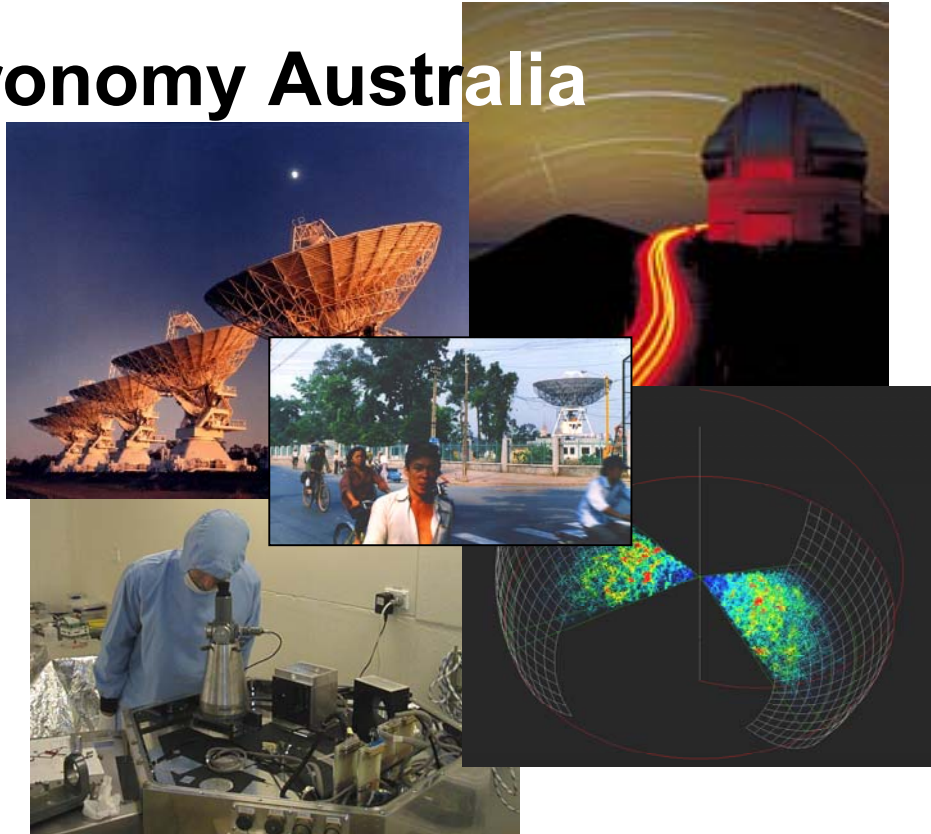


PRIME MINISTER'S SCIENCE, ENGINEERING AND
INNOVATION COUNCIL

TWELFTH MEETING – 17 June 2004

AGENDA ITEM 4

Astronomy Australia



EXECUTIVE SUMMARY

Increasingly, Australian astronomy is generating an industry, whose world-class capabilities, impact and opportunities are amongst the best of Australia's international success stories. **Astronomy Australia** is already a community and industry in which investment pays significant dividends, and has the prospect of stimulating significant growth through attracting major international projects to our shores.

1) Premier Australian Discoveries

Astronomy has guided and excited mankind through the ages, from the prediction of seasons and harvests, to an understanding of our origin and our ultimate fate. Over many years Australia has gained excellent facilities and researchers. In the last decade or so alone, Australian astronomy has achieved many discoveries of worldwide significance and impact.

2) The Cosmic Symphony

Astronomers collect and analyse signals emitted by the cosmos at different frequencies to study the Universe. Different frequencies contain different kinds of information, and require a range of different technologies and telescopes. This diversity makes astronomy a rich, cross-disciplinary field with technological and industrial applications that are equally rich and diverse.

3) Investment in Facilities

Local investment in facilities seeds the development of world-leading Australian businesses, allows for on-shore research training and provides opportunities for tourism and local employment. Sometimes, for the best results Australia's astronomy investments are in shared overseas facilities, but these too involve contracts back to Australian enterprises, to produce and export high value instruments.

4) Academic Excellence

International citation of Australian researchers is highest in astronomy. Per dollar invested, Australia is more than twice as effective in producing the highest impact papers, as the USA or any European country. This helps develop Australia's reputation as an advanced and knowledgeable society, providing the credibility to influence world events, attracting investment to our shores and retaining some of our most talented professionals. Importantly, Australian tertiary astronomy has an excellent track record in training the very best next-generation scientists, engineers, and technical managers.

5) National Public Interest and Education

Strong public support is evident in every new venture in astronomy and space exploration, with strong visitor centre attendance and wide media coverage. Astronomy is recognised in many countries as providing one of the most effective opportunities for inspiring youth to study physics, chemistry and maths – valuable preparation for citizens of an increasingly technical society, and essential for careers in science and engineering. Without an adequate supply of these home grown professionals, Australia is at risk of becoming a technology debtor nation, with significant impact on our trade balance. Many students first stimulated by the high-tech excitement of astronomy, later use these skills to build successful alternative careers in fields as distant as merchant banking and business.

6) The Community and Strategic Planning

Australian astronomy has long been viewed both nationally and internationally as a discipline that works in a highly co-operative and strategic fashion, developing over many years a strong position in world astronomy. A Decadal Planning process sets research goals, while an industry association and various committees maintain and develop links between researchers and business.

7) Technology Transfer

The astronomy industry is closely linked with the aerospace industry and the telecommunications industry, while also generating major advances in precision optics and medicine. The astronomy roadmap is led by science goals that are closely coupled to emerging engineering capabilities. Indeed, the science discovery goals represent a challenging environment that stretches the boundaries of engineering creativity.

8) Infrastructure

Infrastructure underpins globally competitive research, and increasingly, investment in astronomy research infrastructure is also being applied to other, commercial purposes. Super-computing grids and the broadband rollout of fibre-optic cable throughout Australia's main corridors are in part predicated on astronomical use in a bold vision for the future.

9) Australia's Competitive Advantages

Australia has substantial competitive advantages for the conduct of astronomy including a direct view of our galaxy centre (Milky Way), radio-quiet regions, access to a clear Antarctic sky, a highly skilled and networked team of scientists and engineers, advanced industry capability, and a stable and supportive political system. These advantages are attractive to hosting large internationally funded facilities, which can bring significant scientific and economic benefits.

10) Opportunities

Australia has the opportunity to participate in and host very large-scale, internationally funded facilities that would bring a significant level of overseas investment, local employment, national prestige, and the opportunity for leading-edge research and discovery. Currently the most well-progressed opportunity is the Square Kilometre Array (SKA), while there is growing interest and potential in the Extremely Large Telescope (ELT) which may be sited in Antarctica. Government can play an important diplomatic role in attracting these projects and others like the NASA Deep Space Network (DSN).

11) Funding Strategies

Astronomical telescopes and instruments are generally funded from a number of sources, representing a mix of Government, institutions and industry, and sometimes donations or bequests. With the current focus on major international facilities, the great majority (typically 90%) of funding for these projects is planned to come from overseas. If these facilities are sited in Australia, this economy will become a significant beneficiary of the inflow of foreign investment and personnel, as well as maintenance and servicing requirements. Whether overseas or on-shore, early engagement is required in these international projects to reap maximum scientific and economic benefit from local research, manufacturing and construction activities.

12) Recommendations

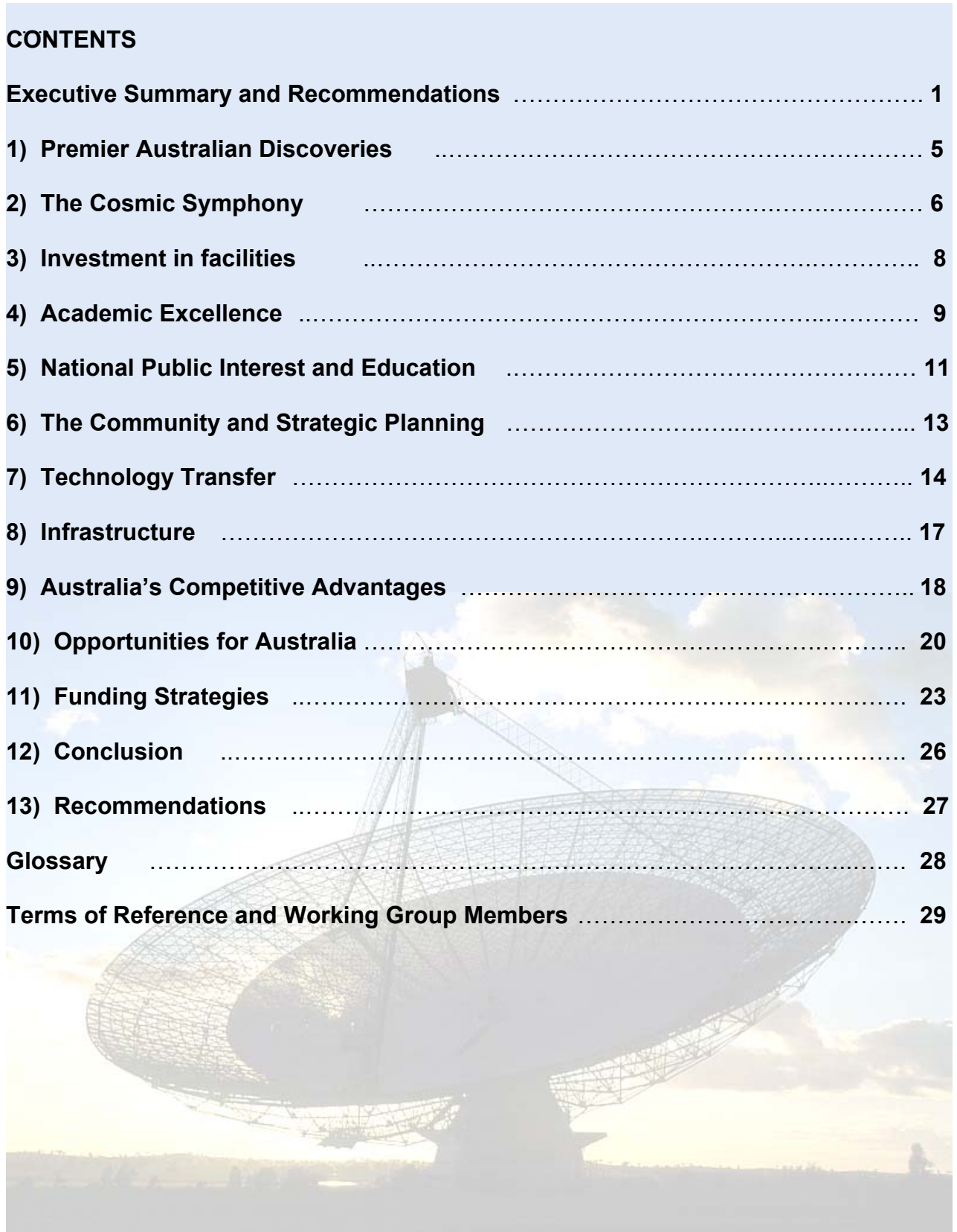
- 1) That guided by the strategic priorities identified in its decadal review process, Australia should build on its research, development and training capability in astronomy - including theoretical, observational and laboratory astrophysics, and instrumentation.
- 2) That Astronomy Australia and Government should work together via a 'whole-of-government' approach, to participate in and potentially host large-scale facilities such as SKA and ELT that are critical long-term major infrastructure investments for astronomy.
- 3) That as a next step toward SKA, Government should proceed to establish a radio quiet zone (~50km radius) at the representative site in Western Australia.
- 4) That as a next step toward ELT, Government should specify and support astronomy within the "agreed priority areas" for the Australian Antarctic Division.

**PRIME MINISTER’S SCIENCE, ENGINEERING AND
INNOVATION COUNCIL**

FUTURE OPPORTUNITIES FOR* **ASTRONOMY AUSTRALIA*

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Astronomy Australia

Increasingly, Australian astronomy is generating an industry, whose world-class capabilities, impact and opportunities are amongst the best of Australia's international success stories. Astronomy Australia is already a community and industry in which investment pays significant dividends, and has the prospect of stimulating significant growth through attracting major international projects to our shores.

1. Premier Australian Discoveries

Astronomy has guided and excited mankind through the ages, from the prediction of seasons and harvests, to an understanding of our origin and our ultimate fate. Over many years Australia has gained excellent facilities and researchers. In the last decade or so alone, Australian astronomy has produced many discoveries of worldwide significance and impact.



We are living at the moment of history in which humans, for the first time, are aware of other solar systems. The first planet orbiting another sun-like star was discovered in 1995. Since then, 14 of the 100 “exo-planets” now known have been discovered from Australia. Last year Australia discovered the exo-planet most like Jupiter, of any yet discovered. This planet provides the most likely environment in which Earth-like planets may form and survive long enough to sustain intelligent life. (Art by David A.Hardy/PPARC www.astroart.org).

Australian radio astronomy has a long and distinguished history stretching back over 50 years, beginning with the discovery of radio signals from the centre of our Milky Way Galaxy. This firmly established Australia as a leader in radio astronomy, a position it has continued to occupy with a succession of key discoveries.

In 1962 the newly commissioned Parkes radio telescope played a key role in the discovery of the first “quasar” (quasi-star – a very distant galaxy shining so brightly that it looks like a local star), and discovery of the magnetic field of our own galaxy. Parkes has found more “pulsars” (pulsing stars) than any other telescope, including the discovery of the first double pulsar in 2003 (right). These small size but very dense stars emit jets of energy that flash like lighthouse beacons as they rapidly rotate.



Australia has also played a key role in mapping hydrogen gas – the most abundant element – in the local Universe. This has provided a rich vein of discovery from the late 1960s when the spiral nature of our galaxy was revealed, through to the present day where a hitherto undiscovered spiral arm of our galaxy, and a large number of galaxies in the local group, have all been revealed.

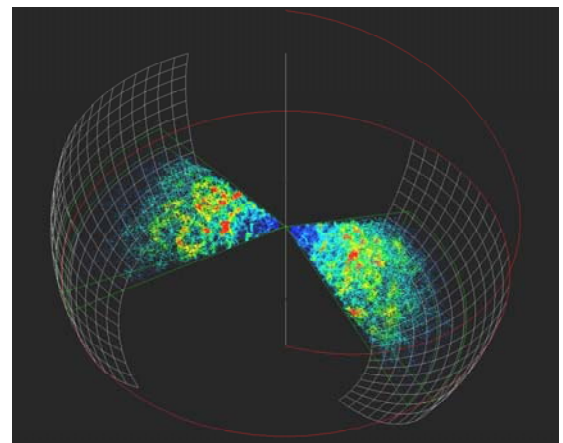


Optical telescopes in Chile and Hawaii enabled an Australian-led team of scientists to discover that the Universe is expanding at an accelerating rate. Searching for very distant “supernovae” (exploding stars, see left), and then using them as “standard candles” to measure the size of the universe over time, the team was able to show that gravity will not ultimately win by pulling the cosmos into a “Big Crunch”. Nor will the Universe coast along, expanding more and more slowly with time. Rather, an unknown repulsive force

(sometimes called dark energy) is causing the Universe to expand at an increasingly faster rate, opposing the attractive force of gravity. This news was rated Story of the Year in 1998 by the international journal *Science*. And only last year, an Australian found the oldest known star in our Galaxy – over 10 billion years old.

A 30-year mystery had surrounded a discovery by US military satellites while searching for illicit nuclear weapons testing. In 1998, by linking both optical and radio telescopes in Australia to a supernova explosion, crucial evidence was provided in the understanding of Gamma Ray Bursts, the most energetic events in the Universe.

Using a unique Australian instrument on the Anglo Australian Telescope, a three-dimensional map of a piece of the Local Universe containing one quarter of a million galaxies, was completed last year. The map has produced precise new measurements of the total amount of matter in the Universe. By combining this Australian map with American satellite data, a very precise age, 13.7 billion years, was determined for the Universe, and the acceleration of the Universe was confirmed. These combined results have been called the Scientific Discovery of 2003.

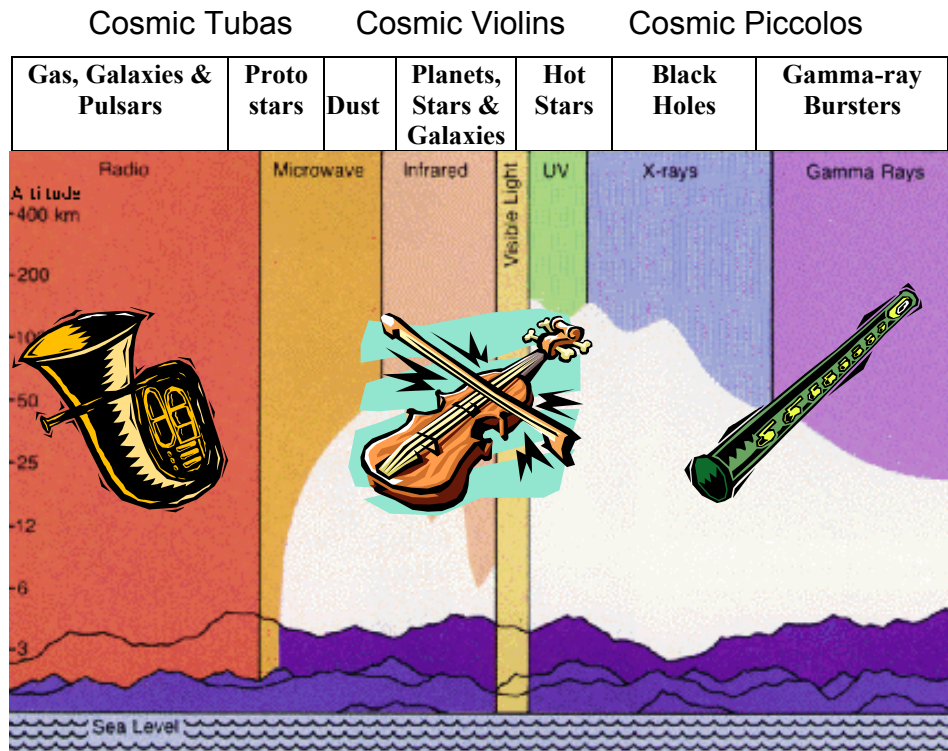


2. The Cosmic Symphony

Astronomers collect and analyse signals emitted by the cosmos at different frequencies to study the Universe. Different frequencies contain different kinds of information, and require a range of different telescopes and instruments. This diversity makes astronomy a rich, cross-disciplinary field with technological and industrial applications that are equally rich and diverse.

Depending on their temperature, physical state and surroundings, objects in the Universe emit signals at different frequencies. No single telescope can provide complete understanding, just as listening to a single instrument, playing over a narrow range of audio frequencies, cannot provide

appreciation for a symphony. The lowest frequency radio waves are analogous to the cosmic tuba. At the other end of the spectrum, extremely high frequency gamma rays are analogous to the cosmic piccolo. We learn about different astronomical processes and cosmic objects by building instruments capable of detecting (hearing) the different frequency signals.



Instruments in the Cosmic Symphony.

Three frequency ranges, radio, infrared and optical (visible light), are particularly important because they can be received through the Earth's atmosphere, and thus can be studied more economically than frequencies requiring space observatories (satellites).

Optical astronomy is the oldest, having begun with naked eye observations of the night sky. The cosmos emits an enormous variety of energy and information at optical and infrared wavelengths of light. Fine detail in the features of this light spectrum of cosmic objects can be analysed to determine their speed, distance and chemical composition. The latter helps in the search for conditions necessary for extra-terrestrial life.

Radio astronomy was consolidated in the Second World War, when radio engineers developed techniques for communication and detection. Dust that is randomly clumped throughout the Universe is transparent to radio waves. This allows astronomers a clear view of some objects that would otherwise remain obscured by a shroud of cosmic dust particles. Radio can also reveal violent activity in a diverse range of cosmic objects (quasars, supernovae, radio galaxies).

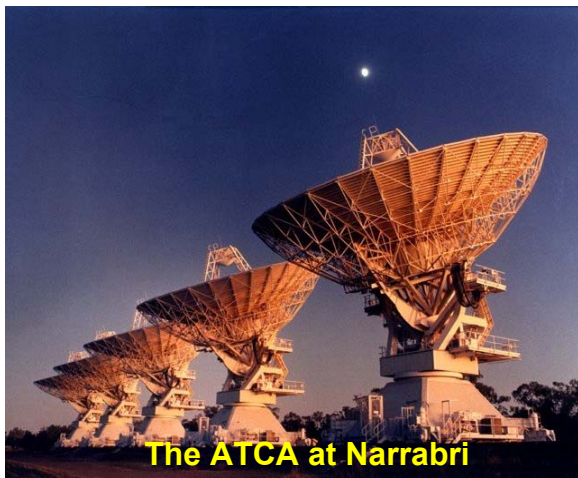
In these two pillars of modern astronomy, optical/infrared and radio, Australia has historically held world-leading strengths, while maintaining important capabilities in theoretical, millimetre, gamma, and cosmic ray astronomy, and playing less of a direct role in aerospace astronomy. In both optical and radio astronomy, Australia has observing facilities on shore, and engineering skills that lead the world, as detailed in this report.

3. Current Investment in Facilities

Investment in facilities on Australian soil seeds the development of world-leading Australian businesses, allows for on-shore research training and provides opportunities for tourism and local employment. Sometimes, for the best results Australia's astronomy investments are in shared overseas facilities, but these too involve contracts back to Australian enterprises, to produce and export high value instruments.

4.1 Australian Radio Astronomy

Many of Australia's radio telescopes and capabilities are unique in the Southern Hemisphere. The Australia Telescope National Facility (ATNF) is operated by CSIRO and provides world-class observing facilities for astronomers in Australia and from overseas. The ATNF comprises:



The ATCA at Narrabri

- The Australia Telescope Compact Array (ATCA) at Narrabri; an array of six 22m diameter radio antennas
- The 22m Mopra radio telescope located near Coonabarabran (partnered with UNSW)
- The 64m Parkes radio telescope
- A laboratory in the Sydney suburb of Marsfield, where the principal engineering capabilities are located.

The ATCA is the only operational cm-wavelength telescope array in the Southern hemisphere, while both ATCA and Mopra provide a unique view of the Southern sky at mm-wavelengths.

Ceduna and Hobart radio telescopes are operated by the University of Tasmania. The University of Sydney operates the Molonglo radio telescope - a cylindrical reflecting antenna located near Canberra, providing a unique survey capability in the Southern sky. In addition, the ATNF, Ceduna, Hobart and Tidbinbilla radio telescopes operate together to form a Long Baseline Array (LBA) facility. Tidbinbilla is a NASA facility otherwise used for space tracking.

Through their leading-edge technology development program, supported in part by a Major National Research Facility (MNRF) fund and their success in gaining contracts to build instrumentation for overseas radio telescopes, Australian engineers have developed world-class expertise in:

- highly sensitive receiver systems at microwave and mm-wave frequencies
- integrated circuit (microchip) design
- multi-beam receivers
- high-performance signal processing

By continuing to develop this expertise, Australia is well placed to play a significant role in capturing key technology areas in the design and construction of the Square Kilometre Array (SKA – see section 10).



Parkes

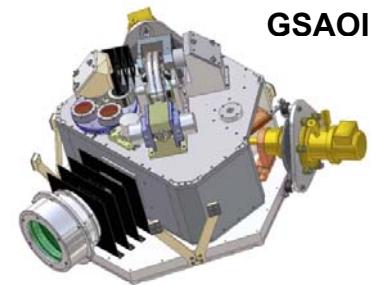
4.2 Australian Optical and Infrared Astronomy



Gemini North in Hawaii

Australia's premier optical/infrared telescopes are the twin 8.1m Gemini, being two of the largest in the world located at two of the best sites for optical/infrared astronomy - Hawaii and Chile. The Gemini Partnership consists of the USA, the UK, Canada, Chile, Australia (6.2% share), Brazil, and Argentina.

The Gemini instrument suite is under constant development within the partnership. Here Australia has been particularly successful - Gemini contracts totalling more than \$10M have been awarded to Australia since 1998. This includes two ANU instruments: NIFS – a near-infrared “spectrograph” being built in collaboration with Australian company Auspace, and GSAOI – an “adaptive optics imager” for Gemini South that will produce images as crisp as those of the US Hubble Space Telescope.



GSAOI

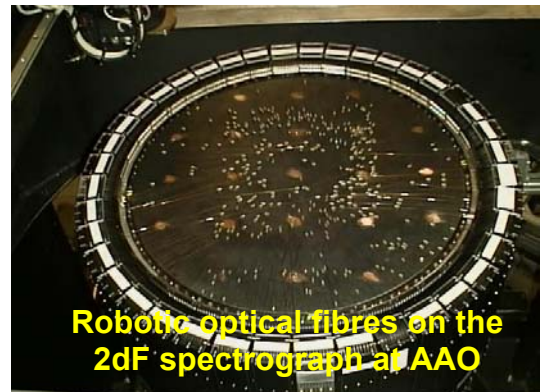


Siding Spring Mountain

Siding Spring Observatory (SSO) is operated by the ANU. Facilities on Siding Spring Mountain include two UNSW telescopes and the mountain's largest, the 3.9m Anglo-Australian Telescope (AAT). In 2006 the three ANU telescopes will be joined by the fully-robotic SkyMapper telescope which will be remotely operated via an AARNet3 data link.

Both the AAT and the UK

Schmidt Telescope (UKST) are operated by the Anglo-Australian Observatory (AAO). AAO-constructed spectrographs operating on both telescopes have generated intellectual property (IP) leading to multi-million dollar contracts to build instruments for large international telescopes, and will contribute to design studies for next-generation Gemini instrumentation, including KAOS, a mammoth new spectrograph for Gemini valued at tens of millions of dollars.



Robotic optical fibres on the 2dF spectrograph at AAO



Mt Stromlo team

ANU's Mount Stromlo Observatory (MSO) is home to Australia's largest research astronomy group. Established in 1924, much of the research infrastructure was destroyed in the firestorm of January 2003. Nevertheless, the 100-strong staff and student population were back within three weeks in the surviving academic buildings. Plans for the Stage I rebuild have been approved; construction is expected to begin in mid-2004 on an Advanced Instrumentation and Technology Centre for Astro-engineering.

Canopus Observatory outside Hobart is operated by the University of Tasmania, and uses a 1m diameter optical telescope primarily for imaging. Perth Observatory is funded primarily by the Department of Conservation and Land Management, to operate several small telescopes used for research and public outreach. Vulcan South, a robotic telescope at the South Pole searching for planets around other stars, is operated by Australian astronomers in cooperation with NASA.

The Sydney University Stellar Interferometer (SUSI) is a long baseline “optical interferometer” (paired telescopes for sharp images), designed, built and operated by the University, combining state of the art technology including adaptive optics, laser metrology, detectors, computer control and data acquisition systems. Pioneering work by the SUSI team has helped optical interferometry become a key feature of major telescopes such as the VLT in Chile and Keck in Hawaii.

4.3 Gravity Waves, Cosmic Rays, Gamma Rays, and Terahertz Astronomy

Gravity wave detection using laser interferometry is a major physics enterprise, with effort distributed over a broad institutional base — CSIRO, University of Adelaide, University of Western Australia and the ANU. It is driving the development of optical technologies in Australia including mirror manufacture, coating and polishing, high power lasers, laser stabilisation and control, high power interferometry and photon control and new ideas on interferometry below quantum limits (very small sizes indeed). This research is producing the most exquisite vibration isolation systems and leading new initiatives in Grid (linked multi-site) computing. Australian-developed experimental techniques are being applied to space interferometers (laser locking) for NASA; to vibration isolators used in airborne mineral surveys; to high sensitivity trace element sensors; and are delivering lasers to other projects (TAMA - Japan).

Cosmic Ray telescopes are operated both in Tasmania and at Mawson Station, Antarctica, providing vital data for “Space Weather” programs that can help mitigate the effect of solar storms on our communications and power infrastructure. In South Australia, the “Cangaroo” gamma-ray telescope is operated in collaboration by Australian and Japanese research teams.

In addition to laboratory astrophysics research, Australia has several groups active in “terahertz” physics (frequencies from 300 ~ 3,000 GHz), notably at the University of Wollongong and the University of Adelaide. Over the next decade there will be major opportunities for Australian astronomers to develop greater involvement in terahertz technology.

4. Academic excellence

International citation of Australian researchers is highest in astronomy. Per dollar invested, Australia is more than twice as effective in producing the highest impact papers, as the USA or any European country. This helps develop Australia’s reputation as an advanced and knowledgeable society, providing the credibility to influence world events, attracting investment to our shores and retaining some of our most talented professionals. Importantly, Australian tertiary astronomy has an excellent track record in training the very best next-generation scientists, engineers, and technical managers.

2.1 International Standing in Research

Astronomy receives about 1% of total Commonwealth R&D funding (\$41M of approx. \$4000M) and accounts for 1.5% of Australia’s scientific publications. As measured by DEST in September 2003, Australian astronomy has a world impact over 15% higher than that of any other Australian

scientific discipline (ref: Australian Science and Innovation System: A Statistical Snapshot). Measured by scientific papers, Australia produces 2.9% of world science, but 4.2% of world astronomy. Based on statistics presented in a Canadian study of astronomy carried out in 2001, Australia is more than twice as effective, per dollar invested, in producing the highest impact papers as the US or any of the European countries.

Australian astronomy's share of world publications, world citations and relative citation impact all climbed during the 1990s (Butler 2001). Its share of citations has risen from 3.4% over the 1990-94 period, to 4.8% in the 1995-99 period. As judged by the Institute of Scientific Information (ISI), which makes international comparisons, six of Australia's current 40 Citation Laureates – *across all ISI research disciplines* – are astronomers (15% share despite 1% of funding).

2.2 Productivity and Research Training

At least 13 universities in Australia conduct astronomical research and training. Each year, a little over 50 astronomers in permanent positions, and another 70 or so on fixed term contracts:

- train over 110 PhD students
- produce 300 refereed journal publications
- provide 140,000 undergraduate student-contact hours of astronomy teaching, and even more in physics teaching
- provide over 200,000 visitor-contact hours in public education and outreach programs,

as well as engaging in a very large number of national and international committees, and normal administrative duties.

Australian Astronomy has a remarkable tradition in training the leaders of tomorrow, in astronomy and in other fields of technical and entrepreneurial endeavour. For example, one Australian institution has trained as many Hubble Fellows (widely considered the most prestigious prize for very young astronomical researchers), as any other institution outside the USA. Australian astronomy can also boast a Young Australian of the Year: Dr. Bryan Gaensler.

The success of Australian astronomy students can be attributed in no small measure to the hands-on experience they receive with telescope facilities at Siding Spring, Mt Stromlo, Narrabri and Parkes Observatories, as well as smaller university telescopes, supercomputing facilities at ANU and Swinburne, and astronomical testing instrumentation in the Antarctic. This is one of benefits that most differentiates an Australian PhD graduate from their overseas counterparts.

5. National Public Interest and Education

Strong public support is evident in every new venture in astronomy and space exploration, with strong visitor centre attendance and wide media coverage. Astronomy is recognised in many countries as providing one of the most effective opportunities for inspiring youth to study physics, chemistry and maths – valuable preparation for citizens of an increasingly technical society, and essential for careers in science and engineering. Without an adequate supply of these home grown professionals, Australia is at risk of becoming a technology debtor nation, with significant impact on our trade balance. Many students first stimulated by the high-tech excitement of astronomy, later use these skills to build successful alternative careers in fields as distant as merchant banking and business.

5.1 Public Fascination and Engagement

The exploration of space fascinates most people and new discoveries regularly engage media interest. A quarter of a million people visit astronomical facilities each year in Australia, and tens of thousands regularly listen to radio programs on astronomy. Combined, web sites of the AAO, ATNF and ANU-Stromlo have received 77 million hits since 2003. UNSW's "Astronomy on the Go" program reached 10,000 young people via 130 presentations.

CSIRO Education regularly includes astronomy in its programs. In particular, some of the most popular and largest events for Double Helix Club members have been star gazing evenings, attracting as many as 1,000 people. CSIRO has also provided teaching units through a national network of Science Education Centres that focus on astronomy - programs that reach 220,000 students and 30,000 teachers a year across Australia.

Mount Stromlo Open Days attract 2000 – 5000 people, and recent public talks and viewing night combinations have drawn such crowds that multiple back-to-back lectures had to be given. Macquarie University's public outreach efforts are remarkably successful at engaging the public through a combination of public talks and viewing sessions, while Questacon is considering a permanent astronomy exhibition and space theatre.

5.2 Aspirational Education

One of the most valuable returns on investment in Australian astronomy is the transfer of people to the technical and business sectors of the nation. Astronomy graduates can be found leading major supercomputing and IT facilities in Australia, working in investment groups, as owners and directors of high-tech companies and societies, as superintendents in the Bureau of Meteorology and important positions within the Department of Defence.

Astronomy has unique educational and aspirational potential. It is multi-disciplinary and most subjects in the arts and sciences can use astronomy to engage student interest at all levels of education. Astronomy and planetary science offer interesting curricula material for studies in physics, chemistry, biology, geology, mathematics, engineering, design, art, music and literature.

A compelling example is provided by the actions of the South African government. The importance of science, and in particular, astronomy, for human society was recognized as early as 1996 by the new government. A white paper issued by their Department of Arts, Culture, Science and Technology at that time, entitled *Preparing for the 21st Century*, states:

“Scientific endeavor is not purely utilitarian in its objectives and has important associated cultural and social values. It is also important to maintain a basic competence in ‘flagship’ sciences such as physics and astronomy for cultural reasons. Not to offer them would be to take a negative view of our future - the view that we are a second-class nation, chained forever to the treadmill of feeding and clothing ourselves.”

In addition to selecting astronomy as the number one national research priority and building significant astronomy infrastructure, the vision of the South African government was to recognize the importance of astronomy in raising the aspirations of its people to undertake technical careers, and to adopt evidence-based decision-making. The same vision is appropriate to Australia.

5.3 Handling the Information Explosion

Astronomy is an information-rich discipline with an ongoing need to develop educational resources for schools and the public alike. In order to convey a great deal of information in a realistic manner, advanced 3D virtual reality technologies developed at Swinburne's Centre for

Astrophysics and Supercomputing have toured major museums in Australia to make the science more accessible and engaging to the general public. At the recent “To Mars and Beyond” exhibitions a 3D virtual flight to Mars was rated by visitors as the most popular exhibit. Astronomers at the Centre also conduct virtual tours of the Universe in their virtual reality theatre for primary school children. These tours have proved so popular that the astronomers won a \$1.3M State government grant to build one of the world’s largest-scale virtual reality exhibits at Melbourne Museum. The “virtual room” won a recent industry award for best new digital content. Australia runs the most visible on-line astronomy programme for graduate students from the Centre, with over 250 students enrolling from 32 different countries. This programme has led to export income in excess of \$1M in the last three years.

6. The Community and Strategic Planning

Australian astronomy has long been viewed both nationally and internationally as a discipline that works in a highly co-operative and strategic fashion, developing over many years a strong position in world astronomy. A Decadal Planning process sets research goals, while an industry association and various committees maintain and develop links between researchers and business.

The Australian astronomical community undertakes major strategic planning every ten years, the last plan covering 1996-2005. Decadal planning is conducted by the Australian Academy of Science - National Committee for Astronomy (NCA), with support from the Australian Research Council (ARC). Mid-term reviews adjust the strategic goals. The most recent review “Beyond 2000: The Way Ahead” was published in June 2001 and led to the successful MNRF-2001 proposal: “Gemini and SKA - Australia’s Astronomy Future”. Later this year, the next decadal review process will begin with this PMSEIC report serving as an input. Another important part of the process will be to update Astronomy Australia's knowledge of industry's capacity to service its future requirements. As a component of a whole-of-Government approach to future opportunities (see section 10), DITR engagement in this aspect would be highly beneficial.

The Australian Square Kilometre Array Consortium Committee (ASKACC) and the Australian Gemini Steering Committee (AGSC) are national bodies that serve as the interface between Astronomy Australia and international consortia on science, engineering and management issues related to the SKA project and Gemini partnership, respectively. The Australian Astronomy Board of Management (AABoM) oversees expenditure of the Astronomy MNRF (under the Federal Government’s Backing Australia’s Ability initiative), and is advised by ASKACC and AGSC.

The Astronomical Society of Australia (ASA) is the professional body representing the needs of individual researchers and educators. ASA provides an interface to similar societies abroad, and with support from the NCA, hosted IAU 2003 General Assembly in Sydney – the largest international meeting of astronomers.

Communication between the astronomy community and its associated industries is also strong and growing. In July 2003, the ANU, CSIRO, Connell Wagner and DITR sponsored a successful Astronomy Industry Day to coincide with IAU 2003. As one result, the Australian Astronomy Industry Network (AAIN) has been established. Objectives include the production of a quarterly newsletter and a website to provide interactive communications, covering business opportunities and a database of advanced technology capability to allow participants to readily locate appropriate skills. Membership of AAIN is free of charge.

7. Technology Transfer

The astronomy industry is closely linked with the aerospace industry and the telecommunications industry, while also generating major advances in precision optics and medicine. The astronomy roadmap is led by science goals that are closely coupled to emerging engineering capabilities. Indeed, the science discovery goals represent a challenging environment that stretches the boundaries of engineering creativity. People of exceptional skill have often moved from astronomy to contribute to industry.

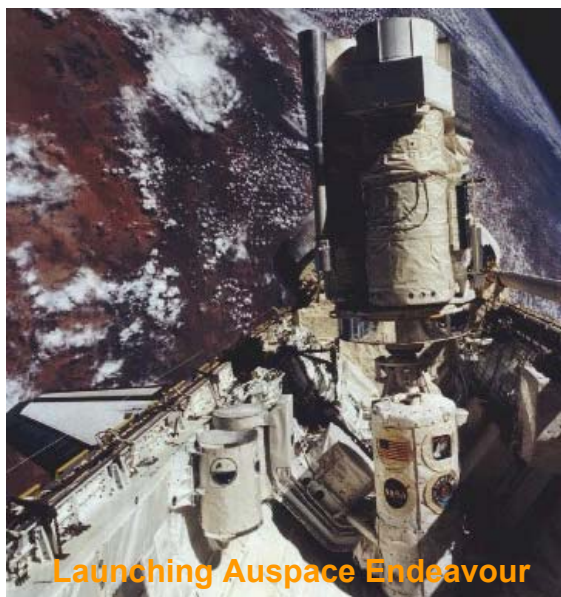
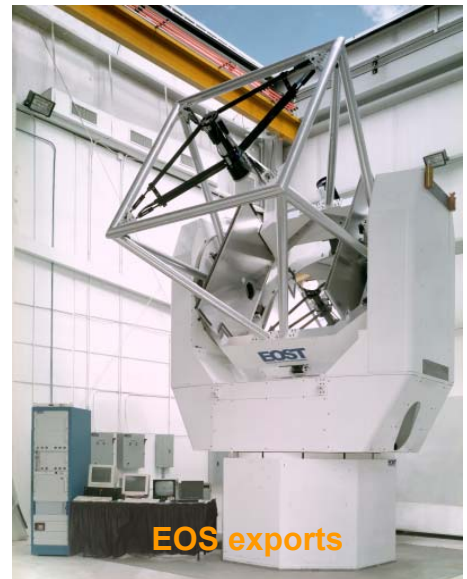
7.1 Commercialisation and Technology Transfer to other Sectors

Astronomy is one of the powerful drivers behind civil development of “terahertz” technology (frequencies from 300 ~ 3000 GHz). This technology is now finding important application in anti-terrorist techniques, as it provides a non-invasive method of “seeing” through mail packages to discover harmful substances and for checking passengers at airport terminals for hidden devices.

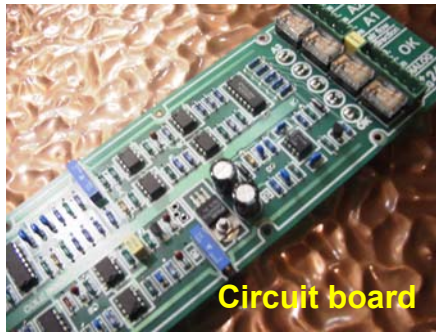


Radiata was a company formed to commercialise the wireless LAN (Local Area Network) system, its rapid success leading to its acquisition by Cisco Systems 3 years ago for \$600 million. The four inventors of this technology and two of the company founders came from a radio astronomy systems background. This LAN opportunity had arisen from development of the “fast Fourier transform” chip at CSIRO, initially developed to process the individual frequency components of radio astronomy signals more rapidly.

Electro Optics Systems (EOS) specializes in the design, development and production of sophisticated laser technologies, applied to a variety of sighting and surveillance applications in the aerospace and defence markets. In addition, the company is one of the world’s largest manufacturers of medium-size telescopes, and is developing adaptive optics. Pictured is one of their larger telescopes destined for use in Hawaii.



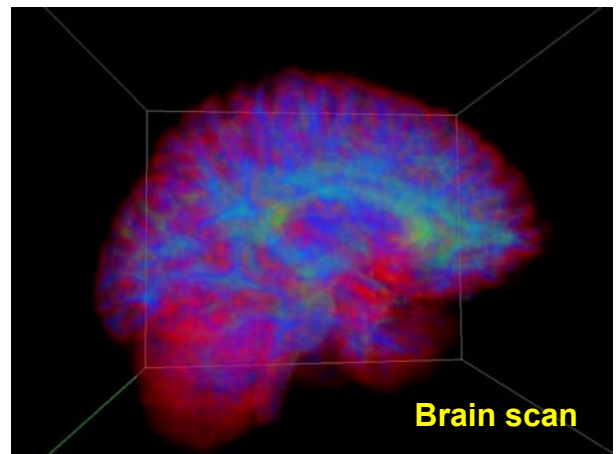
Auspace is an engineering company specialising in electro-optic instruments, satellite communications and space systems. Since its inception in 1983 as a spin-off from Mt Stromlo Observatory, Auspace has provided products and services to many countries, including the Endeavour ultraviolet imager. The company provides instruments to ground- and space-based facilities, and its hardware currently operates on two European remote sensing satellites. Auspace integrated the FedSat satellite in its Canberra facilities.



million to June 2003, 98% of which was derived off-shore.

Austech Microsystems' early contracts were for the CSIRO "correlator" technology, which provided the exceptional processing power required by radio telescopes, and the Fast Fourier Transform chip. Additional flow-on benefits of the latter technology led to the formation of Lake Technologies, the company responsible for the Dolby surround sound available through headphones in international aircraft.

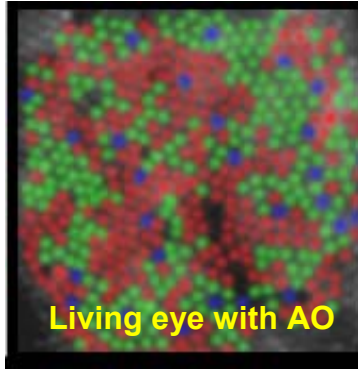
Aperture Synthesis Imaging was a technique developed by astronomers to make radio maps, initially of the sun in the early fifties in Australia, then of cosmic objects by astronomers at Cambridge and other centres. It provided the mathematical basis for CAT-scan systems for X-ray imaging and is now a pivotal technique in brain imaging as well as remote sensing and seismic imaging used in mineral surveys.



When satellite communication commenced, it drew heavily on radio astronomy technology for its ground stations. The needs of the Parkes telescope led to development of the hybrid mode feed, which became commonly used on large antennas throughout the world. The needs of Sydney University's Mills Cross radio telescope led to development of the transconductance multiplier, a circuit which is now one of the most common analogue processing circuits in the electronics world, used widely in radio and television. The drive to improve sensitivity in radio telescopes led to development of low noise amplifiers where Australia again has played a significant role. These advances make possible the low cost satellite receivers used in the domestic scene.

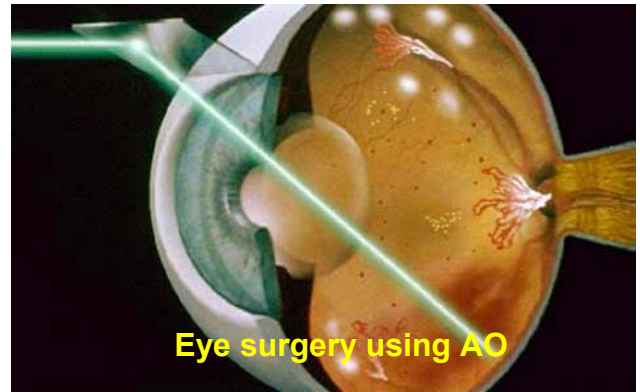
Work on antennas for the ATNF established a strong base for antenna design and allowed completely Australian antennas to be built by Connell Wagner for use by OTC, both in Australia and in South East Asia. A Government study in the early 1990s found that the synergy between radio astronomy and commercial technology in building the ATCA Compact Array had been worth \$110million to Australia in import replacement and export - a benefit-cost ratio of 2:1.





Adaptive Optics (AO) is the correction of image blur due to an intervening medium, such as the Earth's atmosphere (for astronomy). AO has important applications in the fields of ophthalmology, laser machining and defence. For example, imperfections in the eye's lens and cornea cause blurred images to be formed on the retina. AO can be used to measure these imperfections, and a deformable mirror can correct them, so that researchers can see individual cells in the retina.

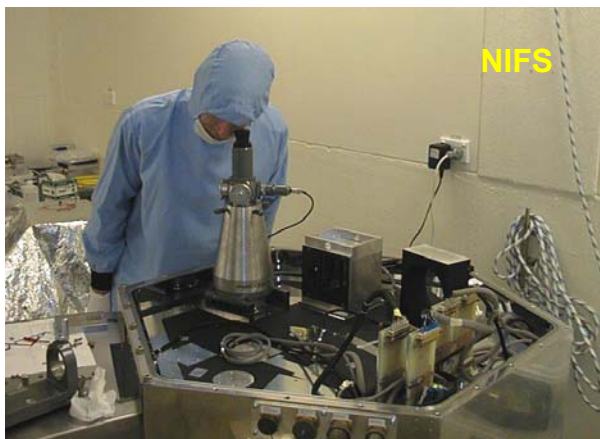
The image (left) shows individual cone photoreceptors in a living eye (Centre for AO, Rochester, USA). AO is also being used to examine how to improve human vision. The Lions Eye Institute in Perth, Western Australia, is the largest eye research institute in the southern hemisphere, providing clinical services to 40,000 patients each year.



With a PhD in astrophysics from UNSW, IT&T consultant Dr Paul Brooks has established an international reputation for leadership in complex systems and network design. Paul was a leader of the global Windows Sockets software standardisation that contributed to the explosion of the World Wide Web. He designed and built an Internet backbone network spanning the Asia-Pacific region, and was engaged by Telstra to design very dense broadband networks in China. Recently he had significant responsibilities in Canberra's innovative TransACT cable broadband service.

A tremendously important new theoretical technique known as "smooth-particle hydrodynamics" for gas flows was developed by Monash University's theoretical physicists that is now in widespread use in aeronautics and engineering.

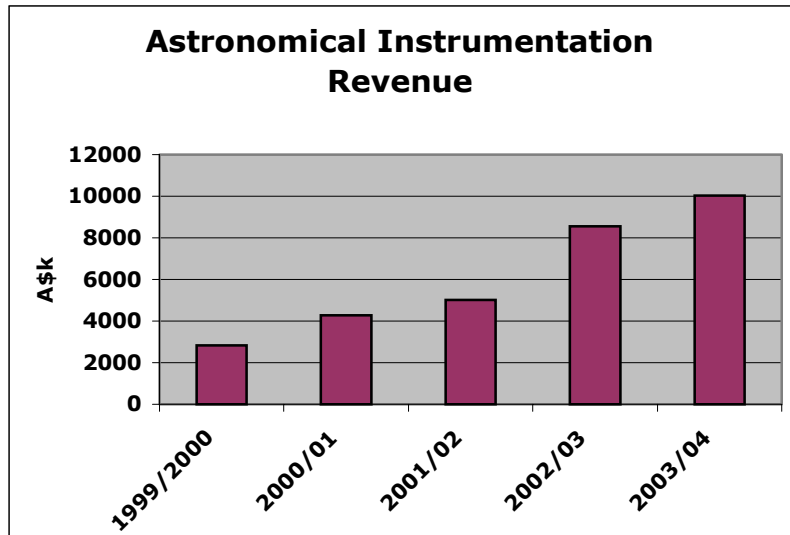
7.2 Leading Technology and Revenue Generation within the Research Sector



In the last five years, Australian astronomy has capitalised on its world-wide reputation in the development of state-of-the-art astronomical instruments, such as the Near Integral Field Spectrograph (NIFS) for Gemini, the 2-degree-field spectrograph for the AAO, and the Parkes multi-beam receiver, to develop a thriving industry in the design and building of optical, infrared and radio astronomical instrumentation to overseas customers such as ESO (Europe), Subaru (Japan), Arecibo (US) and Gemini (multi-national). Additional overseas investment in Australian facilities comes directly from overseas

Governments (e.g. UK share of the Anglo-Australian Observatory) and spacecraft tracking contracts with NASA.

In 2003/04, Australian astronomy captured almost \$10M in overseas revenue from astronomical instrumentation and spacecraft tracking contracts. Over the past three years, revenue from this source has grown by more than 20% per annum.



Overseas revenue earned by Australian astronomical institutions

8. Infrastructure

Infrastructure underpins globally competitive research, and increasingly, investment in astronomy research infrastructure is also being applied to other, commercial purposes. Super-computing grids and the broadband rollout of fibre-optic cable throughout Australia's main corridors are in part predicated on astronomical use in a bold vision for the future.

The National Research Infrastructure Taskforce discussion paper indicated three research infrastructure issues relating to Australian astronomy:

- The need for high capacity broadband communications both nationally and internationally
- The need for access to computational power
- The need to participate in international facilities and consortia

8.1 Investment in Australian Broadband Facilities

During 2003 and 2004, the Australian Government, State governments and research institutions will invest significant sums in developing the Australian Academic Research and Education Network (AARNet). As a consequence, it is expected that by end-2004 this network will comprise:

- 10 Gbps trunk networks between Australian capital cities (except for Darwin and Hobart) with duplicate and redundant routes between Brisbane, Sydney, Canberra and Melbourne;
- Dual, route diverse 10Gbps links between Australia and Hawaii (and thence to North America, UK, Europe, Japan and Korea);
- Regional networks of 1-10Gbps connecting major research campuses and facilities including astronomy sites, in western NSW, Tasmania and possibly Darwin;

The vision behind the future high-speed links between the major supercomputers and academic institutions will provide Australian astronomers with network bandwidths comparable with the best projects overseas (including the "Teragrid" initiative in the US). If fibre links can be established between the major observatories within the next 12 months, real-time Very Long Baseline Interferometry (VLBI) projects can be attempted before major initiatives in the US and Europe are completed. The current broadband network plans will enable the widest bandwidth, and hence the most sensitive, VLBI observations ever attempted in the rich Southern skies.

This infrastructure is also of key importance to optical/infrared astronomy in Australia. Plans to supply Gigabit bandwidth to Siding Spring Observatory represent an important step for remote optical observing, a capability being funded in part by a DEST Systemic Infrastructure Initiative. This infrastructure will enable national and international access to both Australia's current world-class (2dF, HIPASS) and future (SkyMapper, AAOmega) databases.

Australia's case for significant engagement in landmark facilities such as SKA and ELT (see section 10) is enhanced by access to AARNet and its high capacity international links. These provide the foundation for international research access to a facility on a real-time, convenient basis, and permit integration of these facilities into the global observational network.

8.2 Supercomputing Grids

Australian Astronomers make extensive use of the nation's supercomputing infrastructure, with machines like the Centre for Astrophysics and Supercomputing's cluster being dedicated to Astronomy. Astronomers are majority shareholders in this computer and make use of the AC³ cluster, SAPAC's Linux cluster, the VPAC Linux cluster and the Australian Partnership for Advanced Computing (APAC). These represent five of the top six computers in Australia. Funding for the second stage of APAC has been announced to increase access of Australian researchers to significant computing capacity. The ability to access world class computing, communications and instrumentation facilities will drive new developments in this area, and will provide the basic foundations for e-research, middleware and computational applications, and is crucial to many areas of theoretical astrophysics. The world's first large bandwidth, baseband recorder with an in-built supercomputer was installed at Parkes in 2002. This system (CPSR2) is a prototype for future "software radio telescopes".

Astronomers are part of a worldwide effort to create a consistent set of tools that operate across a grid of supercomputers accessing historical archives enabling creation of the virtual observatory. The International Virtual Observatory (IVO) is currently convening a series of workshops that are driving supercomputing grid technologies. Melbourne University is leading similar efforts in Australia supported by the Australian Research Council (ARC) through the Linkage Infrastructure and Equipment Fund. The establishment of high-speed broadband links will ensure Australian astronomers can play a pivotal role in the development of these new technologies.

Often relying heavily on supercomputing, the theory underpinning Australia's observational advances should not be underestimated. Institutions such as Monash have almost 100% of their astronomers involved in theory, whereas Melbourne, Swinburne, ANU, Sydney, UNSW, Adelaide and Macquarie have a least one staff member with a strong theoretical background.

9. Australia's Competitive Advantages

Australia has substantial competitive advantages for the conduct of astronomy including a direct view of our galaxy centre (Milky Way), radio-quiet regions, access to a clear Antarctic sky, a highly skilled and networked team of scientists and engineers, advanced industry capability, and a stable and supportive political system. These advantages are attractive to hosting large internationally funded facilities, which can bring significant scientific and economic benefits.

9.1 Natural Advantages

Australia is rich in the vanishing worldwide natural resource of "radio-quietness". Inland Australia has many areas with very low levels of background radio-frequency interference. This offers

Australia a major competitive advantage for hosting future large-scale international radio astronomy facilities, as these highly sensitive instruments benefit from radio-quiet sites allowing optimum operation. Early establishment of a radio quiet zone (about 50km radius) at the Australian representative site for the SKA core (see section 10) would secure this important competitive advantage, for this and other projects.

Our location in the Southern Hemisphere means that facilities in Australia and its Territories have one of the best views available on Earth of our own Galaxy. Most ground-based, large-scale astronomical facilities being built and planned over the next decades will be constructed in the Southern Hemisphere, with important siting opportunities for Australia including the Australian Antarctic Territory. However, South Africa is a serious contender also.

Pioneering research over the past decade has shown that observing conditions on the high plateau of Antarctica are exceptionally good and, for a wide range of astronomy, may be significantly better than those anywhere else on the planet. All of the best observing sites lie within the Australian Antarctic Territory. Dome C in particular, has the lowest recorded wind speeds of any established observatory in the world and two to four times better spatial resolution at visible wavelengths than any temperate site location.

In the next two years, two major infrastructure developments will occur that are of great potential benefit to astronomy:

- The Australian Antarctic Division are introducing an air-link between Hobart and Casey, together with a capability to fly from the coastal stations to the high plateau.
- The French and Italian Antarctic programs are opening a new year-round station (Concordia) at one of the most favourable locations for astronomy on the plateau.



Moreover, Australian astronomers have pioneered the use of robotic observatories in Antarctica. At the present time we are the only country in the world to have successfully operated a completely unmanned astronomical observatory on another continent. Development of the AASTINO observatory took place entirely in Australia, using technologies that should find ready application in a wide range of remote sensing and environmental monitoring situations.

Australia is leading an international push to deploy a 2-metre optical/infrared telescope at Dome C. Such a telescope is a necessary stepping-stone to much larger facilities, that could include ELTs (Extremely Large Telescopes) and interferometers. Increased international investment in astronomy in Antarctica can bring major economic benefits to Australia – especially Tasmania. Already, Antarctic-related activities contribute \$90m/year to the Tasmanian economy (Davis, 2001). The world currently spends about \$1billion per annum on polar activities, suggesting major growth potential for Tasmania’s Antarctic support industries.

To take advantage of these opportunities it is important that the four “agreed priority areas” for the Australian Antarctic Division should be amended to specifically nominate astronomy, coupled with appropriate resourcing.

9.2 Human Advantages

The worldwide reputation and national performance of Australia's astronomy scientists and engineers has been stressed in previous sections. Not to be overlooked are the innumerable lifestyle benefits and opportunities of this country that attract talented scientists and engineers that prefer to live here. This human capacity and potential will continue to be one of Australia's strengths, as long as adequate support is provided to maintain research and research training.

University physical sciences have struggled to retain staff over the past 20 years. The state of physics as a discipline in Australia is particularly worrying; many departments are either closing or being merged with other entities. Reduction in the physics content of engineering courses is partly responsible – of itself a retrograde trend for an innovative nation. Against this falling tide, astronomy is in a healthier state. For instance at Swinburne and Melbourne Universities, new groups have emerged that employ over 25 astronomers and support staff, and are leading ARC grant winners in their respective institutions. Even in established physics departments, astronomer numbers are firm, with new groups emerging at Macquarie and the University of Queensland in the last couple of years.

Significantly radio astronomy was consolidated by former World War 2 radar groups. These groups were used to working in teams in very demanding conditions, maintaining a discipline that proved appropriate to the high precision required of leading-edge astronomy. The war had driven a similar culture in optical astronomy, when facilities at several laboratories were expanded for the manufacture of bombsights and other instruments. This culture was retained in their subsequent work including when various projects were spun off to industry. Moreover, the demanding work attracted and trained some of the most highly skilled people, many moving out to contribute more widely to the Australian scene. The existence of this long history of success and the resulting networks of people throughout academia and industry committed to these accumulated cultural values, holds great promise for continuing benefits from future major projects.

10. Opportunities for Australia

Australia has the opportunity to participate in and host very large-scale, internationally funded facilities that would bring a significant level of overseas investment, local employment, national prestige, and the opportunity for leading-edge research and discovery. Currently the most well-progressed opportunity is the Square Kilometre Array (SKA), while there is growing interest and potential in the Extremely Large Telescope (ELT) which may be sited in Antarctica. Government can play an important diplomatic role in attracting these projects and others like the NASA Deep Space Network (DSN).

The last few years have seen a huge growth in our understanding of the Universe, largely fuelled by observations from ground- and space-based telescopes receptive throughout the cosmic symphony. Maintaining a world leading position in astronomy requires substantial access to the best telescopes world-wide, and sufficient numbers of high-calibre, trained personnel to exploit the new potential offered by the best instruments.

With the Next Generation radio and optical/infrared telescopes, astronomers will be able to probe the earliest moments of the cosmos when the very first stars were forming, as well as to determine the atmospheres of planets around other stars. These telescopes will have the sensitivity to see further back in cosmic time than ever before, while also having the resolution to see details of

distant and small, faint nearby objects with unparalleled clarity. Australians are already involved in building the science cases for specifying these next-generation, international telescopes.

The design and construction of these new facilities will pose many new engineering challenges, cost hundreds of millions of dollars and require a carefully staged, major international effort to bring to fruition. Australia has the opportunity to reap huge scientific, economical, and social benefits from these projects, while generating IP that can be transferred to other sectors.

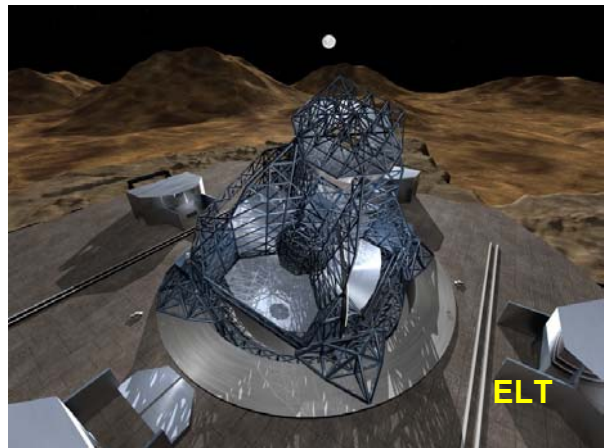
10.1 The Next Generation

The Next Generation radio and optical/infrared telescopes are expected to come on-line between 2012 and 2020, so every major astronomy nation is engaged in preparing for this new era through a substantial investment in the design phases now.



Operating in several radio wavebands, the Square Kilometre Array (SKA) will be the world's largest and most sophisticated radio telescope, with 300 stations spread across a continent. Capable of looking in several directions simultaneously, it will total a square kilometre in signal-gathering area (100 times more powerful than existing radio telescopes). An instrument this powerful is required to map the formation of the universe **before** the first stars condensed from hydrogen gas, and lit up to become visible.

Extremely Large optical Telescopes (ELTs), operating in the optical and infrared parts of the spectrum, will have mirrors 20-100m in diameter. With adaptive optics technology to correct for turbulence in the earth's atmosphere, they will generate images of higher clarity and far more sensitivity than any taken from space. A 100m ELT will have 100 times the light-gathering power of the current largest optical telescopes, allowing it to not only detect, but actually to reveal the chemical content of the most distant galaxies, as well as the atmospheres of planets around other stars.



NASA is exploring the development and construction of a next-generation Deep Space Network (DSN), to dramatically increase its capacity for planetary science through communications with deep space probes. While not an Australian astronomy project, NASA DSN will utilise SKA as well as optical technologies for reception of weak signals. The planned project cost is about A\$4billion, involving significant infrastructure and employment opportunities, and will be entirely US-funded. NASA has already contracted with CSIRO to undertake preliminary research. The decision to site SKA in Australia would provide leverage in any decision to host a key element of DSN in Australia too, and would provide a component of the resourcing strategy for Australian participation in the SKA.

10.1a Square Kilometre Array

The Australian astronomy community has clearly stated through its Decadal Review process that engagement in the Square Kilometre Array is one of its leading strategic priorities over the next decade. The SKA capitalises on Australia's strong technological leadership in radio astronomy and the unique natural resource of its radio-quiet interior.

The Square Kilometre Array is a project that was born 'global', formed by a Memorandum of Understanding between 15 countries in 1999. The International SKA Project Office is currently staffed by the Director and the (Australian) Project Engineer. China, the USA and most notably South Africa have formally submitted bids to host the SKA, in competition with Australia.

SKA offers Australia the opportunities:

- To host a major international project of high visibility, stimulating Australian research and attracting young people to science and engineering
- To build on existing infrastructure initiatives such as the AARNet3 cable network
- To engage Australian industry in international projects at the cutting edge of information and communication technologies
- To invest in rural/regional Australia, providing employment and educational opportunities for local and indigenous communities
- To project internationally the image of Australia as a culturally rich and creative country with a high-technology future
- To gain a "seat at the global table" of international science and engineering.

Australia should view the opportunity to host the SKA as no less prestigious, and with longer-term benefits, than hosting the Olympic Games.

Australia's \$15M investment in the SKA 'concept development' phase, facilitated through the MNRF-2001 program, has already enabled it to play a leading role in all SKA key areas of science and engineering. Australia is exploring opportunities to develop a technology/infrastructure demonstrator system at the representative SKA site in Western Australia over the next two or three years. Based on the outcome of the SKA site decision in 2006, this facility could be readily expanded to form the international SKA demonstrator and ultimately the full SKA.

If the SKA project comes to Australia, it would represent an estimated \$430M in infrastructure work alone. Importantly, the infrastructure provision for the SKA project is demonstrably within the delivery capacity of Australian engineering. The rollout of mobile telephone networks around the country over the last six to eight years has some similarities to the construction program that will be necessary for SKA, and Australia has a track record of successfully delivering low-cost and durable solutions in rural locations. Many prominent remote area projects have demonstrated Australia's ability to innovate in order to ensure long-term functionality and cost effectiveness, as well as showing the capacity to mobilize large, well-equipped, work forces.

10.1b Extremely Large Telescopes

Next generation optical/infrared telescopes will have mirror diameters 20-100m in size and 6 to 100 times the light-gathering power of today's 8m telescopes. Several groups in the US, Canada and almost all European nations including the UK, are now working in concert on development of these Extremely Large Telescopes (ELT). Recently Japan has also begun investigating such options. Possibilities may exist for Australia to join one of these ELT consortia. Canada, Europe and the USA have each expressed interest in seeking joint collaboration with Australia.

Australian astronomers are beginning to gear up for the instrumentation associated with an ELT era. The DEST Innovation Access Program - International Science and Technology grant (funded by Backing Australia's Ability), is supplying funds to aid the ANU in designing and constructing control and test electronics for two deformable (adaptive) mirrors provided by the international Gemini consortium. The same program will allow the AAO to further develop its robotic optical fibre positioners for use in extremely large focal planes. The grant will support travel by Australian science and engineering teams to Europe and North America to further develop collaborations with international ELT teams and to develop Australian-specific plans for ELT design and development.

Europe has welcomed Australia into its 41M Euro bid for ELT design and development at the level of 1.75M Euro; a funding decision is expected by mid-late 2004. Of only four non-EU institutions involved in this bid, three are Australian. This development is particularly significant, given that Australian astronomers have consistently expressed their interest through the Decadal Review process and through other venues, in joining the European Southern Observatory (ESO) consortium. Joining ESO would allow direct and automatic access to ESO's planned ELT, as well as to all current ESO facilities in Chile, including optical/infrared interferometry and ESO's one-of-a-kind ALMA millimetre array which will be completed in a few years.

10.2 Avoiding lost opportunities

Recently Astronomy Australia was disappointed after negotiating for Australia to host an international facility - the Low Frequency Array (LOFAR). This was despite an international committee selecting an Australian site as the world's best on technical grounds. A key lesson learned was the short time scales on which opportunities can arise (and disappear), and the need as a nation to respond quickly, but also to move on quickly if we do not succeed. To position Australia to take full advantage of such opportunities, Astronomy Australia needs to engage Government at the early stages of major international projects. This would increase the chances of success with astronomical facilities such as SKA and ELT, and related projects such as DSN.

A significant element of this strategy would be for Government to investigate establishing a Radio-Quiet Zone at the representative Australian SKA site to give Australia a competitive advantage in hosting the SKA. In addition, Government participation in establishing an Antarctic site for astronomical observations could provide a competitive advantage in hosting ELT.

11. Funding Strategies

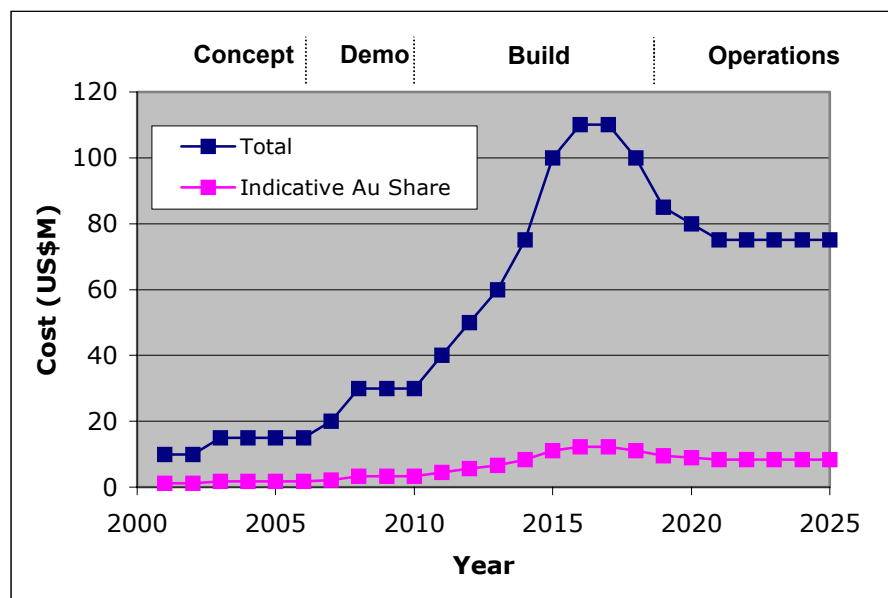
Astronomical telescopes and instruments are generally funded from a number of sources, representing a mix of Government, institutions and industry, and sometimes donations or bequests. With the current focus on major international facilities, the great majority (typically 90%) of funding for these projects is planned to come from overseas. If these facilities are sited in Australia, this economy will become a significant beneficiary of the inflow of foreign investment and personnel, as well as maintenance and servicing requirements. Whether overseas or on-shore, early engagement is required in these international projects to reap maximum scientific and economic benefit from local research, manufacturing and construction activities.

The National Research Infrastructure Taskforce found that development of landmark facilities requires not only significant investment, but also complex international negotiations and design scenario development. They identified the need for staged investment, whereby the early stages of

proposals are funded, prior to decisions on investment in the facility. The Taskforce noted the importance of understanding and sourcing the funding for capital, operating and maintenance costs necessary for the infrastructure viability. A staged funding approach is therefore proposed for Australia's participation in major international astronomical projects.

11.1 SKA

At present, Australia is an 11% partner in the international SKA project. The concept development phase is underway, with site selection planned for 2006 and the selection of key technologies in 2007/8. The total international effort in this development phase will amount to US\$50-100M. This will be followed by an international prototype development phase from 2007-2012 (costing approximately US\$100-200M), with major construction slated to begin in 2012/13. The facility would come on-line from 2018, with commissioning completed by 2020. An indicative spend profile for the facility is shown below, based on an Australian contribution of 11%. The total capital cost of the SKA is currently estimated at US\$1billion, with ongoing operational costs estimated at 5-10% of the capital cost. SKA is planned to have a 30+ year lifetime, through an upgradeable and flexible design, returning benefits to the partner countries until at least 2050.



Indicative spend profile for SKA.

Resourcing strategies for the SKA during the current concept development phase have been focussed on co-investment models with industry, Government (State and Commonwealth) and international partners. This will continue into the later stages of the project. An important factor in gaining industrial support is to demonstrate that involvement in programs such as SKA gives industry a competitive advantage in many areas of technology beyond astronomy. Moreover, the mapping between SKA requirements and Australia's capabilities is strong (see table below).

Strategic investment in the SKA program has already been made by CSIRO, the Government of Western Australia, industry (Connell Wagner, APT, CEA, Dell, SGI, Cray), universities and the Federal Government (via the MNR program). In addition, strong political support at the highest levels will be required if the SKA is to be sited in Australia. Other potential SKA host-nation Governments are providing strong and visible support for siting the SKA in their country. For example, the South African Government recently invested 30M Rand in SKA-related activities, including local infrastructure.

Australian political support in establishing a radio-quiet zone (about 50km radius) at the representative Australian SKA site, would give Australia a strong competitive advantage over other potential host nations - most particularly the USA where such legislation will prove very difficult to obtain. In January the OECD Global Science Forum's Task Force on Radio Astronomy and the Radio Spectrum, recommended Government consideration of establishing such a zone. The Government of Western Australia has already expressed strong support for the establishment of this inland radio-quiet zone, in order to enhance the long-term attractiveness of the WA site for facilities that can help drive the high-technology diversification of that State's economy.

SKA requirements (R & D or Interest Area)	Capability						
	Aust	Canada	China	Europe	India	South Africa	USA
Site studies and major infrastructure engineering	X		X			X	X
SKA scheduling, operations and maintenance models	X		X	X		X	X
Outreach and public education	X	X	X	X	X	X	X
Low-cost manufacturing of small to medium diameter dishes					X		X
Antenna control and feed positioning	X	X	X		X		X
Decade bandwidth feed antennas for dish and lens flux concentrators	X				X		X
Phased arrays for aperture and focal plane applications	X	X	X	X		X	
Low-noise receivers	X	X	X	X	X	X	X
High-speed (Tb/s) links	X	X	X	X	X	X	X
Low-cost, high-speed analog to digital converters	X	X	X	X	X	X	X
High-speed signal processing (Pb/s) and supercomputing	X	X		X		X	X
Software engineering for intelligent array control	X			X	X		X
RF interference mitigation	X			X			X

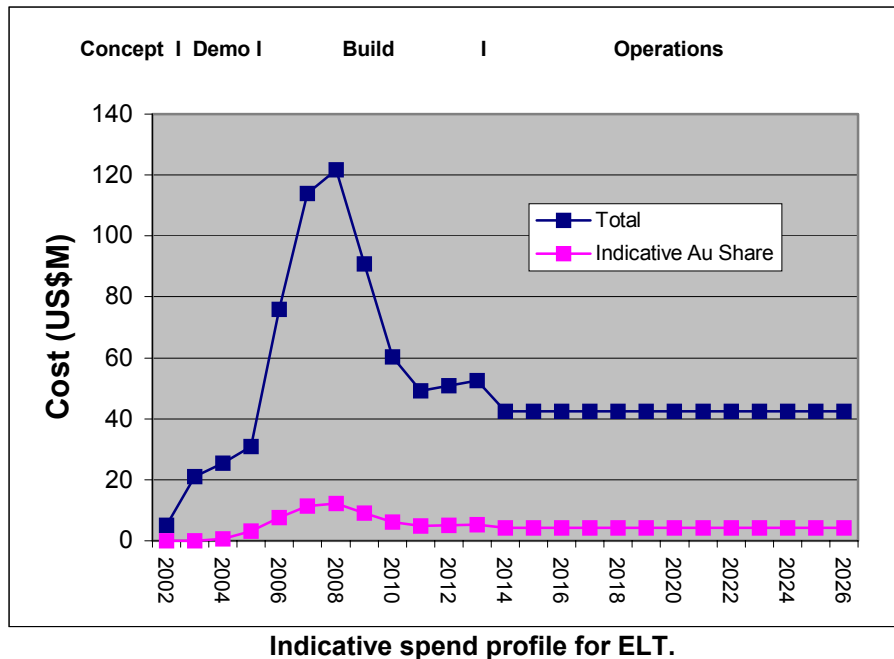
Draft SKA capability map (per: International Engineering Management Team)

The total capital amount required for Australia's participation in the SKA is approximately equal to the capital cost of the ATCA measured in 2004 dollars (A\$150m), spread over the next 15 years. Australia's potential share of the ongoing SKA operational costs is thus likely to be on a par with its current operational commitment to the current ATNF telescopes. Given that the SKA will largely supplant the capabilities of these telescopes, it is only appropriate that current operational resources be considered for re-direction in this fashion on this timescale.

11.2 ELT

The total cost of a 30m ELT is estimated at US\$700M (design, development, construction), with US\$50-75M per year required over at least a 20-year lifespan for operations and improvement thereafter. The design and development stage of an ELT is expected to last 3 to 5 years, followed by a construction phase of 5 to 7 years, so that first light is expected by 2012 to 2016, depending on the size and complexity chosen for the ELT.

For sums of about \$100M capital over 10 years followed by \$7M annually, Australia could obtain a significant share of the world's very best optical telescopes of the next generation. It is worth noting that when scaled to present value, these investments are comparable with those invested by Australia in the past - the construction cost of the Anglo-Australian Telescope (built in 1973), with instruments, would be about \$69M if built today. A sensible resourcing strategy for Australia would include joining international design consortia now in order to reap industrial benefits from the multi-million dollars contracts being let now, and the \$100M contracts that will be let later during the ELT build phase. Some of the operational funds could be released by the phased decommissioning of some older optical-IR infrastructure.



To assess the opportunity for Australian industry to contribute to an ELT program, DITR funded a specialist consultant through the Supplier Access to Major Projects (SAMP) program. This consultant identified several companies capable of producing complete ELT subsystems, and dozens of suppliers of specific components

12. Conclusion

By working together, Government and Astronomy Australia can prepare to achieve a vision:

- A Square Kilometre Array (SKA) built in outback Australia (the process being equivalent to convincing the IOC to have Australia host the Olympic Games)
- An Extremely Large Telescope (ELT) built in Antarctica (or at least Australian participation in an overseas ELT)
- Continued growth in international calibre research and discoveries
- Astronomy training feeding future astronomy research and transferring skills to industry (telecommunications; lasers; optics; medicine; etc)
- Regional development leveraged through tourism, education and infrastructure development
- Industry growth through building and maintaining large scale facilities and instruments
- International prestige for Australia
- A student population encouraged to study physics and mathematics

13. Recommendations

- 1) That guided by the strategic priorities identified in its decadal review process, Australia should build on its research, development and training capability in astronomy - including theoretical, observational and laboratory astrophysics, and instrumentation.
- 2) That Astronomy Australia and Government should work together via a 'whole-of-government' approach, to participate in and potentially host large-scale facilities such as SKA and ELT that are critical long-term major infrastructure investments for astronomy.
- 3) That as a next step toward SKA, Government should proceed to establish a radio quiet zone (~50km radius) at the representative site in Western Australia.
- 4) That as a next step toward ELT, Government should specify and support astronomy within the "agreed priority areas" for the Australian Antarctic Division.

GLOSSARY

AABoM	Australian Astronomy Board of Management
AAIN	Australian Astronomy Industry Network
AAO	Anglo-Australian Observatory
AARNet3	The third and latest Australian Academic & Research Network
AASTINO	Automated Astrophysical Site-Testing Observatory
AAT	Anglo-Australian Telescope
AC ³	Australian Centre for Advanced Computing and Communications
AGSC	Australian Gemini Steering committee
ANU	Australian National University
AO	Adaptive Optics
APAC	Australian Partnership for Advanced Computing
ASA	Australian Astronomical Society
ASKACC	Australian Square Kilometre Array Consortium Committee
ATCA	Australia Telescope Compact Array
CAT	Computer Aided Tomography
CPSR2	Caltech Parkes Swinburne Recorder II
DSN	Deep Space Network (NASA)
ELT	Extremely Large Telescope
EOS	Electro-Optic Systems
ESO	European Southern Observatory
EU	European Union
GSAOI	Gemini South Adaptive Optics Imager
IAU	International Astronomical Union
IR	Infrared
ISI	Institute of Scientific Information
IVO	International Virtual Observatory
KAOS	Kilo Aperture Optical Spectrometer
LAN	Local Area Network
LBA	Long Baseline Array
LOFAR	Low Frequency Array
MNRF	Major National Research Facilities
MSO	Mount Stromlo Observatory
NASA	National Aeronautics and Space Administration (USA)
NCA	National Committee for Astronomy (Australian Academy of Science)
NIFS	Near-infrared Integral Field Spectrograph
OTC	Now AOTC, the Australian & Overseas Telecommunications Corporation
PPARC	Particle Physics and Astronomy Research Council (UK)
SAMP	Supplier Access to Major Projects
SAPAC	South Australian Partnership for Advanced Computing
SKA	Square Kilometre Array
SSO	Siding Spring Observatory
SUSI	Sydney University Stellar Interferometer
TAMA	Japanese gravitational wave experiment (A tama is a drum)
UKST	United Kingdom Schmidt Telescope (now operated by the AAO)
UNSW	University of NSW
VLBI	Very Long Baseline Interferometry
VPAC	Victorian Partnership for Advanced Computing

TERMS OF REFERENCE

(1) Provide a stocktake of Australia's capability in astronomy, including involvement and interest in international projects, and demonstrate its relevance to the development of Australia's excellent science, engineering and technology base (including human capital).

(2) Noting prior work, describe the flow-on benefits to the Australian economy and society from maintaining and developing Australia's astronomy capability.

(3) Based on the above, propose possible priorities for future investment including in international facilities.

(4) Illustrate possible successful resourcing strategies that could be applied in the future.

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- **Professor Matthew Bailes** (Director, Swinburne University Centre for Astrophysics & Supercomputing, Chair Australia Telescope Steering Committee)
- **Professor Brian Boyle** (Director CSIRO-ATNF, Chair-Elect of National Committee for Astronomy)
- **Dr Bob Frater** (Vice-President, Innovation, ResMed; former positions include CSIRO Deputy Chief Executive, and Chief of CSIRO Radiophysics)
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