventually extended into new realms once ELTs become operational.

Note that due to the inherently unpredictable nature of frontier research, this mapping exercise can only be indicative in nature. It may be that emerging technologies or advances in experimental techniques will enable new questions to be posed or allow existing questions to be answered in novel and unforeseen ways.

Fundamental questions will drive astronomical research around the globe.

5. Resourcing the Plan

CANGAROO at sunset

Growth in research support for university-based astronomers ... will be essential.

Australia's top priorities for new infrastructure funding this decade are to commence 10% participation in the SKA and an ELT, maintain 20% access to 8-m class optical/infrared telescopes, continue operations of the AAO and Australia Telescope, and carry out the PILOT program.

In addition, it is vital that there is continued support of the AAO beyond the term of the current AAT Board agreement.

Indicative resource requirements to achieve these objectives amount to approximately A$50M of new money over the next five years, rising to A$75M in the second half of the Decadal Planning period. In addition, reprioritisation of up to A$50M from existing operations is planned to augment these new funding streams.

An equivalent growth in research support for university-based astronomers through the peer-reviewed NCGP will be essential to Australia leveraging the maximum scientific return from these new investments. The increased resources already planned under BAA should be adequate to achieve this goal in the five years 2006 – 2010. This should result in the level of competitive grant support being, on average, A$3M per annum higher than current levels in the first five years of this Plan.

Continuing growth in the NCGP beyond this period will be necessary to arrive at NCGP targets of A$13M – A$17M per annum for astronomy in the second half of the decade. An indicative funding profile is shown in Figure 5.3.

Competitive grant funding—such as that won through ARC and DEST programs—will not only support research with new national and international facilities, but will also be used to support other high priority university programs, including those that leverage international collaboration and support (e.g. Auger, Advanced LIGO, CANGAROO) and those that benefit a broad national community (e.g. SSO, University of Sydney and University of Tasmania radio telescopes).

Figure 5.1 Proposed resource allocation for astronomy infrastructure 2006 – 2015.

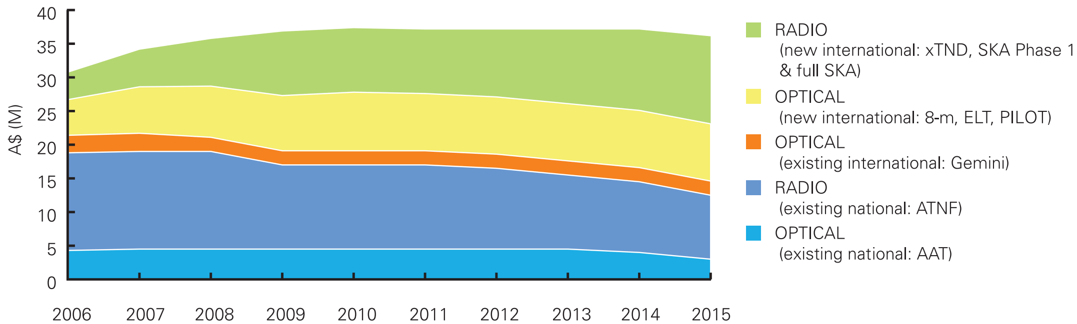


Figure 5.2 Distribution between existing, reprioritised and new investment in infrastructure.

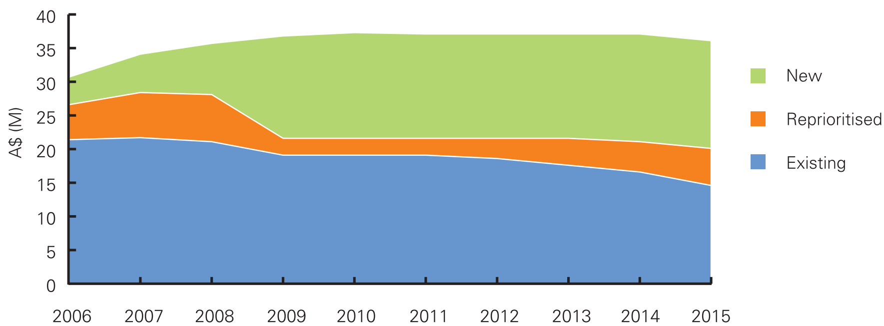
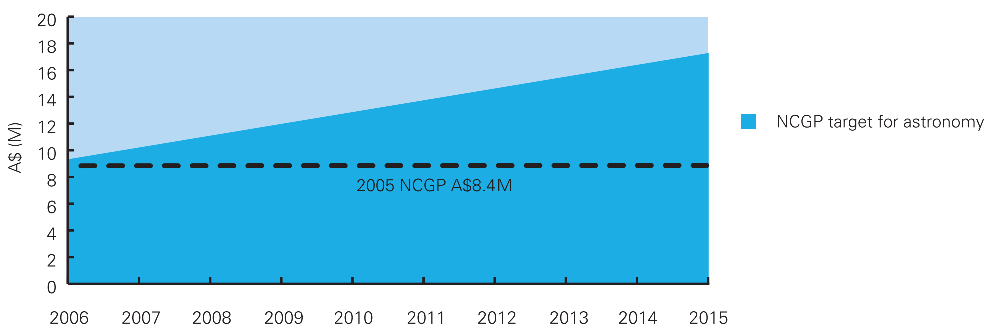


Figure 5.3 Competitive funding support targets for astronomy from 2006 onwards.
The base funding of A$8.4M in 2005 is that awarded through the ARC's NCGP alone.



6. Australian Astronomy 2015

This Plan lays out an ambitious and achievable roadmap.

This Plan lays out an ambitious and achievable roadmap for Australian astronomy over the coming decade. By following these strategies, appropriately resourced, astronomers will make contributions across the community in education, research, industry and society at large.

Astronomy programs will, by 2015, expand their training of PhD students both through graduating more PhDs than 10 years previously, and by doubling the number of those PhDs teaching and working in industry. Australian astronomers will be a catalyst in the enhancement and quality of science education at all levels across the country.

The investments proposed will see the size of the astronomical community in both universities and facilities expanded over 2005 levels. Australian astronomy will maintain its position as the nation's leading scientific discipline as measured by the citation impact of our research results.

Australia will be participating in the leading international projects in which the nation has recognised astronomical strengths.

Australian astronomy has a proud record of outstanding achievement. We want to continue this record of achievement over the decade, so that it can be a source of pride and benefit for all Australians.

Coda: A Future Retrospective

It is October 2020.

Antenna farm for SKA Phase 1 at Mileura, WA

It is October 2020. Presidents and prime ministers from around the globe have traveled to Western Australia to take part in the opening ceremony for the mighty Square Kilometre Array, the largest radio telescope the world has ever seen. Already the SKA Phase 1, which has been operational for several years now, has detected the gas heated up around the first stars to form in the early Universe. The full SKA will map the structure of the Universe's dark ages in unprecedented detail, as well as listening for the ringing of space–time itself as pairs of black holes collide and merge.

Just a few years ago, many of the same world leaders gathered in Chile for the first light festivities of the largest optical telescope to which Australian scientists have ever had access. Built in collaboration with nations from around the world, the giant mirror of this ELT has already seen the tiny pinpricks of light from planets orbiting distant stars. Its enormous light collecting power is also making possible a more detailed understanding of the 14 billion years worth of Universe that the light from the very first stars passed through on its way to the Earth.

These spectacular results, however, are just the tip of the iceberg. Australia and the other Gemini partners have produced an enormous volume of scientific results from their twin 8-m telescopes. In particular, we take enormous pride in the Australian-led partnership that built the WFMOS facility and mapped the reverberations left behind in the fabric of the Universe by the Big Bang, allowing us to finally unravel the nature of the mysterious dark energy.

Meanwhile, on the dry, cold highlands of the Australian Antarctic Territory, the world's first fully-cryogenic optical and infrared telescope, PILOT, is closing up at the end of its last six-month-long night of observing. Amongst its achievements was the detailed study in 2011 of weather patterns on Mars and Titan that re-ignited the debate about life in our solar system. But the pace of development in astronomy is rapid, and PILOT is now being closed, as larger and even more powerful telescopes take its place.

All the data from these, and the rest of astronomy's ongoing explorations of the cosmos, are flowing into a vast storehouse of knowledge—the International Virtual Observatory. This treasure trove of information is used by schools and universities across the globe, and has been the engine powering an international explosion of interest in astronomy, as students and researchers alike use it to better understand the formation and evolution of the Universe, the seeds of life, and the fundamental nature of matter and energy.

Glossary

AAO	Anglo-Australian Observatory
AARNet	Australian Academic Research Network
AAT	Anglo-Australian Telescope (optical/infrared) operated by AAO
AAIN	Australian Astronomy Industry Network
ACIGA	Australian Consortium for Interferometric Gravitational Astronomy
AIGO	Australian Interferometric Gravitational Observatory
ALMA	Atacama Large Millimeter Array (radio)
ANU	Australian National University
APAC	Australian Partnership for Advanced Computing
ARC	Australian Research Council
ATNF	Australian Telescope National Facility (radio) a division of CSIRO
AURA	Associated Universities for Research in Astronomy (USA)
Auger	Pierre Auger Observatory (cosmic rays)
BAA	Backing Australia's Ability
CANGAROO	Collaboration between Australia and Nippon for a Gamma-Ray Observatory in the Outback
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEST	Department of Education, Science and Training
ELT	Extremely Large Telescope (optical/infrared)
ESO	European Southern Observatory
Gemini	Gemini Observatory (optical/infrared)
GSAOI	Gemini South Adaptive Optics Imager
GWFMOS	Gemini Wide Field Multi-Object Spectrograph
LIEF	Linkage, Infrastructure and Equipment Fund managed by ARC
LIGO	Laser Interferometric Gravitational-Wave Observatory
MCAO	Multi Conjugate Adaptive Optics system
MNRF	Major National Research Facilities
NASA	National Aeronautics and Space Administration (USA)
NCGP	National Competitive Grants Program managed by ARC
NIFS	Near-infrared Integral Field Spectrograph
OWL	Overwhelmingly Large Telescope (optical/infrared)
PILOT	Pathfinder for an International Large Optical Telescope (optical/infrared)
RSAA	Research School of Astronomy & Astrophysics (ANU)
SKA	Square Kilometre Array (radio)
SKAMP	SKA Molonglo Prototype
SSO	Siding Spring Observatory
WFMOS	Wide Field Multi-Object Spectrograph
(x)NTD	(extended) New Technology Demonstrator (radio)

Notes

[1] All monetary amounts are in 2005 dollars.
[2] *Australian Science and Technology at a Glance*, DEST, 2004 (Chart 51).
[3] *New Horizons: Volume II—Report of Working Group 1.1.*
[4] Joint study by Royal Australian Chemical Institute, Australian Institute of Physics, Australian Mathematical Sciences Council, and The Institution of Engineers, Australia, reported in www.raci.org.au/national/news/EnablingSciencesPressRelease.pdf and www.raci.org.au/national/news/EnablingSciencesData.pdf.
[5] *New Horizons: Volume II—Report of Working Group 1.1* (see also Annex E3: Australian Astronomy University Expenditure).
[6] PMSEIC Astronomy Working Group Report, June 2004
[7] *Maximising the benefits from Australia's formal linkages to global scientific activities.* Australian Academy of Science (2005).
[8] 81.8% of Australian publications in 1997 involved international collaborators. Ibid.
[9] Over the period 2000 – 2004 overseas users of the ATNF's Compact Array and Parkes telescopes average approximately 40% of total users (*ATNF Annual Report 2004*), while 41% of AAT users have been from outside Australia and the UK (*AAO Annual Report 2004-2005*).
[10] *New Horizons: Volume II—Report of Working Group 3.1 Annexe W1 (case 6).*
[11] *New Horizons: Volume II—Report of Working Group 1.2.*
[12] Internationally co-authored publications have increased from 55% to 77% of all Australian astronomical publications over the last 10 years. *New Horizons: Volume II*—Biglia & Butler (2005) *A Bibliometric Analysis of Astronomical Sciences Publications*.
[13] *New Horizons: Volume II*—Report of Working Group 1.1, Table 2.
[14] Annex E2. Support for Astronomy from the National Competitive Grants program.
[15] *ARC Budget 05/06*, Figure 2 & Table 5.1 www.arc.gov.au/about_arc/arc_budget.htm.
[16] Facilities are classified by scale, rather than partnership. Both at the national and university level, facility partnerships often involve overseas partners, but are classified as national or university based on their smaller scale.
[17] University facilities have been responsible for one sixth of all astronomical citations gathered by Australian astronomers over the past decade. *New Horizons: Volume II—Report of Working Group 3.1,* Annex W1.
[18] One third of Australian astronomy citations over the past decade are of publications arising from the use of international ground-based or space-based facilities in which Australia is not a direct participant. *New Horizons: Volume II—Report of Working Group 3.1*, Annex W1.
[19] 45% of Australia's citations over the last ten years have come from the AAO, ATNF and ANU optical/radio observatories. *New Horizons: Volume II—Report of Working Group 3.1*, Annex W1.

Credits

Opening spread: Gemini Observatory/AURA

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