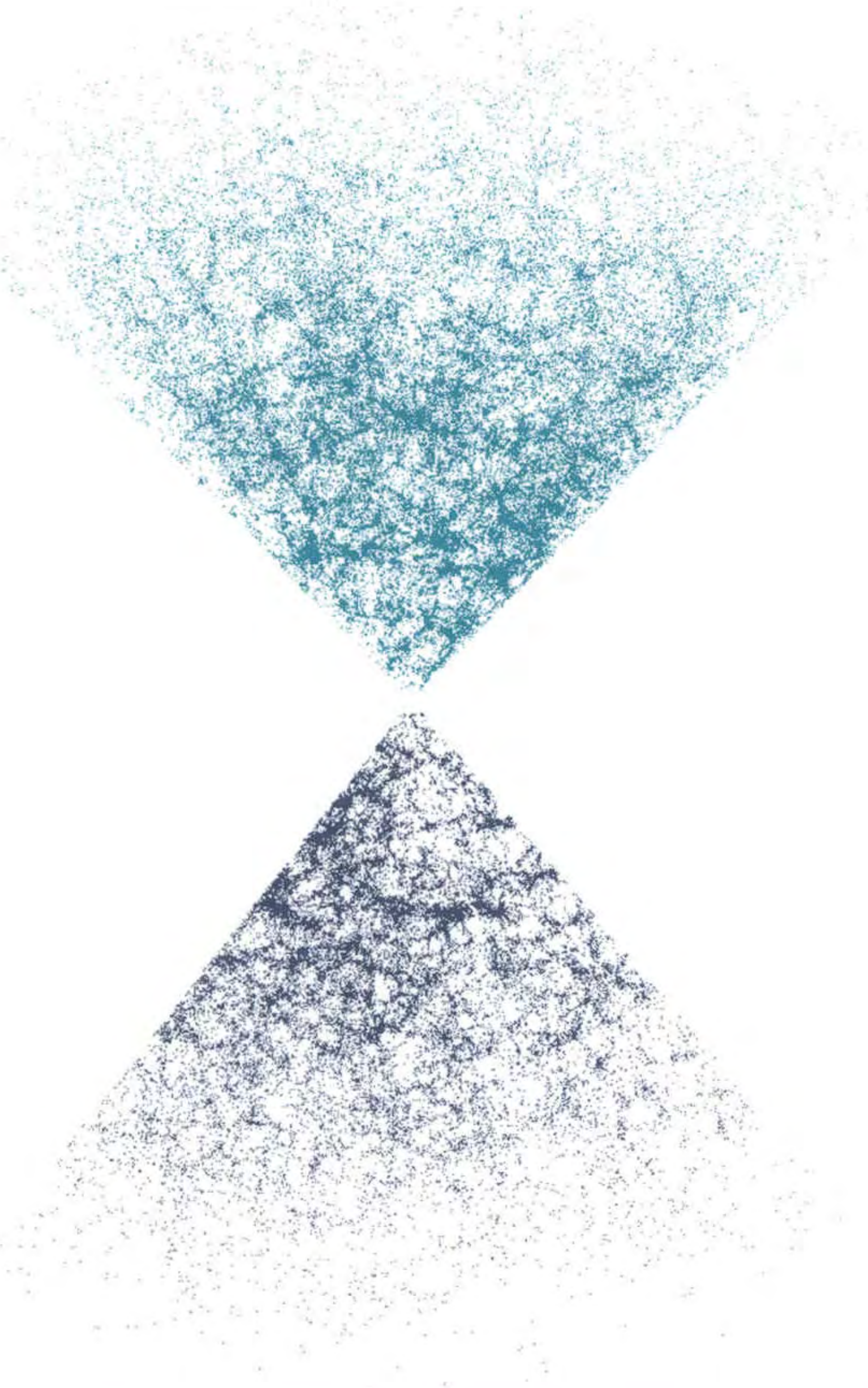
AUSTRALIAN RESEARCH COUNCIL

Beyond 2000: The Way Ahead

A Mid-Term Review of 'Australian Astronomy: Beyond 2000'



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

AUSTRALIA

Australian Research Council

Beyond 2000: The Way Ahead

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June 2001

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Cover Design: An actual map of 170,000 galaxies developed from information collected through the 2dF (Two-degree Field) Galaxy Redshift Survey. The 2dF Galaxy Redshift Survey is an international collaboration involving more than 30 scientists from 11 institutions including the Anglo-Australian Observatory, the Australian National University and the University of NSW. The survey aims to learn more about the structure of the Universe, how galaxies are made and how they form into larger structures.

Foreword

The discipline research strategy *Australian Astronomy: Beyond 2000* was published by the National Board of Employment, Education and Training in June 1995. The strategy, which was prepared by the National Committee for Astronomy of the Australian Academy of Science, outlined a ten-year plan for astronomy research in Australia including the research community's priorities for investment.

In *Beyond 2000: The Way Ahead* the astronomy community have refocused the priorities identified in 1995 taking into account the considerable developments that have taken place in astronomy since that time. One example of those developments is Australia's partnership in the International Gemini Project which was announced by the Government in early 1998. I was very privileged to be able to attend the dedication for the North Telescope in Hawaii in June 1999 and visit the telescope site.

The review reinforces the features of the discipline highlighted in the original strategy – for example, the scale of the investment involved and the critical importance of international collaboration. It also updates the strong record of the astronomy community in spreading the message of science to the Australian community, in contributing to discoveries in the field, and in driving technological developments.

At the same time that this review was being finalised (in January 2001), the Government released *Backing Australia's Ability: An Innovation Action Plan for the Future*. The Plan, which responded to the recommendations of the Science Capability Review and the Innovation Summit Implementation Group, announced a range of initiatives to encourage and support innovation in Australia over the next five years – initiatives addressing education, research and research training as well as commercialisation.

The Plan, in recognising the fundamental importance of basic research, people and ideas, is a first step for Australia in establishing itself as a competitive knowledge economy. The commitment of the research community to identifying the strengths of and opportunities for particular disciplines, such as indicated in this review, will be critical input to ensuring that the promise of Australia's capabilities continues to be realised in the future.

Professor Vicki Sara
Chair, Australian Research Council
June 2001

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Acronyms and Abbreviations

2dF	Two-Degree Field
AAO	Anglo-Australian Observatory
AAS	Australian Academy of Science
AATC	Australian Astronomy Technology Centre
ACIGA	Australian Consortium for Interferometric Gravitational Astronomy
AGN	Active Galactic Nuclei
ALMA	Atacama Large Millimeter Array
ALT	Australian Large Telescope
ARC	Australian Research Council
ASTEC	Australian Science and Technology Council
DMT	Douglas Mawson Telescope
DSN	Deep Space Network
EOS	Electro-Optic Systems
ESA	European Space Agency
ESO	European Southern Observatory
GDP	Gross Domestic Product
HST	Hubble Space Telescope
ICRR	Institute for Cosmic Ray Research
LIGO	Laser Interferometry Gravitational Observatory
MNRF	Major National Research Facilities
NASA	National Aeronautics and Space Adminstration
NCA	National Committee for Astronomy
NITA	National Institute for Theoretical Astrophysics
NGST	Next Generation Space Telescope
OECD	Organisation for Economic Cooperation and Development
Optical/IR	Optical/Infrared
OWL	Overwhelmingly Large Telescope
SEST	Swedish ESO Submillimetre Telescope
SET	Science, Engineering and Technology
SKA	Square Kilometre Array
UK	United Kingdom
USA	United States of America
VLBI	Very Long Baseline Interferometry
VLT	Very Large Telescopes
VLTI	VLT Interferometer
UV	Ultraviolet
WSO/UV	World Space Observatory/Ultraviolet

Executive Summary

In 1995 Australian astronomers prepared *Australian Astronomy: Beyond 2000* - a strategic plan laying out the community's vision for the decade ahead. In the years since, the public's phenomenal interest in astronomy has continued unabated, and astronomy courses have become more popular than ever at tertiary institutions. New discoveries by Australian astronomers have maintained astronomy as one of the nation's flagship sciences, supported by strategic investments in the International Gemini Project and an upgraded Australia Telescope National Facility.

Australian astronomers are an acknowledged international force: they publish with astronomers worldwide; they win access to competitive international facilities; and they support astronomers from around the globe in the use of Australian facilities. The years since *Beyond 2000* have seen a revolution in international astronomy, with major overseas investments in new facilities dramatically increasing competitiveness. In the period 2001-2005 the major nations with which Australian astronomers work[1] are planning to invest $US0.5 billion per annum in new facilities. It is timely, therefore, to update the priorities of *Beyond 2000*, so that Australian investment in astronomy leads to the greatest national benefits.

New investment in astronomy research facilities will return important benefits to the nation, its science, engineering and technology base, and its new economy. We therefore outline in *The Way Ahead,* a program of investment in Australian astronomy focussing on the national strategies set out in the recent government reports *The Chance to Change* and *Innovation: Unlocking the Future*. The program has two major components: facilities and people.

Facilities

Participation in the new generation of world-class optical/infrared and radio facilities is essential to Australia's internationally competitive research program. The immediate priority is to double the Australian involvement in international 8-metre class optical/infrared projects. The longer term vision, (one requiring immediate R&D investment), is for the Square Kilometre Array radio telescope.

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[1] The USA, Canada, United Kingdom, Japan and the member countries of the European Southern Observatory (Belgium, Denmark, France, Germany, Italy, Netherlands, Portugal, Sweden and the United Kingdom).

These two major new international facilities must be complemented by strategic investments in multiplier programs – theory and technology programs which will expand Australia's enviable reputation for innovation, and ensure that the nation benefits from future international developments.

People

Re-invigoration of Australia's research effort through a major investment in people will stimulate increased public awareness of science and technology, encourage the education and training required in a culture of innovation, and sustain new research and commercial spin-offs.

With approximately two percent of the world's Gross Domestic Product, Australia must invest $A16.5 million per annum in new astronomical facilities and programs to maintain the health of one of the nation's flagship sciences. The highest priority components of *The Way Ahead* (the Major New International Facilities and the Multiplier Programs summarised in the following table) can be funded within this envelope. This investment will be repaid through the enhancement of the science, engineering and technology base, by the attraction to Australia of significant instrumentation projects, and by fostering a science-aware society.

New Major International Facilities 2002-2010			
	Facility	**Total Cost**	**Equity**
Optical/Infrared Astronomy	European Southern Observatory or Gemini	$US1.1b $US294m	$A96m $A32m
Radio Astronomy	Square Kilometre Array	$US500m	$A100m
Multiplier Programs			
Facility		**Cost**	
Theoretical Astrophysics		$A1.4m per annum	
Australian Astronomy Technology Centre		$A5m per annum	
International Virtual Observatory		$A1m per annum	
Strategic Programs			
	Facility	**Total Cost**	**Equity**
Antarctic Astronomy	Douglas Mawson Telescope	$A20m	$A10m
Space Astronomy	Next Generation Space Telescope	$US1.3b	$A80m
	Deep Space Network Array	$US300m	$A40m
	Very Long Baseline Interferometry	$US500m	$A15m
Optical/Infrared Astronomy	Australia Large Telescope	$A80m	$A40m
Gravitational Wave Astronomy	Southern Detector	$US300m	$A30m

1

Astronomy and the New Economy

Two recent reports - *The Chance to Change*[2], and *Innovation: Unlocking the Future*[3] - have presented the nation with blueprints to unlock the Australian science, engineering and technology base and propel Australia's new economy in the coming decades. Both documents emphasise the importance of investment in three key areas:

- Culture – fostering a science-focussed society;
- Ideas – nurturing a vibrant research base; and
- Commercialisation – turning innovation into products.

In the first two areas, astronomy is ideally placed to play a leading role. In the third area of commercialisation, astronomy has a strong track record in stimulating technology developments that have influenced commercial products.

1.1 Culture

> *The culture needs to change. We need more support for those who inspire our children to study science and math.*
> *(The Chance to Change, p.10)*

Astronomy captures the imagination. Its universal scope and its tackling of profound questions, inspires awe and wonder. It is an extraordinarily effective way of carrying the message of science to the broadest possible audience. The public's fascination with the universe is clearly apparent in the constant stream of astronomical stories we read in the press, hear on radio and see on television.

This places the astronomical community in a position to play a leading role in developing a science culture in Australia. Astronomers work hard to explain their breaking research results to the public through the press, and so contribute enormously to the public awareness of science. In the future, astronomers, like all scientists, will expand their outreach activities into the entire life-long learning experience of every citizen. They will convey the excitement and innovation of astronomy, and science in general, to teachers and students at all levels. In this way they will foster and inspire the education of a technically capable and scientifically aware society.

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[2] *The Chance to Change*, Final Report of the Science Capability Review, Chief Scientist, November 2000, http://www.isr.gov.au/science/review/ChanceFinal.pdf
[3] *Innovation: Unlocking the Future*, Innovation Summit Implementation Group final report, David Miles, Chair, August 2000, http://wwwisr.gov.au/industry/summit/isigreport.pdf

Given support, Australian astronomers will:

- inspire students to study science-related subjects throughout their education, with a special focus on encouraging primary and secondary students.
- provide material for appealing outreach projects, which lead to interest and involvement in science and technology. Astronomy, because it is information rather than laboratory based, is well suited to scientific outreach in schools with modest investment.
- develop on-line curriculum resources to reach the widest possible audience and encourage interest in science, engineering and information technology.

1.2 Ideas

> *Publicly funded basic research plays an important role in supplying much of the knowledge, skills and new ideas critical to a competitive and innovative economy. A high quality research system is the key to successful innovation. (Innovation: Unlocking the Future, p.15)*

Inspirational science is carried out by inspired researchers with cutting-edge facilities. This is emphasised by both *The Chance to Change* and *Innovation: Unlocking the Future*. Australian astronomers whole-heartedly support the call for increased research funding and infrastructure, to support the nurturing and training of innovative Australian researchers and their provision with state-of-the-art facilities.

Australian astronomers have an international reputation far above their per capita or funding ranking in international astronomy[4]. Astronomy is one of Australia's highest profile sciences. Astronomical training and research requires the application of core science and engineering strengths – physics, mathematics, chemistry and information technology – at the highest levels. They are a key motivator in making these subjects accessible and appealing to students at all levels of the education system. And they provide the economy with people who are highly trained in areas valuable outside astronomy.

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[4] A Comparison of Astronomy in Fifteen Member Countries of the OECD, P.C. van der Kruit, 1994, Scientometrics, 31, #2, p.155; Scale-independent Indicators and Research Evaluation, J.Sylvan Katz, 2000, Science and Technology Policy Research Unit (SPRU) Electronic Working Papers Series, No 41

1.3 Commercialisation

> *Great research can drive commercial activity, and commercial activity can create the right environment for new exciting products and processes. (The Chance to Change[5], p.28)*

Astronomical research routinely drives new technological developments. Australian radio astronomers and engineers are at the forefront of developments in new technologies for sensitive radio- and microwave-receivers. These technologies have direct spin-offs in the information and satellite markets. As a specific example, the company *Radiata,* founded by a group including former Australian radio astronomers to commercialise radio technologies, was recently sold for $A500 million to *CISCO Systems*. Similarly, research for radio astronomy's next generation instrument – the Square Kilometre Array (SKA) – will require the development of antenna technologies with enormous commercial potential. Optical/Infrared (IR) astronomers' demand for larger and more sensitive detectors pushes the development of the technologies at the heart of every camcorder. At present Australia has overseas-funded contracts exceeding $A12 million for instrumentation for offshore astronomical facilities, with many other opportunities in the pipeline. This income represents a significant return on Australian investment in astronomy facilities. The contracts are awarded in international competition and capturing them demonstrates that Australian engineering, project management and computing skills match the best in the world.

International collaboration drives modern astronomical facilities, as nations pool their expertise and resources to fund, construct and operate a cutting-edge facility. The key to a significant return to industry from any international collaboration is early entry. Early entry means that technological developments and industrial participation can be leveraged from the overall cost. A new generation of international facilities requiring significant technological development is getting under way. Australia must act now to enter these projects at the ground level, and win significant engineering and technology benefits, while also obtaining access to front-rank astronomical facilities.

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[5] *The Chance to Change*, Public Discussion Paper, August 2000

2

A Decade of Success

The 1990's have seen Australian astronomy remain a focus of the nation's science effort, with an international impact far in excess of our Gross Domestic Product (GDP) or population. In this golden decade for global astronomy, Australian astronomers have stood at the centre of many profound discoveries. These include the direct detection of dark matter using the MACHO telescope at Mount Stromlo Observatory in 1993; the discovery of radio emission from a gamma-ray burst by the Australia Telescope in 1998 and its link with the birth of a black hole; doubling of the known numbers of pulsars and quasars by the Parkes and the Anglo-Australian Telescope respectively between 1998 and 2000; the discovery of the acceleration of the Universe in 1998; the measurement of the expansion rate of the Universe in 1999; new theories for the origin of dark matter, high-energy cosmic rays and shock waves in galactic nuclei developed by Australian theoretical astrophysicists, and the first detection by Australian astronomers of planets around other stars in 2000.

2.1 Innovative Technology Yields Excellent Science

Australian astronomy continues to build on these successes with innovative new instrumentation and programs. These include:

- mapping the nearby radio universe with an order of magnitude better sensitivity than ever before, using the unique multi-beam receiver on the Parkes radio telescope.
- uncovering the large-scale structure in the distribution of galaxies and quasars, and measuring the overall density of matter in the universe, using the world-leading 2dF optical-fibre spectrograph on the Anglo-Australian Telescope.
- extending the capabilities of the Australia Telescope Compact Array near Narrabri to provide the world's most sensitive microwave interferometer for detecting the cool gas from which stars are born, by being the first to apply microwave monolithic integrated circuits to high frequency radio receivers.
- finding distant radio galaxies with the unique wide-field imaging capability of the University of Sydney's recently upgraded Molonglo Observatory Synthesis Telescope.
- demonstrating that the atmospheric conditions on the Antarctic plateau make it a potentially far superior site for thermal infrared and sub-millimetre observations than anywhere else on the surface of the Earth.

The facilities making these discoveries possible provide Australian astronomers with information revealing the origins of stars and galaxies and the basic contents of the universe; they also are used by astronomers from around the world, ensuring that Australian astronomy remains firmly in the vanguard of the international community.

Australian expertise in astronomical instrumentation is recognised internationally. Observatories across the globe are lining up to sign contracts with Australian institutions for advanced instruments and technology. These include building a new $A2 million receiver for the Swedish SEST telescope in Chile, a $A3 million fibre system for the European Southern Observatory's (ESO) Very Large Telescope (VLT), a $A3.6 million contract to build a receiver system for the National Aeronautics and Space Administration (NASA) to track the Galileo spacecraft and a $A4 million integral field infrared spectrograph for the Gemini Telescope consortium.

2.2 Outstanding Achievements by Australian Astronomers

Astronomers are amongst the nation's highest-profile scientists. Dr Bryan Gaensler, named Young Australian of the Year in 1999, has a PhD in astronomy and continues to work as a research astronomer while promoting science and technology. In October 2000, Dr Brian Schmidt was awarded the inaugural Prime Minister's McIntosh award for Achievement in the Physical Sciences, as a result of his work on supernovae and the acceleration of the universe. Moreover, in the past decade astronomers have won the Eureka prize for the Communication of Science on no fewer than four occasions.

Australian astronomers also compete with great success on the international front. The USA's multi-billion dollar Hubble Space Telescope (HST) is the world's most difficult telescope on which to capture time. Yet Australian principal investigators win more than six percent of the time on that facility. As a proportion of GDP or population, this makes Australia one of the most successful nations at gaining time on the Hubble Telescope – more successful even than the United States of America (USA).

The prowess of Australian astronomical research is not limited to isolated breakthroughs, but extends across the entire field. Bibliometricians investigating the international impact of Australian science have found that Australian astronomers not only have a higher publication rate than the average Australian scientist, but also, more importantly, their publications have a much higher average impact than for the countries of the Organisation for Economic Cooperation and Development (OECD) as a whole. This is clearly demonstrated at the recent symposium held by the Institute for Scientific Information called "Honouring Excellence in Australian Research", where nine of the 33 most cited researchers were astronomers.

2.3 Australian Astronomy: Beyond 2000

The astronomical community's strategic plan for the coming decade was laid out in *Australian Astronomy: Beyond 2000,* a document prepared by the entire astronomical community in 1995. It prioritised future capital expenditures, and outlined the broad scientific objectives the community wished to pursue in the period 1996-2005.

The highest priority issue addressed by *Beyond 2000* was Australian access to the new generation of large 8-metre optical telescopes then under construction. To achieve this goal, the plan advocated membership of the ESO, a consortium of eight leading astronomical nations. Although the bid to join ESO was ranked highest by peer review of all science proposals for Major National Research Facilities (MNRF) funding in 1995, ESO membership was not funded. However, the community's goal was partially met when Australia joined the Gemini Partnership with a five percent share.

Beyond 2000 also recommended upgrading the southern hemisphere's leading radio facility, the Australian Telescope Compact Array, so that it could observe at higher frequencies and with greater angular resolution. The upgrade, first funded in 1996, will be completed in 2001. At completion, the Compact Array will become the most sensitive microwave telescope in the world, and will remain so until the second decade of the new millennium. A further recommendation of *Beyond 2000* was that the recurrent funding for theoretical astronomy in Australia should be maintained at least at the then current proportion of support for astronomy as a whole, and this was achieved until 1999 with support for the Special Research Centre for Theoretical Astrophysics at Sydney University.

Beyond 2000 was prepared at a time of great vigour in the construction of new optical/IR facilities, including the ESO VLT and the Gemini telescopes, and in the exploitation of the full power of the HST. These projects are now operational, and their outstanding success has stimulated exciting new concepts for the next generation of international facilities. Participation in the development of these concepts and the consequent construction and operation of the proposed facilities is a cornerstone of the national science and technology programs of most economically advanced countries. Australia, with its world-renowned researchers and world-leading instrumentation, is poised to participate in and lead many of these projects. Not to participate in these ventures will leave Australia vulnerable to being bypassed in technologies and know-how essential for sustaining economic growth. These innovative facilities will open up exciting new windows on the cosmos, allowing Australians to continue to lead international research initiatives.

3

The Astronomy of the Future

3.1 The Scientific Context

Astronomical research remains one of the most fruitful areas of scientific progress, as potent new facilities allow astronomers to tackle a host of fundamental and exciting questions, such as: What sort of planets are there around other stars? How do stars and planets form? What were the very first stars and galaxies in the universe like?

Planets around other stars - The speed with which astronomical knowledge moves is demonstrated by the impact of the detection of planets orbiting other suns. Unknown five years ago, the discovery of these "*exo-planets*" has galvanised public and international astronomical interest, spawning plans for astronomical facilities pushing back the limits of technology. Over the course of the next five to fifteen years, astronomers expect to discover hundreds of exo-planetary systems. Some will be like our own; most will be radically different. New instruments will measure the masses of these planets, detect light from their surfaces, and eventually explore Earth-like planets around other stars.

How stars and planets form - Just as important as the search for planets, is the need to understand how stars and planets form. How are planetary systems different from binary stars? What sorts of planetary systems are possible – are most like our own Solar System, or do they differ widely? The current generation of ground-based 8-metre optical/IR telescopes, and the coming generation of extremely large telescopes (with proposed sizes from 30 metres to 100 metres in diameter), will enable astronomers to probe the inner mysteries of star- and planet-formation and answer these key questions.

The first galaxies in the universe - Deep observations by the HST have revealed the contorted and disturbed shapes of the most distant galaxies. Astronomers have concluded that since the first galaxies were born, more than thirteen billion years ago, these gigantic star-systems must have undergone remarkable evolution. Large galaxies, it seems, grow out of violent mergers between smaller ones as well as the steady accretion of primeval gas clouds. The next generation of telescopes will probe the epoch of formation of the very first galaxies. Enormous new 30-50-metre ground-based optical telescopes, new 8-metre space-based telescopes, and new infrared and sub-millimetre facilities will be pointed at the sky for the first time in the next five to fifteen years, to detect the first galaxies, and understand their formation and evolution.

The first stars in the universe - Current observations by astronomers have used the light from galaxies and stars to probe within the one billion years of the universe's birth. Before the first galaxy, before the first star, the universe slumbered in a 'dark age', unilluminated by the light to which optical telescopes are sensitive. To understand this early phase of our universe's evolution, and its transition into the current phase with the birth of the first stars, requires a new generation of radio telescope – the Square Kilometre Array (SKA). This giant international project will be able to detect the hydrogen gas warmed by the first objects in the universe. Excitingly, one of the prime locations to place this facility is in the thousands of square kilometres of radio-quiet desert available in Western Australia.

Black Holes: Powering the Universe - Some galaxies show extraordinarily violent activity in their central regions, to the extent that these regions outshine the rest of the galaxy. The powerful emission from these active galactic nuclei (AGN) can only be the result of accretion of matter on to a massive black hole. The high spatial resolution of the new generation of optical and radio telescopes will provide the opportunity to peer into the hearts of many galaxies to these questions directly. This includes the state-of-the-art 0.1arcsec spatial resolution in the infrared provided by Gemini, to the milli-arcsecond resolution provided by linking radio telescopes across the globe and into space. The development of the SKA as a major element in these types of observations will provide the sensitivity to probe AGN back to their origin in the earliest galaxies in the Universe.

3.2 The International Context

Many of these new scientific opportunities can come to fruition only with close international cooperation. International cooperation was a major theme in *Beyond 2000*, and it remains essential to align the strategic directions of Australian astronomy with the forward planning of other nations with strong astronomical traditions. Given that most of these nations have published recent plans and programs for the development of new astronomical facilities in the early part of the millennium, it is timely to review the priorities of *Beyond 2000*.

The trend amongst nations with vigorous astronomy programs is for a major expansion in astronomy investment over the next five years. International funding for large astronomical facilities was $US6 billion during the period 1995-2000. This will increase to $US12 billion over the period 2001-05 (of which 50 percent is US funding). Space astronomy, a field in which Australia has very low investment, accounts for much of this expenditure. When space astronomy is excluded, the total investment will be $US0.5 billion per year over the next five years. To maintain one of its most successful scientific areas at a level consistent with its 2 percent share of world GDP, Australia would need to invest $A16.5 million per year in new astronomical facilities. The rate of investment over the past five years has been less than 30 percent of this amount.

The plans of the USA, Canada, the United Kingdom (UK), and the European members of the ESO and the European Space Agency (ESA) articulate a balanced, internationally focussed program of facility development that will advance astronomical research into exciting new areas and also maximise the community benefits of technological spin-off.

The United States – The January 2000 report *Astronomy and Astrophysics in the New Millennium* lays out priorities for the USA for the period 2000-2010. It plans a total of $US4.7 billion expenditure on astronomical research. The USA sets as its top-priority the ground-based project the Giant Segmented Mirror Telescope ($US350 million), a 30-metre diameter optical and infrared telescope. This large telescope is one of several concepts for giant optical telescopes foreseen for the next 10-15 years, and represents the benchmark in cutting-edge optical astronomy. The top-ranked space project is the Next Generation Space Telescope (NGST) ($US1 billion). Major strategic initiatives are highlighted for the longer term and funded for development in the next 10 years. These include the Terrestrial Planet Finder space mission ($US200 million) and development funding ($US22 million) for the SKA.

Europe – Europe’s top priority ground-based facility continues to be the ESO. Since Australia’s unsuccessful bid to join ESO in 1995, ESO has continued to grow, with the addition of Portugal and the 2002 entry of the UK. Four other nations are currently negotiating possible entry. This consortium provides its member states with access to a suite of world-leading facilities. These include the four 8-metre VLTs; the combined VLT Interferometer (VLTI); involvement in ESO’s large segmented-mirror optical telescope project, the 100-metre Overwhelmingly Large Telescope (OWL); and partnership in the forthcoming Atacama Large Millimeter Array (ALMA) – a breakthrough facility for radio astronomy at very short wavelengths.

The United Kingdom – The UK has announced that it will join the ESO at a cost of £GB160 million over the next 10 years. This initiative will provide UK astronomers not only with greater access to the current generation of large telescopes than provided by their 25 percent share of Gemini, but also with early strategic involvement in future facilities such as ALMA and OWL. Also highlighted as a national priority is partnership in NGST at a level beyond the UK’s existing ESA membership.

For three decades Australia and the UK have enjoyed particularly close linkages in astronomy through the Anglo-Australian Observatory (AAO). There remains a strong mutual desire to maintain this relationship, and the AAO has a well-conceived, community-endorsed strategy of evolution in the face of its changing environment.

However, unless Australia invests at an appropriate level in new astronomical facilities, interest in international collaborations by the UK and other advanced nations will decline. This will seriously disadvantage Australian astronomy and cut off important potential sources of technology exchange between Australia and leading industrialised countries.

Canada – With a similar population and GDP, and a traditionally resource-reliant economy, Canada has many features in common with Australia. Canada has recently embarked on a campaign to expand its astronomical facilities via international collaborations. Prioritised initiatives include membership of the ALMA project ($CA46 million) and NGST ($CA50 million). Canadian astronomers have also focussed on a strategic aim of developing their own large 25-metre optical telescope. Each of these projects has a clear focus on technological spin-offs and on sustained excellent research. The growth in facilities sits within an overall expansion of Canada's science and engineering base via $CA1.6 billion of funds for research infrastructure, $CA900 million for 2000 new research professorships, and a $CA1 billion per annum R&D tax credit.

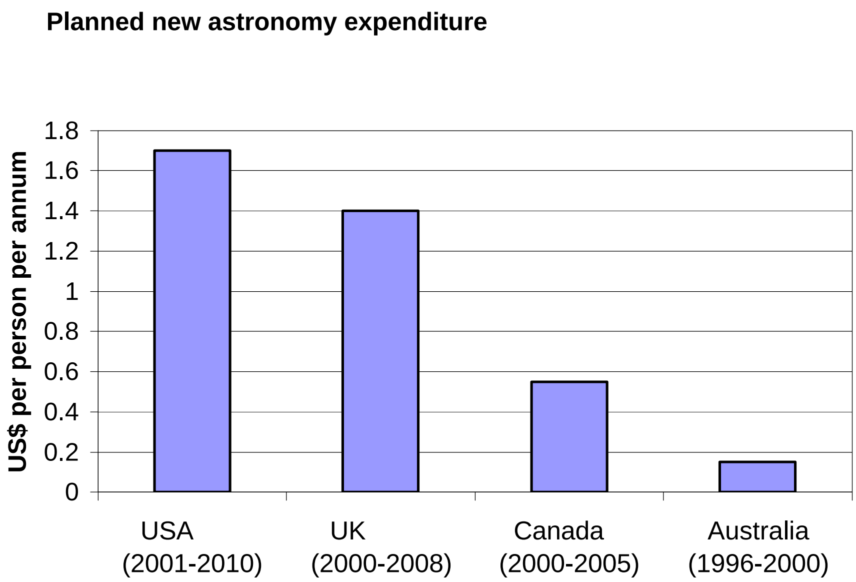
3.3 The Australian Context

Since *Australian Astronomy: Beyond 2000* was released in 1995 by the Australian Research Council (ARC) and the Australian Academy of Science (AAS), Australian astronomy has benefited from two major investments in new facilities: membership of the Gemini Partnership ($US9.6 million), and an upgrade of the Australia Telescope ($A11 million). For the nine years to 1999, the ARC also funded the Special Research Centre for Theoretical Astrophysics.

These astute investments will help to maintain one of Australia's most prestigious scientific pursuits. However, they represent an annual commitment of less than $A5 million per annum. The level of investment in new activities lies below 50 percent of the $A10 million per annum suggested by the 1989 report *The Future of Australian Astronomy* (prepared by the Australian Science and Technology Council (ASTEC)) and by *Beyond 2000*. It is less than one-third of the investment required for Australian astronomy to be funded at the annual level *per capita* adopted by leading European and North American nations.

For example, membership of Gemini provides less than 50 percent of the 8-metre telescope time envisaged by *Beyond 2000*, leaving Australian astronomers lagging well behind astronomers in Europe and North America. Australian astronomers have assigned a high priority to involvement with the SKA, at a level of $A20 million over the next five years. With this exception, no strategic investments have been considered in the next generation of facilities (such as NGST, ALMA, the 30-50-metre class of optical telescopes, or Antarctic astronomy).

The figure below compares the future astronomical expenditures of several nations with published long-term plans, in $US per person per annum, with the current Australian expenditure. Australia's current level of expenditure is half that planned in 1996-2000, and both the planned and actual level of investment is significantly less than that planned by international colleagues in the future.



There is clearly a sharp contrast between the international trends outlined in Section 3.2, and the modest rate of investment in one of Australia's most successful sciences. This review advocates expenditure corresponding to Australia's international share of world GDP (two percent) of the total international investment in astronomy, corresponding to $A16.5 million per annum when space astronomy is excluded.

4

The Way Ahead

4.1 Australia's Goals and Strategies to Achieve Them

The focus of this mid-term review is the reassessment of priorities for new programs and facilities. This takes place in the light of international developments and of Australian investment decisions over the past five years. In particular new investments in astronomy must have significant strengths in the following areas.

Potential for public interest and outreach activities - Every new astronomical facility must have the capacity, and the resources, to inspire young Australians and contribute to the development of a Science, Engineering & Technology (SET)-focussed society.

Provision of world-leading astronomical facilities - Australian astronomers at present are severely under-supplied with access to front-rank optical and infrared facilities on 8-metre telescopes. Provision of additional access to these facilities is their highest current priority.

Long-term, strategic development of astronomical facilities - As well as looking to address immediate needs, astronomers must also look to the future, and invest in the long-term health of the SET base. Leveraging the maximum astronomical, technological and industrial value from new facilities requires innovation, early involvement and significant forward planning.

Significant return to Australian industry, and significant development of new Australian technologies - New facilities that provide significant return of the invested funds and significant return of technologies must receive high priority. The easiest way to ensure this happens is to join major projects at an early stage, and select projects where return to Australian industry is built in.

Meaningful international collaboration - the scale of international astronomy is now such that Australia cannot hope to plan its future without looking to other nations. International collaboration is the life-blood of SET research.

4.2 The Way Ahead – Facilities

We therefore propose *The Way Ahead* - a coherent national investment strategy required to maintain the vibrancy of one of Australia's flagship sciences. *The Way Ahead* accepts the challenge of aligning the specific research priorities of astronomy with national priorities for the advancement of science, engineering and technology in the key areas of Culture, Ideas and Commercialisation. Among Australian sciences, astronomy is uniquely placed to achieve this alignment, in view of its enormous popular appeal and uncontroversial community support, the outstanding international impact of its research results, and its traditions of developing and exploiting cutting-edge technologies. This investment strategy will support the people and facilities required to ensure that astronomy will continue to inspire interest in science and technology, to attract gifted researchers capable of making the most significant scientific discoveries, and to energise new commercial enterprises.

The core of the strategy is to maintain Australian participation in the coming generation of Major New International Facilities. These are essential to sustaining a first-rate, internationally competitive research program encompassing Australia's two great observational strengths:

- optical/IR astronomy; and
- radio astronomy.

Underpinning the major facilities is the requirements to provide resources for the development of new technologies, and the theoretical exploitation of new research results. The second major theme of *The Way Ahead* is therefore two Multiplier Programs:

- theoretical/computational astrophysics, and
- a new astronomy technology centre.

The provision of adequate near term and long-term support for these programs provides the rationale for the agreed highest priorities of the Australian astronomical community.

The strategy also recognises that Australian astronomy has an enviable international reputation for outstanding innovation in new astronomical techniques. This reputation can be sustained only if there are adequate funds to support activities beyond the baseline program. The strategy calls for enhanced investments in the ARC's Discovery and Linkage programs and in other portfolios that support astronomy, to ensure that the very best Australian ideas continue to contribute to the advancement of knowledge and to the generation of business opportunities.

4.3 The Way Ahead - People

Astronomy is an ever more popular subject in Australian universities, and the number of students taking the subject is increasing steadily. In response, physics and astronomy departments appear to have cut the numbers of academic astronomers at a slower rate than cuts being made to other areas. Encouragingly, several universities have been able to increase their astronomy staff. The increase in demand for astronomy subjects comes from general undergraduate interest rather than growth in research degrees. Several universities are exploiting this interest as a means of providing undergraduate science programs with strong experimental and information technology elements within a sound, modern pedagogy. This trend is consistent with the needs for greater awareness of science, engineering and technology cultures identified in *The Chance to Change*.

University astronomers and their research students can undertake world-class research by accessing large-scale astronomy facilities through national and international facilities such as the Australian Telescope National Facility, the AAO and Gemini. Over the coming years, further opportunities will arise as Australian astronomers play key roles in advancing areas of research and technology where they have already demonstrated their international competitiveness. To take advantage of these enhanced opportunities, both nationally and internationally, this review strongly supports recommendations made in *The Chance to Change*, and *Innovation: Unlocking the Future*.

These include:

- expansion in the number of fixed-term postdoctoral positions;
- increases in the number of ARC Research and Professorial Fellowships; and
- improved career paths.

However the decline of almost 20 percent in the number of professional and technical staff supporting Australian astronomical research is a significant and potentially serious trend. The 50 percent decline in university-based support staff reflects a trend encountered across the science, engineering and technology disciplines. Some of the reduction in staff numbers has been balanced by increased reliance on just-in-time commercial expertise in areas such as electronic and metal fabrication, site works and maintenance, and drafting, photography and illustration. However, much of the reduction represents a real loss of support for astronomy research, and the trend should be monitored carefully. The cuts continue the trend identified in *Beyond 2000*, which showed that annual funding for the recurrent operational costs of astronomy had declined by 20 percent between 1982 and 1993. The current figures imply a decline in operational funds of an additional five percent to 2000.

4.4 The Highest Priorities – Major International Facilities

Australian astronomy aims to sustain its three great strengths: radio astronomy, optical/IR astronomy, and theoretical/computational astrophysics. The identification of these elements of Australia's astronomy program is consistent with the fact that each field occupies 25-30 percent of the national research effort in astronomy. The remaining 15 percent of effort is divided between high-energy astrophysics, space astronomy and gravitational wave astronomy. Consistent with their central importance, both radio astronomy and optical/IR astronomy are supported by national and international facilities. Theoretical/computational astrophysics has no national facility, but the discipline will be a large-scale user of the new national infrastructure being established by the Australian Partnership for Advanced Computing.

The two parts of the cosmic electromagnetic spectrum readily accessible to ground-based observatories are the optical/IR band and the radio band. Australian astronomers have outstanding international reputations for their success in exploiting both of these bands. Many of the most exciting frontiers of observational astronomy demand the further application and development of ground-based facilities operating in these bands and Australian astronomers must maintain their involvement in this research and their command of the relevant key technologies. Accordingly, this mid-term review identifies as its top priority a development program that will ensure participation in the construction of, and ongoing access to, state-of-the-art optical/IR and radio telescopes designed to satisfy the observing requirements of many users.

The importance of theoretical astrophysics to the balance of the Australian astronomy program was stressed in the 1989 ASTEC Review, *The Future of Australian Astronomy*, and in the 1995 ARC Discipline Strategy, *Australian Astronomy*: *Beyond 2000*. This mid-term review reaffirms the high priority of theoretical astrophysics, and identifies it alongside the provision of access to radio and optical/IR facilities as an essential element of the baseline Australian astronomy program.

4.4.1 Optical and Infrared Facilities

Gemini Membership

In May 1998 the ARC signed the enabling Agreement of the International Gemini Partnership, guaranteeing Australian astronomers nominally 5 percent (in practice, 4.76 percent) of the two Gemini telescopes, one located on Mauna Kea, Hawaii, and the other on Cerro Pachon, Chile. Gemini North has already begun regular observations. Gemini South achieved first light ahead of schedule in late 2000, and will start scientific observations in late 2001. Australian astronomers have established the Australian Gemini Steering Committee to advise the ARC regarding membership of Gemini, and to appoint a senior astronomer as the Australian Gemini Scientist to liaise with the international project.

By virtue of its membership of Gemini, Australia may bid to construct instrumentation for Gemini. Already, several contracts have been awarded to Australia for conceptual studies that rely on the unique expertise of Australian astronomers and instrumentation engineers. A contract for almost $US3 million has been awarded to the Australian National University for NIFS, a near-infrared imaging system that will become part of the core suite of instrumentation for Gemini North.

Adequate Access to Optical/Infrared (IR) Telescopes

Membership of Gemini provides Australian astronomers with access to 4.76 percent of two of the world's most advanced 8-metre class optical/infrared telescopes. This amount of access is insufficient to sustain the community’s position at the front rank of international astronomy, since *per capita* the astronomers of most comparable countries have access to at least twice this amount of time. For example, astronomers in Canada have 15 percent of Gemini time, while European members of the ESO have access to the *four* 8-metre telescopes of ESO's VLT. UK astronomers have access to both 25 percent of Gemini and to the four VLT telescopes. Australia must at least double its access to the new class of optical/IR telescopes to maintain its pre-eminent position in world optical/IR astronomy. There are two routes currently open to the primary goal of closing the “Gemini Gap” by increasing access to large telescopes.

Membership of the European Southern Observatory

By joining ESO, the Australian astronomical community would treble its access to 8-metre class optical/IR telescopes. ESO membership would also provide Australian astronomers with access to, and the ability to construct instruments and develop technologies for, three major next-generation facilities: the VLT Interferometer, ALMA, and the ground-breaking OWL 100-metre optical/IR telescope. Finally, ESO membership would provide Australian astronomers with access to one of the world’s leading publicity and outreach programs, ensuring the world-class work done by Australian astronomers continues to inspire young Australians. ESO membership is based on the GDP of member countries, and the cost of entry for a new partner is subject to negotiation. Nominally, Australian membership would cost capital investment of $A46 million plus an annual fee of $A6 million.

Expanded Share of the Gemini Partnership

A reappraisal of astronomical priorities in Chile has highlighted the large amount of guaranteed time available to Chilean astronomers by virtue of having telescopes sited in the Chilean Andes. Accordingly, Chile's five percent share of Gemini is available for redistribution to the partners, and Australia could acquire a share of up to an additional five percent. The Gemini telescopes were designed to provide the full advantages in terms of image quality and wavelength coverage available from 8 metre telescopes. Users have already demonstrated that these requirements will be reached, and there is no doubt that the facility will deliver the performance required for Australian astronomers to carry out their planned research programs. Membership of Gemini, particularly at a higher level than at present, offers potential Australian involvement in design studies for the next-generation optical/IR facility, MAXAT. Subject to negotiation, an additional 5 percent of Gemini would cost $US9.6 million plus an annual subscription of approximately $US1.2 million.

Of these two routes, membership of ESO is seen as the clear top priority by the Australian community.

4.4.2 Radio Astronomy Facilities

The Australia Telescope Upgrade

Australian Astronomy: Beyond 2000 assigned a high priority to upgrading the Australia Telescope. This priority was met by funding of $A11 million from the 1995 MNRF program. Three major areas were supported: (1) an upgrade of the Australia Telescope Compact Array to operate at high frequencies and to extend its Very Long Baseline Interferometry (VLBI) capabilities, (2) an expansion of, and operational support for, VLBI facilities operated by the University of Tasmania in Hobart and Ceduna, and (3) a program to enhance international collaboration by developing links between major astronomical research facilities in Australia and overseas.

The first fringes from the high-frequency upgrade of the Compact Array were detected in late 2000, and full operation at 3.5 mm will start from late 2002. Following the upgrade, the AT will be the world's most powerful high-frequency microwave telescope, providing a unique opportunity for Australian astronomers prior to the commissioning of ALMA late in the decade. These investments have helped to ensure that Australian radioastronomy can maintain its leading position, and provide a foundation for the next major radioastronomy development in the baseline program, the SKA.

The Square Kilometre Array (SKA)

The SKA will be 100 times more sensitive than any existing radio telescope and is the international radio telescope of the future. Scientific planning and technical prototyping has been underway in many institutes in the countries committed to the SKA international consortium. The SKA will be used to study the very early universe and the formation of the first stars, galaxies and quasars from the primordial hydrogen gas. It must use radical new technologies to reduce the cost of such a large facility, and to view many areas of the sky simultaneously while actively correcting for man-made interference. Australia is well-placed to contribute to the SKA since (1) Australia would provides an excellent site for the SKA stations, which need to be located over an area of thousands of kilometres with low radio interference and good infrastructure support, and (2) Australian scientists are world-leaders in major areas of the technology required by the SKA.

SKA Research and Prototyping

For Australia to play a major role in this international project, supplying technological input and possibly providing the site for the facility, funding is required over the next five years to support technology development, prototyping and site testing. The Australian contribution to the SKA development over the next five years requires an investment of $A20 million, most of which will be used to support construction of an astronomically useful prototype. The prototype will demonstrate important technologies in areas such as antenna structures and interference mitigation. Australia will need to contribute to the funding of an international project-planning facility, and to establish a national project management office to co-ordinate the activities of local researchers and industry.

Further information on all these major international facilities is provided in Appendix 2.

4.5 Multiplier Programs

Underpinning the observational advances are the requirements for a vibrant theoretical astrophysics community, and the continued development of technology base for the astronomical instrumentation program.

4.5.1 Theoretical and Computational Astrophysics

Theoretical astrophysics is concerned with the interpretation of astronomical observations, the modelling of astrophysical phenomena often using the most advanced computing facilities, and with fundamental theoretical physics of possible relevance to astrophysics.

Australia's theoretical astrophysicists, although small in number, undertake research in specific areas of astronomy that is of the highest international standard. The development of the Australian Partnership for Advanced Computing and related nodes at state and institutional level represents an important opportunity for Australian theoretical astrophysicists to engage in, and advance, several of the key enabling technologies for the new economy.

Beyond 2000 applauded the creation of the Special Research Centre for Theoretical Astrophysics at the University of Sydney in 1991 and the Astrophysical Theory Centre at the Australian National University in 1994. With ARC funding in the period 1991-1999, the Special Research Centre for Theoretical Astrophysics sustained an exceptionally productive, world-class research program including support for visitor and workshop activities throughout Australia. Unfortunately, ARC funding for the Centre was not sustained beyond 1999, and the level of activity in theoretical astrophysics that can be supported is no longer adequate to satisfy the baseline requirements of Australian astronomy.

Australian astronomers wish to see a cohesive theoretical astrophysics community, particularly in fields complementing Australian strengths in observational astronomy. The community strongly supports proposals to restore and enhance these fields either by increasing funding for a nationwide research network (National Institute for Theoretical Astrophysics), or by founding a national research centre similar to those in some other countries. Approximately $A1.4 million per annum is needed to maintain the necessary critical mass in theoretical astrophysics.

4.5.2 Australian Astronomy Technology Centre

An Australian Astronomy Technology Centre (AATC) would allow Australia to capitalise on its international reputation as a leader in innovative astronomical technologies in both radio and optical/IR astronomy. AATC would enhance existing international collaborations and allow Australia to engage in other global astronomical projects with direct technology benefits returning to Australia. With over $US4 billion global expenditure planned for astronomy projects over the next decade, AATC would be ideally placed to capitalise on Australia's existing technology expertise and play an aggressive role in bidding for instrumentation projects for the next generation of astronomical facilities.

Australia is a recognised world-leader in many key technological areas including fibre-optics, robotics, cryogenics, receivers, low-noise electronics and software control – all of which have direct applications in the astronomical facilities of the future. All of these technological areas also have strong potential commercial applications and linkage with Australian industry would be a key part of the AATC's corporate strategy. It is expected that the annual Australian investment in the AATC could be $A5 million, primarily for projects identified elsewhere in this plan. Potential models for investment in theoretical/computational astrophysics and an AATC are presented in Appendix 2. In addition, Australia has the opportunity to become involved in the development of an International Virtual Observatory as described in Appendix 2.

4.6 Strategic Projects

Australian astronomers have developed important strengths and provide leadership in a range of projects that should be supported through the normal competitive schemes (ARC, MNRF). Descriptions of these projects are listed in Appendix 2.

4.7 Funding Arrangements

The integrated capital development program recommended in *Beyond 2000* could have been funded within the $A10 million per annum envelope identified by the 1989 ASTEC report *The Future of Australian Astronomy*. However, funding was provided at less than 50 percent of this level, and the gap between Australian investment and the investments of other countries with major astronomical programs has rapidly widened. Australia's share of world GDP is approximately two percent and a reasonably proportionate investment in astronomy must be made if Australia is to maintain credibility in one of its most successful sciences.

We note that the funding required is new funding; the program outlined in this review assumes that existing facilities and programs will be funded at least at the current levels.

In the period 1995-2000, international funding for new, large astronomical facilities was $US6 billion, and this is planned to rise to $US12 billion over the period 2001-2005. If space astronomy is excluded, the investment will be $US0.5 billion per annum over the period 2001-2005. To maintain its two percent share of this investment, Australia would need to invest approximately $A16.5 million per annum in the period 2001-2005, in ground-based astronomy.

The accuracy of this estimate, and the urgency for the investment, can be illustrated by the plan to invest in Canadian astronomy at the rate of C$16 million per annum for ground-based programs, and an additional C$10 million per annum for space astronomy. Investment rates in new astronomy facilities by the UK and by the European countries of ESO are significantly higher than these amounts, on a per capita basis.

The funding schedule for participation in the International Megafacilities and the new theory program required to sustain Australian astrophysics can be achieved for a total expenditure of between $A12 million and $A20 million over the next five years. The range represents the two options that close the “Gemini Gap”, membership of ESO or a doubling of our share in Gemini.

The sources of funding for the investment program are not identified at this time, in view of the plurality of science funding arrangements in Australia. Indeed, there are possible symbiotic relationships between individual projects (such as satellite ground stations and the SKA), and there is some scope for covering part of the cost from existing institutional programs.

Appendix 1

Methodology of the Mid-Term Review

Australian astronomers have a tradition of planning the strategic development of their discipline. The lineage of this mid-term review may be traced directly to a report presented by the Australian Science and Technology Council (ASTEC) to the Prime Minister in September 1989, on *The Future of Australian Astronomy*. The Astronomical Society of Australia played a major role in the processes of that review, sponsoring a conference on future developments at the AAS, and organising the work of an *ad hoc* drafting committee. At that time it was recommended that a further review be undertaken in approximately five years to examine the progress that had been made towards fulfilling the aspirations of the astronomical community.

Accordingly, early in 1994 the National Committee for Astronomy (NCA) of the AAS proposed to the ARC that it should undertake such a review and prepare a Discipline Research Strategy. The outcome of this was the report *Australian Astronomy: Beyond 2000*, published in June 1995. The report was prepared with wide community involvement through the mechanism of Subcommittees, followed by a full-day Plenary Meeting at the University of New South Wales in December 1994, attended by over 40 Australian astronomers. At the time of launching Beyond 2000, the then Chair of the ARC, Professor Max Brennan, invited a review of progress in approximately five years. This invitation was confirmed by the current Chair of the ARC, Professor Vicki Sara.

By early 2000 it was evident that new developments in the directions of international astronomy projects required a re-consideration of Australia's priorities. An opportunity to brief the Australian community on developments in optical/IR astronomy arose in conjunction with a meeting of the Board of the International Gemini Partnership, held in Sydney in May, 2000. Held with support from the ARC's Strategic Research Initiatives program, a one-day workshop in Sydney on 15th May was attended by more than fifty astronomers and international research managers. One outcome of this workshop was a strong plea for the NCA to revisit urgently the strategies in, and outcomes of, *Beyond 2000.*

A decision to undertake a mid-term review of *Beyond 2000* was taken at the July 2000 meeting of the NCA in Hobart, following additional discussion at the parallel meeting of the ASA. At a full-day meeting of Australian astronomers held at the Australia Telescope National Facility on 8 November, a wide range of options and strategies was discussed. The following day, the NCA developed an outline of the structure and thrust of the mid-term review, and asked a small group of astronomers to prepare a draft.

This draft was circulated electronically to the community for comment, and discussion meetings were held at many of the larger astronomy nodes in Australia. Members of the NCA attended these meetings when convenient, and conveyed their assessment of community sentiment to a meeting of the NCA held on 18th December. Revisions to the draft were agreed at this meeting, and the next draft was circulated electronically to the entire community for comment in January 2001. A Plenary Meeting to discuss the review was held at the Australia Telescope National Facility on 6 February, and the final report submitted to the AAS and the ARC in March 2001.

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Appendix 2

Major New Facilities and Programs

The Square Kilometre Array

Description

The Square Kilometre Array (SKA) is a unique radio telescope planned by an international consortium. It will represent a revolutionary advance over today's radio telescopes because:

- It will have a collecting area of one square kilometre, giving it 100 times the sensitivity of the largest existing radio telescopes.
- It will be the first large radio telescope to view a large number of independent fields, with up to 100 different sources or regions of sky being observed simultaneously.
- It will integrate computing hardware and software into signal paths on a massive scale, to perform functions like active interference rejection.

The SKA's one square kilometre of collecting area will be distributed over many stations at locations up to a thousand kilometres apart. The total cost of the SKA is likely to be near $A1000 million. Australia would aim to have a 10-20 percent stake in the SKA. The International SKA Steering Committee was formed in 2000, and an international agreement on the telescope design and site is sought by 2005. Construction of the SKA is slated to begin in 2010, with scientific operations beginning in 2015. Australia needs to maintain its leading position within the consortium by funding the development of technologies, designs and prototypes. The long-term goal is for Australia to host the SKA, build a major part of the telescope, and play a leading role in the science.

Science

The SKA will be an extremely versatile instrument that will be able to make major contributions to a broad range of astronomical topics:

- **The first stars and galaxies** - The SKA will detect the very first objects formed after the Big Bang from the primordial hydrogen gas.
- **The structure of the universe** - The SKA will detect the 'cosmic web' of hydrogen and reveal the distribution of the matter in the early universe.
- **Dark matter** - The SKA will measure the amount of dark matter in the universe by observing the rotation of galaxies and the gravitational distortion of distant objects.

- **Gravitational waves** - By timing many rapid pulsars, the SKA will be able to detect gravitational waves produced by the collisions of black holes anywhere in the universe.
- **Planets around other stars** - By accurate positional measurements of nearby stars, the SKA will be able to detect Jupiter-like planets and study their orbits.

The SKA also has applications in radio science communities outside astronomy, such as Deep Space Network communications and geodesy.

Involvement

The international SKA consortium currently consists of 24 institutions in Australia, Canada, China, Europe, India and the USA. Australia's involvement could take several forms, including:

- **Science leadership** - Australian radio astronomers have already taken a leading part in defining the scientific goals for the SKA, and would expect to play a major role in the major science programs it will perform.
- **Construction of the SKA** - Australia is an acknowledged leader in many of the new technologies required for the SKA, such as high-frequency integrated circuits and the design of radio antennae and dishes.
- **Hosting the SKA** - Australia is an excellent candidate to be the host nation for the SKA. It offers a vast area with low radio interference where the many SKA base stations could be located; it has excellent support and infrastructure facilities and a strong history of successful radio astronomy projects.

Benefits

The benefits to Australia of the SKA correspond to the level of involvement:

- Participation in one of the outstanding astronomical projects of the next decade.
- The development of unique new technologies with wide commercial application.
- The economic benefits of a massive construction project if Australia hosts the SKA.

European Southern Observatory

Description

The European Southern Observatory (ESO) was created in 1962 and is supported by nine countries: Belgium, Denmark, France, Germany, Italy, the Netherlands, Portugal, Sweden and Switzerland. The UK has committed itself to joining ESO by 2002.

ESO operates at two sites. The La Silla observatory lies in the Atacama desert, 600 kilometres north of Santiago de Chile, at 2400 metres altitude, and operates fourteen optical telescopes with diameters up to 3.6-metres and a sub-millimetre radio telescope. In addition, ESO has just completed building the largest optical/IR observatory in the world, the Very Large Telescope (VLT), on Paranal, a 2600 metre mountain in the driest part of the Atacama Desert. The VLT consists of four 8.2-metre and several 1.8-metre telescopes. These telescopes can be used in combination as the giant VLT Interferometer (VLTI), which is scheduled to achieve first light in early 2001.

ESO is currently studying the requirements of the next generation of ground-based telescopes. Analysis of the future needs in observational astrophysics indicate the scientific goals of the next decade will require telescopes of 50- to 100-metre diameter. Dubbed OWL (the Overwhelmingly Large Telescope), this project is vigorously exploring possible designs and technologies for a fully-steerable telescope with milli-arcsecond resolution.

ESO will also participate in the Atacama Large Millimeter Array (ALMA). ALMA consists of sixty-four 12-metre sub-millimetre antennas located at an altitude of 5000 metres in the Atacama Desert of northern Chile. The combined collecting area of the telescopes will be 7000 square metres – roughly the size of Stadium Australia – making the array incredibly sensitive to very weak sources of cosmic radiation and one of the largest ground-based astronomy projects ever. Construction of the 64 antennas will start in 2002, with completion scheduled for 2009.

Science

ESO’s scientific aims cover the entire spectrum of astronomical research, due to its incredibly broad suite of facilities – from detecting and measuring the masses of planets around other stars with VLTI; to probing the dark hearts of star forming regions and probing the evolution of galaxies with the VLT; to detecting the very first galaxies and star formation with ALMA.

Involvement

ESO membership is based on a contribution to the capital cost of existing facilities, and an annual on-going membership fee. Both are pro-rated within the consortium in line with the member states' GDP. Australia was invited to become a member of ESO in 1994, but the invitation was not accepted at that time. The current cost to Australia of joining ESO would be $A46 million in capital investment and $A6 million for the annual subscription.

International Gemini Project

Description

The International Gemini Project aims to construct and operate two telescopes that capture the full benefits of the combination of light gathering power and superb imaging quality available with 8-metre apertures. The telescopes are optimised and sited for superior infrared performance. Their locations in Chile and Hawaii offer Gemini users access to the entire sky. Gemini North will be available for regularly scheduled observing from Semester 1, 2001, and Gemini South will be available with limited instrumentation from late 2001. The Gemini project has established an ambitious instrumentation development program, including the investigation of laser guide-star systems perhaps leading to wide-field diffraction limited imaging based on the technique of multi-conjugate adaptive optics and feasibility studies for the next-generation large aperture optical/IR telescope.

The capital cost of the Gemini project is $US294 million, and the telescopes will be finished on budget and several months ahead of the planned completion date. Australia's contribution to the capital cost was $US9.6 million. The annual operational cost of the Gemini facilities is approximately $US24 million, and Australia's contribution approximately $US1.2 million per annum.

Science

Gemini telescopes are designed to be versatile and to satisfy the wide range of requirements appropriate for cost-effective, common-user facilities. The key research programs for which Gemini was designed include investigations of circum-stellar disks and planetary systems, star formation, stellar structure, the formation of the elements, and the formation and evolution of galaxies. These science areas led to an instrumentation specification that included image quality better than 0.1 arcsec, wavelength coverage from 0.3 to at least 30 microns, low emissivity, a wide field, and flexibility of operational mode to exploit optimally the atmospheric conditions.

These specifications have been met by ensuring that the two telescopes are similar in many respects, allowing efficient operations, that provision has been made for future upgrades over a planned lifetime of 50 years, and that both telescopes are equipped with advanced active imaging capabilities.

Involvement

Gemini is a partnership between the USA (50 percent), UK (25 percent), Canada (15 percent), Chile (5 percent), Australia (5 percent), Argentina (2.5 percent) and Brazil (2.5 percent). Australia is given a pro-rata share of the observing time, which is allocated by competitive peer review by the Australian Time Assignment Committee. Australian institutions are also entitled to bid for Gemini instrumentation projects, and recently the Australian National University has been allocated a $US3 million contract to construct the Near InfraRed Imaging System.

An additional 5 percent share of Gemini is available for purchase by Australia following a reassessment by Chile of the scale of its need for access to large optical telescopes. The share will cost approximately $US9.6 million for the capital contribution, and an operations payment of $US1.2 million per annum.

Benefits

The 1995 report “*Australian Astronomy: Beyond 2000*” identified membership of the ESO and consequent access to the ESO Very Large Telescope as the top priority for the development of Australian astronomy. While funding for ESO membership was not available, membership of the Gemini partnership provides Australian astronomers with facilities comparable to, and even superior in some respects to, the VLT. However, the available Australian time on 8-metre class telescopes is only 50 percent of the time that would have been available through ESO membership (and therefore 50 percent of the time available per capita to European astronomers), and only one-third of the time available to Canadian astronomers through Gemini membership. There is thus a significant gap in the level of support for front-line Australian astronomy that can be closed by taking up the additional 5 percent share in Gemini.

The National Institute for Theoretical Astrophysics

Description

The National Institute for Theoretical Astrophysics (NITA) will develop and promote theoretical astrophysics within Australia; it will address the outstanding issues in contemporary astrophysical research, and will foster discussion in the astrophysics community designed to define the issues of the future. NITA will provide new facilities for theoretical astrophysics, in the form of a distributed network which develops existing strengths in university-based research groups, and possibly, through a new physical centre. It will provide a significant and sustained expansion of the level of effort in this discipline, ensuring that the scope of theoretical investigations matches that of Australia's strong observational program. NITA will work to develop an improved national career structure for theoreticians, develop an integrated national undergraduate and graduate teaching program in astrophysics, undertake work to enhance the science return of current and future observational projects, and pioneer the development of new concepts and techniques which change our understanding of the Universe. Key initiatives designed to further these objectives will be the provision of new-blood fellowships, the initiation of a vibrant visitor program, the sponsorship of a national series of workshops and conferences in key subject areas, and the provision of student fellowships on a national scale. NITA will also undertake a cooperative educational initiative through video-conferencing of undergraduate and post-graduate courses between the participating organisations.

Science

NITA will work to sustain a world-class theoretical program in Australia across a broad spectrum of astrophysical research. It will provide theoretical support for the major Australian observational projects, and foster a strong body of independent theoretical work. Key science goals would initially include:

- Developing multi-dimensional PPM, SPH, and new adaptive mesh composite hydro-codes.
- Developing models for active galaxies, jets, high-energy and space plasma phenomena.
- Undertaking theoretical research in cosmology and the development of large-scale structure.
- Generating a theoretical understanding of the epoch of galaxy formation.
- Building dynamical models for stars in galaxies, in order to understand the history of star-formation and galaxy mergers and the nature and distribution of dark matter in galaxies.
- Developing improved evolutionary models of stars with the aim of providing improved estimates of chemical yields, mass-loss rates, and colour evolution.

Involvement

NITA will consolidate existing effort in theoretical astrophysics within Australia, linking the geographically dispersed university research groups in a coordinated network, with the goal of the creation of a new physical centre for research activity. A distributed virtual centre would require up to $1.4 million per annum. The creation of a new research hub demands an additional capital investment of $3 million and $1.5 million in annual operating costs.

Benefits

NITA will provide the vital theoretical dimension for Australian astronomy, ensuring that the country capitalises on its investments in observational facilities. It will develop high-level expertise in analytic and computational methods, and will provide training in these techniques. There is a clear need for a better career structure for theorists within Australia, to retain their skills within the community. NITA will address this problem area by supporting individuals at all stages of development, providing studentships, post-doctoral fellowships, long-term positions and tenure-track University fellowships.

NITA will also link the existing university research groups, facilitating communication and collaboration amongst Australian theorists, and their international colleagues, via a strong visitors program coupled with a vigorous schedule of topical workshops. NITA will promote understanding and interest in astrophysics by educational and public outreach.

Australian Astronomy Technology Centre

Description

Australia is an internationally recognised leader in innovative astronomical technology (for example, The Australia Telescope, 2-degree field). An Australian Astronomy Technology Centre (AATC) would allow Australia to capitalise on its position; enhancing existing international collaborations and allowing Australia to engage in other global astronomical projects with direct technology benefits returning to Australia.

Many of Australia's international partners have foreseen the need for such a facility. Established in 1997, the Astronomy Technology Centre in the UK has already allowed that country to position itself strongly with respect to technology developments in the current generation of front-rank world facilities (for example, Gemini) and future global projects (ALMA, NGST, very large optical/IR telescopes). Investment in the UK Astronomy Technology Centre corresponds to approximately $A25 million per annum. Scaled to planned astronomy expenditure (see Table in Executive Summary), this implies an investment level of $A5 million per annum in an AATC if Australia is to maintain technological parity with its international partners.

The core functions of the AATC would be to:

- maintain and develop key technological expertise to enable Australian participation in future astronomical projects through the provision of leading-edge instrumentation;
- provide a focus for Australian instrumentation activity through the stimulation/facilitation of programs in Australian universities and national facilities;
- maximise linkages with Australian industry and seek to exploit commercial aspects of technology developments; and
- promote Australian innovation to a wide international audience.

The goals seek to maximise the user base of the AATC, while maintaining a focussed role in the provision of front-rank instrumentation for astronomical programs of high priority to the Australian astronomical community. The opportunities mapped out by the strategic document "*Partnership in Innovation: the AAO of the Future*" could provide for up to $A1.5 million per annum for AATC-like activities at the AAO beyond 2005. Additional matching funding should be seen as the minimum requirement to maintain a viable technology base in Australia.

With over $US4 billion global expenditure planned for astronomy projects over the next decade, an AATC would be ideally placed to capitalise on Australia's existing technology intellectual property and play an aggressive role in bidding for instrumentation projects for the next generation of astronomical facilities. With global expenditure at these levels, demand is likely to exceed supply and so investment in an AATC will undoubtedly reap rewards.

Science

Astronomy is still very much an observationally-led science. As such, major scientific advances come from the opening up of new areas of observational parameter space. Leading-edge instrumentation provides means by which to do this. Through involvement in instrumentation, Australian astronomers will form the scientific vanguard in the exploitation of the global facilities of the future.

Involvement

The AATC would, in principle, allow Australia to engage in all major international astronomical programs planned over the next two decades. Australia is a recognised world-leader in a wide variety of key technological areas including fibre-optics, robotics, cryogenics, receivers, low-noise electronics and software control; all of which have direct applications in the astronomical facilities of the future. All of these technological areas also have strong potential commercial applications and linkage with Australian industry would be a key part of the AATC's corporate strategy.

Australian Large Telescope

Description

The Australian Large Telescope (ALT) is a proposed collaboration between the Australian astronomical community and Electro-Optic Systems (EOS) of Queanbeyan. EOS builds small-to-medium telescopes for observatories worldwide; ALT represents an aggressive expansion into the large-telescope market. ALT will be a 6.5-metre telescope with a particularly large field of view (1.2 degrees). It will specialise in wide-field spectroscopy, exploiting Australia's international leadership in this field. Compared to similar facilities being built or planned, ALT will offer a field of view larger by more than a factor of four, and will be able to simultaneously observe more than twice the number of targets. The total estimated cost of the telescope and instrumentation is $80 million. With funding from 2001, ALT could be in operation by 2005.

Science

The ALT will offer the most advanced wide-field spectroscopy facility in the world, and will have a wide range of applications. Particular science goals will include:

- Mapping the distribution of galaxies at high redshift in order to understand the formation of large-scale structure in the universe.
- Mapping the dynamics of stars in the Galaxy, in order to understand the history of star-formation and galaxy mergers that formed the Milky Way.
- Spectroscopy to match the deep and wide imaging surveys like the Sloan Digital Sky Survey and the VISTA deep surveys.

ALT is highly complementary to Gemini. Gemini specialises in high-resolution imaging and spectroscopy of small numbers of objects over a small field, whereas ALT allows spectroscopy over a much larger field for much larger numbers of objects.

Involvement

The ALT would be a uniquely Australian telescope in design, construction and instrumentation. Australia could build ALT on its own or could find international partners to share the cost. One natural partnership is with Gemini, both because of Australia's existing membership of Gemini and because of the complementarity between the Gemini telescopes and ALT. The present plan envisages an equal partnership with the Gemini Consortium. By placing ALT at the Gemini observatory in Chile, we would have access to one of the outstanding astronomical sites. By contracting-out the running of ALT to Gemini, large savings on operating costs can be made.

A possible model for this arrangement is given in the table below, where the value of the partners' contributions are computed over the first 7 years of telescope operations.

Partner	***Contribution***	***Value ($m)***	***Share of time (%)***
Australia	50% capital cost of telescope and instrumentation	40	40
Electro-Optic Systems	Design of telescope and maintenance costs	10	10
Chile	Site at Cerro Pachon (for 7 years)	10	10
Gemini partners	50% capital cost of telescope and instrumentation	40	40

Benefits

ALT would be designed and built by EOS, an Australian company. It would provide the Australian astronomy community with a home-grown facility that would be in the front rank internationally. It would provide EOS with a flagship project that would enable it to break into the large telescope market. It could also leverage additional large-telescope time from Gemini, subject to negotiations.

Douglas Mawson Telescope

Description

The Douglas Mawson Telescope (DMT) is a proposed 2-metre class infrared/sub-millimetre telescope for the Antarctic high plateau, to be sited at either the South Pole or Dome C. Exploiting the cold, dry conditions, the facility will be the most sensitive available for wide-field, thermal infrared imaging. It will be used to explore our origins, studying the early stages of the formation of galaxies, stars and planets. The DMT will provide complementary functionality to existing 8-metre telescopes, as well as to future space facilities, which are focussed on deep, narrow-field imaging. Site testing at the South Pole (altitude 2900 metres) has shown that, compared to good temperate-latitude sites, the infrared sky background is 20–100 times lower, the water vapour in the air is five times lower, and field over which sharp images can be obtained is 30 times larger. At Dome C (3200 metres), one of the summits of the Antarctic plateau, conditions are expected to be even better. The best potential sites all lie within the Australian Antarctic Territory. The Australian Antarctic Division is now planning aircraft links to Antarctica, providing Australian scientists with access to the plateau.

Science

Three focus areas present themselves for 2-metre class Antarctic telescopes:

- **Wide-field, thermal infrared imaging** - For this, an Antarctic 2-metre telescope is as sensitive as a temperate-latitude 8-metre telescope, but in addition has a far wider field of view and simpler requirements for instrument design.
- **Continuous observation near-infrared wavelengths** - At 2 microns the background is lowest, 100 times less than at temperate-latitude sites, and interstellar dust extinction low, allowing one to see through to the centre of the Galaxy.
- **Mid–infrared interferometric imaging**, exploiting both the lower sky background and improved sky stability over temperate-latitude sites.

Illustrative science programs that could exploit such advantages include:

(a) near–infrared and thermal-infrared imaging of embedded star-forming regions, identifying the youngest proto-stars and the proto-planetary disks around them;

(b) near–infrared surveys for proto-galaxies and early stages of star formation in galaxies;

(c) micro-lensing studies towards the Galactic centre to identify planetary systems; and

(d) mid–infrared interferometric imaging of nearby star systems to search for proto-planetary disks, zodiacal dust clouds and Jovian-size planets around them.

Linkages

The DMT offers Australia access to unique scientific programs for modest cost. The site-testing program in Antarctica has been conducted in collaboration with the USA, who are now undertaking a $US100 million upgrade of the South Pole station. The French/Italian station at Dome C, being built at a cost of approximately $A100 million, is being nominated as a European Large Scale Facility, with Australia as a partner country, opening the way for significant European Community funding.

The wide-field DMT will be a powerful complement to the narrow fields of view of 8-metre telescopes at temperate latitudes and future space facilities such as NGST. In another decade, astronomy may be focussing on the space interferometers needed to find Earth-like planets around other stars and an Antarctic Infrared Interferometer would provide a pilot for developing the necessary technology.

Partner	*Contribution*	*Value*
Australia	Capital Cost of telescope and instrumentation	$10m
France/Italy and/or USA	Infrastructure	$10m

Benefits

Through exploiting our natural Antarctic advantage, Australia will be able to participate in leading-edge science while remaining a significant partner in a major project, all at a cost consistent with our historical expenditure on basic research.

For further information see:
http://www.phys.unsw.edu.au/~mgb/Antbib/antbib.html.

Next Generation Space Telescope

Description

The Next Generation Space Telescope (NGST), as the name suggests, is the second major optical/IR space telescope planned by NASA, and is scheduled for launch in 2009. The telescope is designed to operate primarily in the infrared band (0.6-20 microns) with a planned lifetime of 5-10 years. NGST will have a 6-metre mirror, and will orbit the Sun (not the Earth) in a location using the Earth as a shield from the solar radiation.

Science

The infrared sky background for NGST observations will be between a factor of 300 and one million times lower than for existing ground-based telescopes. This will enable astronomers to map the universe at much fainter levels – and therefore much greater distances – than has been possible previously. In addition, the technical specification for the telescope is more stringent than for any previous satellite. The primary scientific goals are studies of the first stars and galaxies in the early universe and of planets around nearby stars. These programs are fundamental to our understanding of the formation and evolution of the universe and the origin of planetary systems.

Involvement

The NGST project is led by the United States under the auspices of NASA. It has been ranked as the highest priority for US astronomy and astrophysics for the first decade of the new century. However the project is an international collaboration: in addition to European and Canadian participation, other major astronomical countries are negotiating partnerships in the project. There is an opportunity for Australia to negotiate a partnership in the program, with the expected basic entry level of $US50 million.

Partner	***Contribution***	***Value***
NASA	Capital cost of telescope and instrumentation	$US1000m
Canadian Space Agency	Deep Space Network, instruments, data-archiving, space sub-systems	$US50m (5%)
European Space Agency	Instruments; space sub-systems	$US200m (15%)
Australia	Deep Space Network; instruments; software development	$US50m (5%)

Benefits

Partnership in the NGST project would provide Australia with a high-profile slice of the most sophisticated space program currently planned. Australia's role would include participation in a new Deep Space Tracking Network, development of new instruments, and software and database development. Early membership of the project would permit negotiations to ensure that most of the Australian contribution was spent on-shore.

DSN Far East Array

Description

NASA is considering options for the next generation Deep Space Network (DSN) communications antennas. An innovative proposal by Sandy Weinreb of JPL is to build an array with 4000 5-meter diameter antennas which are combined as a phased array for spacecraft tracking. New technology based on the Allen Telescope Array have now made this approach feasible with the required operational performance achieved at a much lower cost than using a conventional single aperture telescope.

The proposal envisages three stages: a design phase, a prototype with sensitivity comparable to the present Tidbinbilla 70 metre DSN antenna and a full system with 10 times more sensitivity. One station will be built with a Far East longitude to provide continuous sky coverage with antennas in the United States and Europe. Australia becomes an obvious site. The frequencies needed for spacecraft tracking are 8, 32, and 40 GHz.

Schedule and Cost

Phase	***Schedule***	***Activity***	***Cost***
Phase 1	2000-2002	Evaluate 2 antennas	$US2.5 million
Phase 2	2002-2004	200 x 5m antennas – equivalent to current 70m antenna	$US25 million
Phase 3	2004-2010	Full system equivalent to 10x the current 70m antenna	$US300 million

The proposal is a technology stepping-stone for realisation of the SKA, and could in fact be the high frequency implementation of the SKA.

Science

Of course the main science drivers are the NASA deep space missions which make ever-increasing demands on communications technology. The array can meet these demands in a flexible manner since it can form multiple beams, for example, to simultaneously track all the spacecraft orbiting Mars. It can also be partitioned for multiple missions when the full sensitivity is not required.

The large collecting area, array design and range of frequencies covered make this a very exciting astronomical instrument. Even with minor modification the phased array output needed for spacecraft tracking could be used like a single dish for pulsar or Very Long Baseline Interferometry (VLBI) experiments. If a backend astronomical correlator were built it could tackle any of the high frequency imaging experiments considered for the SKA. For example, at 30GHz with 10 times the collecting area of a 70 metre dish it would be far more powerful than any other telescope for Cosmic Microwave Background (CMB) and Sunyaev-Zeldovich (S-Z) observations. Its sensitivity would far exceed ALMA at 7mm. It would see any CO at redshifts of more than 2 and could do all the stellar astronomy proposed for the SKA. If the array is split into patches spread over a large area it becomes a VLBI array in its own right.

Involvement

The location, technology and scientific applications for such an array provides interesting opportunities for an Australian involvement and location. Australian involvement is particularly interesting because we have much of the required technology in the country and are doing some of the required developments as part of the SKA project. NASA has indicated that they have a problem with the short timescale on which they need to develop the new technology. By providing access to the Parkes radio telescope we may be able to provide interim tracking relief.

Possible Australian Participation could include the following: fund and build Phase 2 in Australia as a trade with NASA for NGST membership; fund a radio astronomy backend as part of the SKA prototype in return for access to the telescope for astronomy. This would involve building a Correlator and a VLBI system.

Benefits

The concept is well matched to Australia's capability, provides a path to membership in other NASA activities, such as NGST, and is a step to realise the high frequency SKA.

Next Generation Australian VLBI System.

Description

The Next Generation Global VLBI System is being designed to take advantage of the most recent advances in digital technology, to provide a 60 fold increase in recordable bandwidth from the current 0.128 GHz to 8 GHz, similar to that envisaged for future upgrades of the Australia Telescope Compact Array. Future requirements for both ground and space-based VLBI programs will call for such systems to be available in Australia before the end of the decade, primarily in support of the space missions VSOP-2 (Japan) and ARISE (USA). The VSOP-2 mission is under active development by the Institute of Space and Astronautical Science (ISAS) and is aiming for a 2007-08 launch. ARISE is included in the current US Decadal Plan and under active study at the National Radio Astronomy Observatory (NRAO) and NASA. Moreover, the addition of 3 new antennas to the existing Australian array would produce an instrument equivalent to Northern Hemisphere arrays like the European VLBI Network or the Very Long Baseline Array, but with exclusive access to the Southern Hemisphere sky and the unique objects it contains. These new antennas should be equipped with high frequency receivers to complement existing and planned facilities in Australia and the Asia-Pacific region, as well as the aforementioned space missions. Construction of the SKA in Australia would open the capability of a further ten-fold increase in sensitivity.

Science

In the foreseeable future, VLBI will provide the only instrumental technique capable of providing sub-milliarcsecond and microarcsecond angular resolution images. Such imaging is essential to investigate the extreme physical conditions in regions surrounding the super-massive black holes at the centres of distant active galactic nuclei (AGN). The same processes that power AGN also power, albeit on a much smaller scale, the micro-quasars being found in increasing numbers at X-ray and Gamma-ray wavelengths in our own Galaxy.

High precision polarization VLBI further allows a determination of the magnetic field structure and its evolution, and an understanding of the "jet" processes so prevalent in astrophysics. High precision astrometry and intercontinental geodesy also require high resolution and sensitivity VLBI observations.

Involvement

Ground-based VLBI technical developments world-wide are aiming for improved capability through recent advances in wide bandwidth digital electronics, as well as through the addition of new radio telescopes to existing facilities. Australia is well placed to participate in this development, and reap the associated commercial advantages. Further, by its nature VLBI is a global activity, requiring cooperation and coordination between multiple organisations in many different countries, including NASA and the Japanese Institute of Space and Astronautical Science. Australia is especially important to the development of an Asia-Pacific VLBI capability. Also, if Australia is chosen as the site for the SKA, then the upgraded VLBI array would complement it, providing unparalleled sensitivity and image quality.

Benefits

The benefits to Australia include participation in two major space missions, the development of unique wide-band technology with considerable digital applications, and the scientific and cultural benefits of advancing our understanding of fundamental processes ranging from those deep within the active Earth to those in the farthest regions of the Universe. VLBI telescopes are greater than the sum of their parts. In return for a modest investment in Australian facilities, Australian astronomers would receive the scientific benefits obtainable from a global set of resources, along with associated technology transfer. It is worth noting that, by their nature, any new Australian facilities would be located in rural and regional areas, bringing significant cultural and economic benefits.

The Australian Virtual Observatory

Description

The Australian Virtual Observatory will be an integral component of the International Virtual Observatory, which will link the archives of all the world's major observatories into one distributed database, with powerful tools to optimise the extraction of science from the data. As a result, data from all the world's major observatories will be available to all users, and to the public. A user can simply request some data or an image of some particular part of the sky, and the International Virtual Observatory will provide the result to the user. If the data does not yet exist, the Observatory may tell the user how to obtain it, or might in some cases direct a robotic telescope to obtain the data.

The Australian contribution will be in four distinct areas:

- Providing Australian data to the rest of the world, to enable the best science to be done with, and highest international visibility to be achieved by, our existing cutting-edge facilities.
- Providing Australian researchers with a data grid to optimise access to data from overseas, facilitate data mining, enable the extraction of science from disparate data sets, and compare data with theoretical models.
- Developing software, techniques, standards, formats required for the establishment of the International Virtual Observatory.
- Upgrading Australian instrumentation where necessary to provide top-quality data necessary for the International Virtual Observatory.

Science

The concept of a Virtual Observatory is based on the fact that scientific discoveries are generated as much by use of archive data as by use of “live” observations. For example, data from the HST typically gets used four times: once by the original investigator and three times more by other astronomers accessing the HST archive. To extend this grand concept to all major observatories requires a great deal of IT development. There is support in the United States and Europe to develop this concept, funded at a level of tens of millions of dollars. Australia has some of the world’s major observatories and key expertise required to develop the International Virtual Observatory. Both Australian science and the Australian information technology industry stand to gain from Australian involvement in the International Virtual Observatory.

Involvement

We propose to set up an Australian component of the International Virtual Observatory which we call the “Australian Virtual Observatory”, which will work closely with its counterparts in the United States, Europe, and elsewhere. In collaboration with our overseas partners, we will aim to:

- Establish data standards, formats, compression techniques and protocols for transparent access of data across the International Virtual Observatory.
- Develop software for pipeline processing of data from telescopes (at all wavelengths), including on-line editing and calibration. This software will be used both by observers and by archive users, with the result that raw data can be stored rather than processed data, and the most recent algorithms and calibration solutions can always be applied.

- Set up a national distributed database with adequate computing power as the prime server of leading-edge Australian data (for example, HIPASS, 2dFGRS, 2QZ, etc.) to the world.
- Provide computing power and modelling facilities to the theoretical community, so that their models can also become an integral part of the Australian Virtual Observatory.
- Extend the capabilities for visualisation and cross-comparison (including modelling) of different datasets.

Benefits

- Basic science as a leading-edge customer.
- Cross-fertilisation with other disciplines (for example, bioinformatics and crystallography).
- Strengthen position of Australian astronomy on world stage.

World Space Observatory/Ultraviolet

Description

The World Space Observatory/Ultraviolet (WSO/UV) telescope is conceived as the United Nations/European Space Agency initiative, and the participation of many nations will be required. A potential Australian contribution to the project might be the provision of a ground station requiring a dish of the 15-metre category. The WSO/UV telescope is an f-10 1.7-metre instrument designed for imaging, low resolution and high-resolution spectroscopy in the solar blind UV region between 110 and 350 nm. For imaging purposes the field will be one arcminute and the spatial resolution will be 0.12 arc seconds. The spectrometer will consist of a vacuum UV échelle spectrograph with a resolution of 60,000 operating at 110-189 nm, and a second UV échelle spectrograph operating in the 178 to 350 nm range and delivering a resolution of 48000. The effective area of the spectrographs is between 300 and 500 square centimetres, and the limiting magnitude in a one hour observation is approximately 16 at high-resolution and 20 at low resolution.

The telescope already exists in the Soviet Union. Argentina has agreed to supply a second ground station, and the Chinese are interested in launching the facility on a Long March rocket. The European Space Agency will support the project provided that sufficient overseas interest has been gathered. The capabilities of WSO/UV have been chosen to be such that it will not duplicate any capability available from the ground nor in space. The life span of the facility is up to ten years.

Science

The WSO/UV facility will be the only space UV facility operating in the latter half of this decade. The facility will be complementary to our ground-based facilities, and contribute to our understanding in the following areas:

Stellar Science - The photospheric, chromospheric and coronal domains of a star can be studied, but also high frequency phenomena that will give information on the interiors of stars can be studied very effectively. The rapidly changing shock phenomena in Young Stellar Objects and the physical mechanisms driving jets in such objects are extremely exciting areas of application of the WSO/UV.

Star Formation in Galaxies - WSO/UV will provide images that can be directly compared with those obtained in, for example the Hubble Deep Field. The ultraviolet emission has been shown to accurately measure the distribution and rate of star formation in galaxies, a vital part of galaxy evolution.

Chemical Evolution of Galaxies and the Cycling of Interstellar Matter - WSO/UV has the capability to study such phenomena systematically over the full range from zero redshift to high redshifts.

The Universe – In this area the very fundamental question of the re-Ionisation phase is well within the capabilities of the WSO/UV. The general problem to establish the nature, location and time of the Galaxy formation can be addressed in a highly meaningful way. Of course also the study of the Inter-Galactic Matter and its relation to Clusters of Galaxies and other sources of ionisation will present a superb challenge for the capabilities of the WSO/UV.

Unpredictable Phenomena - The nature of astrophysics is that many breakthroughs in the field are the consequence of unforeseen or unpredicted occurrences. We mention here discoveries of comets and their behaviour during their passage near the sun, novae, supernovae, gamma-ray bursters, optically violent variables (OVVs) and others. All these objects can be profitably studied with WSO/UV thanks to its rapid response capability.

Benefits

The WSO/UV telescope offers Australians observational access to the vacuum-ultraviolet in an extremely cost-effective way. The costs could be simply the setting up and operating of a ground station, which could be sited at any suitable institution. It represents a highly affordable route to space and it provides unique science returns to the Australian community.

High Energy Astrophysics

Overview

There are two main areas of High Energy Astrophysics. The branch of astronomy known as *Cosmic Ray Physics* represents the first contact of Science with energetic particles on a cosmic scale. It is mainly concerned with highly energetic charged particles from space, which are directly detected by instruments on Earth or by nearby satellites. More recently (in the last thirty years or so) astronomers have also detected highly energetic photons, in the form of X-rays and gamma-rays. For the most part, this area of high energy astrophysics involves observatories in space, for example, the recently launched Chandra X-ray observatory and the gamma-ray satellite, GLAST which is under construction. However, detection of the highest energy gamma-rays has recently taken an interesting turn. These can be detected by ground-based observatories through the flashes of blue light they produce when interacting with particles in the Earth's upper atmosphere.

Cosmic-Ray Research

Australia has a long tradition in cosmic ray studies. The field is currently strongest at the University of Tasmania and the Australian Antarctic Division where low energy cosmic rays enable studies of the heliosphere and its environs, and at the University of Adelaide where studies concentrate on the highest energy cosmic rays. A very important facility is operated at the Mawson base in Antarctica which is uniquely accessible to low energy particles through the Earth's magnetic field. Tasmania is at a southern magnetic location which is complementary to northern Japanese locations and a great deal of Australian/Japanese collaboration results from that coincidence. High energy cosmic ray studies at the University of Adelaide are now based on collaborations in the USA (the High Resolution Fly's Eye, HiRes) and in Argentina (the Pierre Auger Project). Both of these projects are fully funded with international support. HiRes is operational and is now producing important data. Auger is just beginning construction that will take several years. The latter is a huge international project ranking with the largest projects current in international astronomy.

X-ray and Gamma-Ray Astronomy

Traditionally Australia's involvement in these fields at the instrumental level has not been extensive due to expense of space. Nevertheless, the high quality of our optical and radio facilities and the high international standing of Australian astronomy, has meant that access to international space facilities either independently, or through collaborative arrangements has been feasible and productive.

The advent of the Imaging Atmospheric Cerenkov Technique (IACT) for detecting gamma-rays has meant that appropriately constructed ground based observatories can play an important role in the study of gamma-ray sources. High energy gamma-rays are detected by the flashes of blue Cerenkov light that they produce when they enter the Earth's upper atmosphere. Such an observatory is being constructed near Woomera, South Australia, through the CANGAROO project (Collaboration between Australia and Nippon for a Gamma-Ray Observatory in the Outback). This joint Japanese-Australian project is led by the Institute for Cosmic Ray Research (ICRR) at the University of Tokyo, involves several Japanese universities and the University of Adelaide and the Australian National University. This four-telescope array is scheduled for completion in 2003 and will be important in gamma-ray astrophysics in the energy range of approximately 100 GeV to 20 TeV. Most of the approximately $A15 million expenditure on this project has been committed by the Japanese government through a grant to ICRR. However, it is important that Australia provides the necessary infrastructure (power, telescope pedestals etc.) for the project to be brought to a successful outcome. The protection of the dark sky environment in the vicinity of the array is also fundamentally important.

Summary

It is essential that Australia maintains and develops its core of expertise in high energy astrophysics. This field is becoming a key area in international astrophysics, it introduces a new perspective into the study of important astronomical phenomena, and its organisational techniques bring new ideas to astronomy from a broad range of other scientific areas.

Gravitational Wave Astronomy

Description

The worldwide program of gravitational wave astronomy aims by 2010 to have detectors working at the sensitivity required to guarantee detection of a known class of source at a reasonable rate, based on minimum conservative estimates. In the next years a first generation of laser interferometers will operate at a sensitivity where prospects of detection are modest but not certain. For the same reason that VLBI benefits from geographical coverage and the number of detectors, there is a need for a southern hemisphere detector to obtain maximal north/south baselines and to improve noise rejection from the global telescope comprised of a world wide array of detectors.

Involvement

The Australian Consortium for Interferometric Gravitational Astronomy (ACIGA), comprising the Australian National University, the University of Western Australia, the University of Adelaide and Monash University, leads Australian research in gravitational wave detection. The consortium has built a test facility at the Gingin Site provided by the Western Australian Government for the proposed Australian International Gravitational Observatory. The test facility consists of a system with an 80-metre arm, currently funded for a research program to test advanced interferometer technology, particularly very high optical power interferometry using sapphire optics. The work is taking place in collaboration with the US Laser Interferometry Gravitational Observatory (LIGO) project aimed directly at developing the technology for the LIGO 2 upgrade proposed for 2007. The test facility will also demonstrate the technology for a southern hemisphere detector and evaluate the suitability of the Gingin site. The current program has been funded by the ARC, ACIGA universities, and the US LIGO project to a total of $A2.4 million ($750,000 from LIGO) for the next 2-3 years.

The facility requires funding of a minimum of $A1 million per annum to maintain adequate progress, and requires a long term funding commitment to obtain maximum benefit from the research. The demand for a Southern Hemisphere Detector will become greater as the northern hemisphere detectors are developed. Currently a working group under the auspices of the Gravitational Wave International Committee is completing a scientific evaluation of the need for a southern hemisphere detector. ACIGA is participating closely in various international working groups: in particular the LIGO Scientific Collaboration, and the Japanese Large-Scale Cryogenic Gravitational Wave Telescope (LCGT) Collaboration, on various technical topics including site selection for the Asia-Pacific region.

It is expected that the future Australian long baseline detector will be an international collaborative project requiring an Australian contribution of approximately $A30 million.