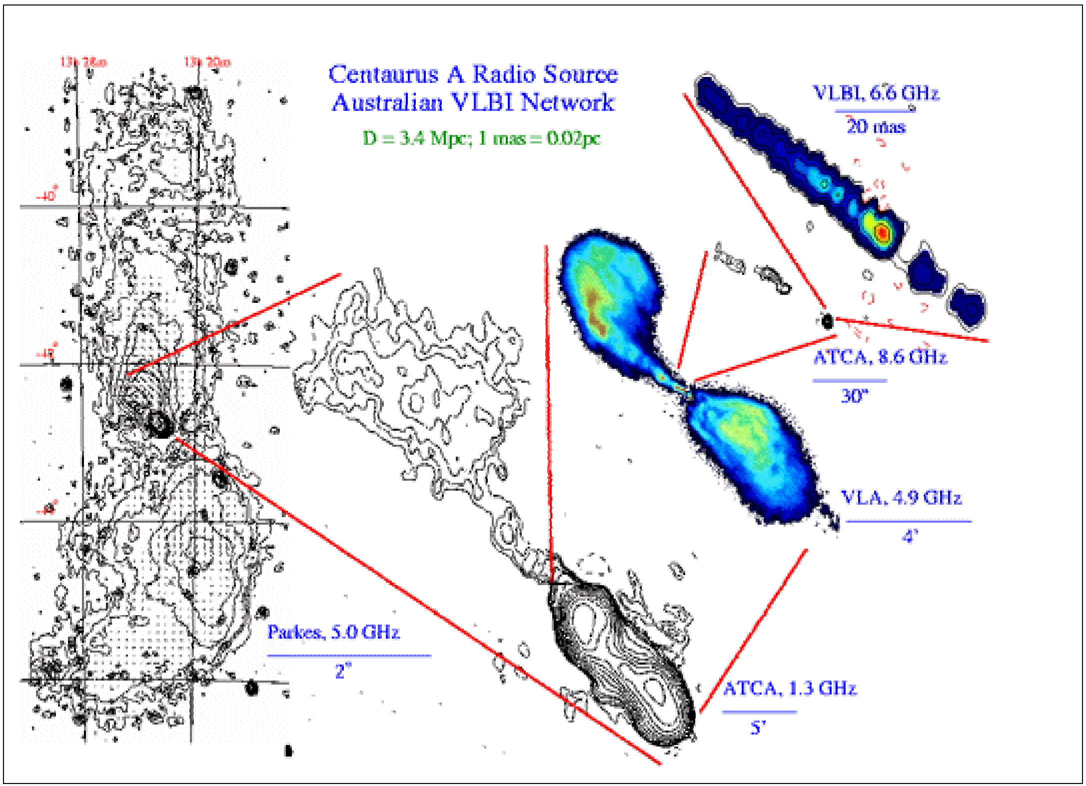
Australia Telescope National Facility
Annual Report Number 4, 1999 - 2000

Upgrade of ATNF and University of Tasmania Radio Astronomy Facilities

Established and Supported Under the Australian Government's Major National Research Facilities Program



Images of the radio galaxy Centaurus A obtained using progressively increasing angular resolution. The highest resolution image (right) shows the 'jet' of the galaxy and was produced using the Australian very long baseline interferometry (VLBI) array, incorporating the newly-commissioned Ceduna antenna operated by the University of Tasmania. The VLBI array has been upgraded substantially in the course of the MNRF Program, with most of the upgrade activities now being complete.

Australia Telescope National Facility

Mission

- To operate and develop the Australia Telescope as a national research facility for use by Australian and international researchers
- To exploit the Telescope's unique southern location and technological advantages to maintain its position as a world-class astronomy observatory
- To further the advancement of knowledge

Objectives

- To continue to operate the Australia Telescope in such a way as to maintain a leading international position
- To upgrade the Telescope to maintain its competitiveness in the medium term (3-8 years), including the MNRF-sponsored upgrades
- To position the Telescope to participate in major international radio astronomy projects developing over the next decade, including projects such as the Square Kilometre Array
- To conduct an effective outreach program

ATNF Annual Report

In addition to this annual report detailing MNRF-related activities, the ATNF publishes a comprehensive Facility annual report covering areas such as governance, staffing, administration, performance indicators, and outreach activities. The Facility annual report for the calender year 1999 is submitted as an adjunct to this MNRF report.

Australia Telescope National Facility

Major National Research Facilities Program

Annual Report No. 4, 1999 - 2000

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P J Hall, 31 August 2000

Director's Foreword

The first scientific results from the MNRF Program upgrades have excited all of us associated with the Program. The beautiful image of Centaurus A, shown on the cover of this report, illustrates clearly the VLBI capabilities now available to Australian astronomers. While the AT Compact Array high-frequency upgrade is less advanced, an early 22 GHz astronomical image (Figure 4-6) shows the shape of things to come. The final outcomes and time-scales are coming into focus and we are starting to look at the niche we will occupy with the upgraded Australia Telescope Facilities.

The first astronomy results are very encouraging but it is equally impressive to see the engineering successes necessary to exploit advanced technology, such as high-frequency integrated circuit technology. A less direct benefit of this upgrade investment is also becoming increasingly apparent. The vigorous R&D effort required by the engineering and scientific staff at the ATNF allows us to maintain a leading-edge position in technology. This is a very healthy situation and will keep the ATNF in a good position to influence future developments in radio astronomy world-wide. At the last meeting of the Australia Telescope Steering Committee the importance of the R&D programs being conducted at the ATNF was acknowledged, and a new performance indicator based on our ability to meet development milestones and to bring new systems into operation was adopted. Targets for costs, time-scales and performance are being met, as is also clear from this annual report.

The mid-term review by the Australia Telescope Steering Committee, described in Section 3, provided important feedback. The reviewers endorsed the proposed changes in direction and timescale. In particular, the reliance on leading-edge integrated circuits for receivers has led to the end-point of the Program being slipped from January to December, 2002. From a performance viewpoint, the new-generation devices will substantially increase telescope sensitivity relative to those proposed at the outset of the Program.

With the VLBI upgrade almost completed, the challenge for the ATNF, the University of Tasmania, and the Australian astronomy community is to promote and operate the new network in a way that maximizes scientific return. An area of concern is the resource pressure on the Department of Physics at the University of Tasmania. The reviewers noted the effects this may have on the productive and safe operation of the Ceduna and Hobart radio observatories. On 7 July, 2000 Russell Cannon (Chair of the Australia Telescope Steering Committee) and I discussed the future of the University of Tasmania involvement with Prof Andrew Glenn, Pro-Vice Chancellor (Research), University of Tasmania. Within the financial constraints now imposed on the University we were assured that they would continue to support the upgraded facility. Opportunities to use the new facilities as a focus for future support for physics in the university should be explored.

I am pleased to report that the ATNF strategic research into the proposed Square Kilometre Array (SKA), which was supported largely by the MNRF Program, has led to CSIRO funding a new four-year $1.5M project. Australia stands a good chance of hosting the $1000M SKA and it is vital that our contribution to, and influence of, the international project continues. While the SKA is likely to begin operation around 2015, critical technology and siting decisions will be made in 2005.

On a somewhat shorter time-scale, the ATNF will be collaborating with the Institute of Astronomy and Astrophysics of the Academia Sinica, Taiwan who have funding to build a highly sensitive telescope to probe variations in the cosmic microwave background. Known as AMiBA, the instrument will be operational before 2004. We will use the high-frequency design and production capability developed by the ATNF under the MNRF Program to develop some parts of this instrument. While our support for AMiBA will have some impact on the MNRF program itself, the direction of the research aligns very well with our strategic instrumental objectives in these areas. We have already identified an opportunity to develop a wide band continuum correlator, based on the AMiBA prototype, which could be incorporated in the ATCA concurrent with the MNRF upgrade. This would give the upgraded ATCA a continuum sensitivity greater than any other telescope in the world.

Prof Ron Ekers
Program Director

Executive Summary

The Australia Telescope National Facility and the University of Tasmania are upgrading the AT Compact Array (ATCA) and the Australian Very Long Baseline Interferometry (VLBI) network to provide new leading-edge radio astronomy capabilities. The upgrades will give the Australian and international astronomy communities instruments which complement space optical telescopes, and which provide scientific and technological stepping stones to very sensitive radio telescopes likely to be operational in the decade 2010-2020. The Australian upgrades are funded largely by the Commonwealth's MNRF program and were begun in early 1997; the last activities are now scheduled for completion by the end of 2002. In September 1999 a mid-term review of the ATNF and University of Tasmania projects was conducted on behalf of the ATNF Steering Committee; the review was at the request of the ATNF Director and its findings are summarized in Section 3 of this report.

The biggest of the upgrades is the extension of the ATCA to operate at high frequencies (or millimetre wavelengths). Using a variety of advanced electronic, electromagnetic and mechanical engineering techniques, the upgrade will allow astronomers to make, for the first time in the Southern Hemisphere, very detailed images of the radiation from many common molecules in space. As well, the order-of-magnitude increase in Telescope maximum operating frequency gives a similar increase in potential angular resolution, giving much finer detail in radio images of the southern sky. The MNRF funds have been augmented by some $3.5M in additional support from CSIRO, allowing a two-dimensional ATCA configuration and better high-frequency receivers. These extensions to the project have increased substantially the scientific potential of the instrument.

Good progress is being made on the high-frequency upgrade and the last year has seen important milestones reached in the project. These include:

- completion of a new north spur interferometer track and extra stations (antenna locating and connection points) on the original east-west track;

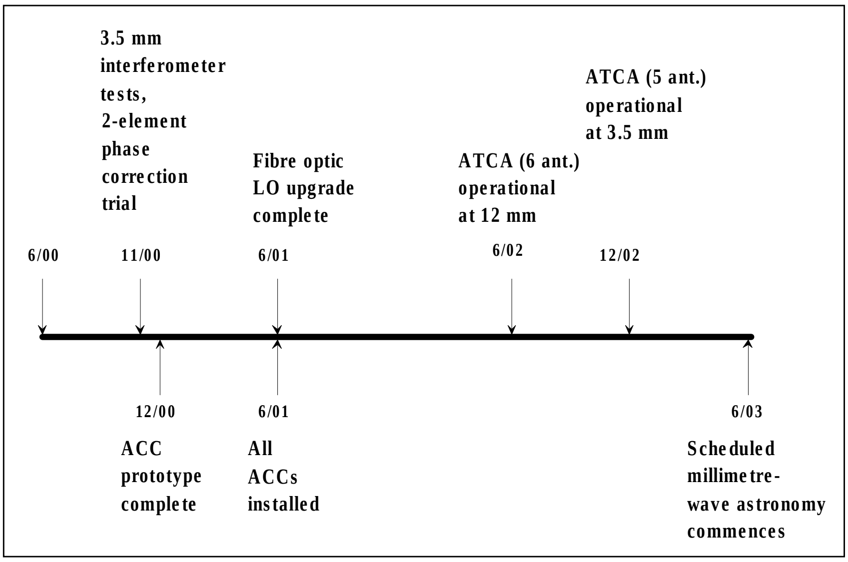
- installation of extended high-frequency reflecting surfaces on five ATCA antennas to be used regularly in millimetre-wave observations;

- trial of prototype receiver, local oscillator and computing systems in a limited test interferometer at Narrabri, resulting in the first astronomical image from the ATCA operating at millimetre-waves;

- delivery and initial evaluation of the first of five atmospheric sensing receivers designed to correct the image distorting effects of atmospheric water-vapour.

While the ATCA will have some operational high-frequency receivers by the contract target date of January 2002, the incorporation of more sensitive receivers than envisaged originally has required some revision of ATNF program plans (see Program Director's Foreword, Page

1). A summary timeline incorporating remaining major projects is shown below; note that it is expected to offer scheduled high frequency observing from the winter of 2003.



Summary timeline for ATCA high frequency upgrade.

The second of the MNRF upgrades, undertaken jointly by the ATNF and the University of Tasmania, involves expanding the Australian Very Long Baseline Interferometry network. VLBI is a technique in which cosmic radio signals received by widely separated antennas are recorded, then subsequently combined electronically to produce highly-detailed images of the sky. The upgrade of the Australian network has included commissioning of a 30 m antenna at Ceduna in South Australia, provision of improved receivers and high-stability, hydrogen-maser frequency sources at a number of observatories, and installation of new signal processing and recording equipment. Although some high performance (and relatively costly) receiving systems for Ceduna and Hobart are still being constructed by the University of Tasmania, the remainder of the VLBI upgrade is now functionally complete and in routine operation.

The third of the areas covered by the MNRF Program is different in concept to the two facility upgrade programs in that it involves the promotion of collaborations between Australian astronomers and their international colleagues. In particular, the aim has been to gain Australian access to the operation or design of existing (or planned) large-scale instrumentation. Eleven projects, covering the electromagnetic spectrum from gamma rays to radio waves, have been supported. No new allocations have been made in the past year but outstanding work continues in a number of projects, including strategic research which has been instrumental in attracting CSIRO funding for a new $1.5M seed research program to investigate key aspects of the Square Kilometre Array (Section 4(c)*(iv)*).

Several aspects of the MNRF Program are at the leading edge of technology but, in some cases, agreements with R&D partners limit the immediate commercialization potential. However, the ATNF actively disseminates its technology and techniques within the international astronomy community, including those sections developing next-generation telescopes such as the Square Kilometre Array. While opportunities for outsourcing very advanced electronic systems are limited in Australia, the ATNF is working closely with companies developing new precision metal forming techniques; this work is central to the MNRF high-frequency receivers and is described in Section 4.

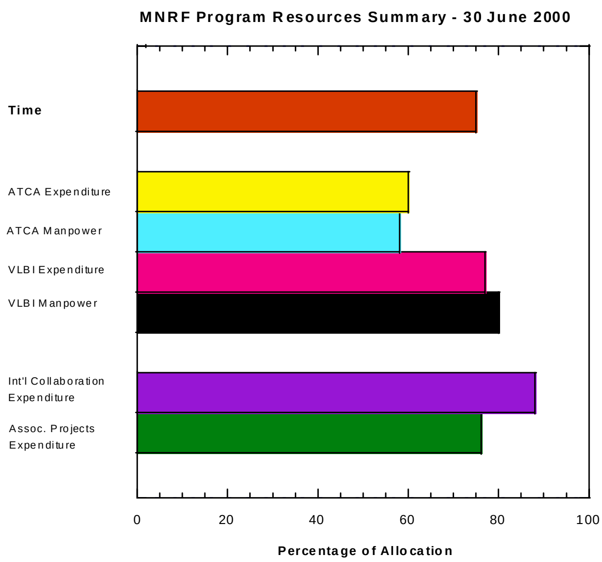
The table below summarizes the financial situation for the MNRF Program as at 30 June 2000. The category "associated projects" includes funds for ATNF strategic research, project management, manpower and test equipment.

ATNF - U. Tas. MNRF Program - Summary Financial Information as at 30 June 2000

Project	Provision	Expenditure to Date	Balance
AT Compact Array High-Frequency Upgrade	5,550 000	3,295,400	2,254,600
VLBI Upgrade (ATNF + U. Tas.)	2,040,000	1,585,897	454,103
International Astronomy Collaboration	1,260,000	1,105,400	154,600
Associated Projects	2 150 000	1 629 500	520,500
TOTAL	**11,000,000**	**7,616,197**	**3,383,803**

All amounts are in Australian dollars and account has been taken of unspent funds held by the University of Tasmania. Interest on these funds has, however, been excluded.

The state of the Program resources is summarized in graphical form below. Expenditure and (where appropriate) manpower is shown relative to elapsed time. For simplicity, a single Program duration of six years (January 97 – January 03) is assumed. This reflects the amended timescales outlined in the Program Director's Foreword. As noted in the last Annual Report, substantial early utilization of the international astronomy collaboration funds and the associated projects budget was planned. While this has been largely achieved, re-allocation of some funds within each category has enabled effective continuing projects (in the areas of international travel for millimetre-wave astronomers and Square Kilometre Array strategic research).



1. Introduction

This document is the fourth annual report by the CSIRO Australia Telescope National Facility (ATNF) to the Department of Industry, Science and Resources (acting for the Commonwealth of Australia) covering activities supported under the Major National Research Facilities (MNRF) Program. The report covers the period 1 July 1999 to 30 June 2000. It incorporates material supplied by the University of Tasmania, a co-signatory to the MNRF agreement, as well as summaries lodged by recipients of funds paid under an MNRF-supported international astronomy collaboration scheme. For completeness, an overview of the ATNF Program background, extracted from earlier annual reports, is included as Section 2 (below). Section 3 summarizes recent ATNF and other management decisions relevant to the Program, while Appendix 1 provides a full description of the ATNF and University of Tasmania Program management. Remaining sections of this report summarize progress in individual projects supported by the MNRF scheme and provide financial summaries for the Program.

2. Background

The ATNF, together with co-proponents the University of Tasmania and the (then) CSIRO Division of Radiophysics, lodged an initial funding submission under the Major National Research Facilities Program scheme in November 1994. A final proposal by the ATNF and the University of Tasmania was submitted in January 1995. Following notification of the success of the application in January 1996, a contract was signed between the Commonwealth, CSIRO and the University of Tasmania on 19 February 1997. The contract covers three major areas:

- an ATNF upgrade of its Compact Array radio telescope to operate at high frequencies (corresponding to millimetre wavelengths), and an extension of its very long baseline interferometry (VLBI) capabilities;

- a University of Tasmania expansion of its VLBI capabilities at radio observatories in Hobart and Ceduna, and the operation of those observatories as national facilities;

- a program to fund international astronomical collaboration, administered by the ATNF acting on recommendations from the Australian Academy of Science’s National Committee for Astronomy.

In addition to the major ATNF upgrades, the contract provides for the funding of two small ATNF strategic research projects, purchase of test equipment by both the ATNF and the University of Tasmania, program definition and project management, and project manpower. The contract also specifies a number of milestones, the principal dates being March 2000 and January 2002 for completion of the VLBI and high-frequency upgrades.

The upgraded ATNF and University of Tasmania telescopes will provide Australian astronomers with important new observational tools with which to view the universe. The ATCA millimetre-wave capability will permit astronomers, for the first time in the Southern

Hemisphere, to image, at resolutions comparable with space-based optical telescopes, the signature emission from many cosmically abundant molecules in the near and distant universe. Similarly, the VLBI upgrades will allow data from radio telescopes, separated by thousands of kilometres, to be combined to produce images with a resolution far superior to those from the largest optical telescopes, whether ground- or space-based.

3. Program Management Update

Appendix 1 contains an overview of the MNRF Program management arrangements. As noted in the Appendix, the ATNF Steering Committee has roles involving program guidance and annual report submission. To facilitate these functions, the Steering Committee has a sub-committee to comment on progress and expenditure relating to the Program and to review annual report drafts. The sub-committee now comprises Dr R Cannon, Dr P Scaife, and Prof J Storey (Appendix 2). At the request of the Program Director, Prof R Ekers, the sub-committee convened a formal mid-term review of the Program in September 1999. The structure and outcomes of the review were reported in a submission by Dr R Cannon to the Department of Industry, Science and Resources (dated September 22, 1999); major points noted are summarized below:

- MNRF projects were making excellent progress in almost all respects;
- planning, management and execution of the Program has been very well handled by the ATNF, with most projects keeping to time and budget;
- just over half the funds have been expended in half the allocated Program duration, and continuing projects are on track for completion by the end of 2002;
- the reviewers endorsed the minor changes and adjustments which have been made to optimize astronomical outcomes given new technological developments;
- good progress has been made by the University of Tasmania in establishing the Hobart and Ceduna antennas as components of the upgraded Australian VLBI network;
- the reviewers expressed concern about the continuing size reduction of the Department of Physics at the University of Tasmania, the host institution for the Hobart and Ceduna facilities, noting possible effects this may have on the productive and safe operation of the radio astronomy observatories;
- the MNRF international collaboration support has forged very productive relationships (from both scientific and external investment viewpoints) and the reviewers expressed the hope that a replacement funding program can be continued when the MNRF Program terminates.

At its meeting in March 2000 the full Steering Committee acknowledged the efforts of those involved in the review process and did not add further to the reviewers' commentary.

4. ATNF Upgrades and Extensions

The ATNF upgrade of the Australian VLBI network is now complete and the extended network is in routine astronomical use. Good progress continues to be made in the high-frequency upgrade of the AT Compact Array (ATCA) at Narrabri. An important milestone - the test of a 12 mm interferometer - was met in October 1999. Efforts now centre on completing the remaining receiver, local oscillator and phase correction equipment.

MNRF Annual Report No. 3 reviewed the alignment of a CSIRO integrated-circuit design initiative with the MNRF Program. The situation concerning the use of CSIRO-designed monolithic millimetre-wave integrated-circuits (MMICs) in the new ATCA receivers has become much clearer in the last year. Successful "on-wafer" tests of the high-frequency, low-noise, amplifier chips have now been made. These MMICs are advanced indium phosphide (InP) types and will provide the highest attainable telescope sensitivity. The chips are yet to be diced (separated) by TRW Inc., the US foundry manufacturing the MMICs, and it is likely that delivery of high-frequency observing capability at the ATCA will be delayed beyond the original MNRF target date of January 2002. However, with a factor of nearly two in sensitivity at stake, the ATNF has decided against implementing any interim solutions and has taken the view that a delay of 6-12 months is acceptable; this position was endorsed at the mid-term MNRF Program review outlined in Section 3.

Summaries of the ATNF high-frequency and VLBI upgrades are given in the following sub-sections.

(a) High-Frequency Upgrade

This extension adds two new observing bands to the ATCA: 12 mm (16 - 25 GHz) and 3.5 mm (85 to >95 GHz). It increases the angular resolution of the Telescope by an order of magnitude and makes accessible the radiation from a range of cosmically abundant molecules not previously observable by Southern Hemisphere synthesis instruments.

Good progress has been made in implementing the new ATCA capabilities and the first images at 12 mm have already been produced (Section 4(d)), albeit with a limited observing system. More detailed project summaries are given below but it is worth noting that the second half of 1999 was an especially busy time, with much on-site installation and testing work. Apart from the outfitting of four antennas with new panels, a series of 12 mm interferometer tests were conducted, with the first visibility fringes using prototype receivers (using interim low-noise amplifiers) being recorded on October 28. It was originally planned to extend the testing to 3.5 mm but problems obtaining low-noise amplifiers prevented this. It is expected that the first 3.5 mm tests will be carried out in November 2000 and that the delivery of final 3.5 mm systems in 2002 will be possible.

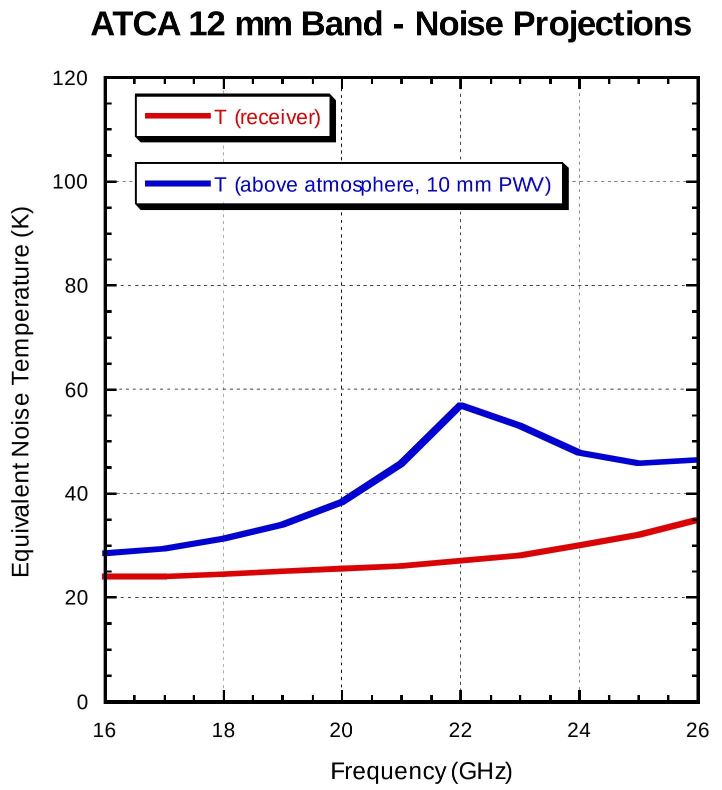
While much of the hardware engineering effort is obvious, it is especially important to stress the considerable efforts being directed to system testing and commissioning. It is this work which provides the vital link between raw engineering and final astronomy. The ATNF is unique in its range of system engineering and testing skills, and the past year has seen substantial efforts by both Narrabri and Sydney staff. While much work remains, especially in establishing satisfactory 3.5 mm operation, the initial system tests validate the overall design philosophy adopted for the ATCA upgrade.

Based on initial component performance measurements, projections of ATCA high-frequency specifications have been updated; a summary is given in Table 4-1 (below). Note that the projections are based on typical values of atmospheric precipitable water-vapour (PWV).

Table 4-1 ATCA Millimetre Wave Performance Projection

Band (mm)	**12**			**3.5**		
Frequency (GHz)	16	22	25	85	100	110
Number of 22 m Antennas	6			5		
Antenna Efficiency	0.59	0.59	0.59	0.45	0.40	0.37
Array Physical Area (m^2)	2280			1900		
Maximum Baseline (km)	6			3		
Field of View (arcsec)	211	153	135	40	34	31
Best Synthesized Resolution (arcsec)	0.77	0.54	0.49	0.29	0.25	0.23
Receiver Type (SSB, Dual-polarization)	Cooled (20 K) InP MMIC					
T_{rx} (Flange) (K)	24	27	32	85	76	80
T^*_{sys} (Above-atmosphere equivalent, zenith, 10 mm PWV) (K)	28	57	46	138	136	162
Continuum Flux Sensitivity ΔS^* (6 hr, 10 mm PWV, 2 x 128 MHz IF, 2-bit sampling) (mJy/beam)	0.031	0.063	0.050	0.24	0.26	0.34

Figure 4-1 gives more detailed information about the expected variation in system temperature as a function of observing frequency.



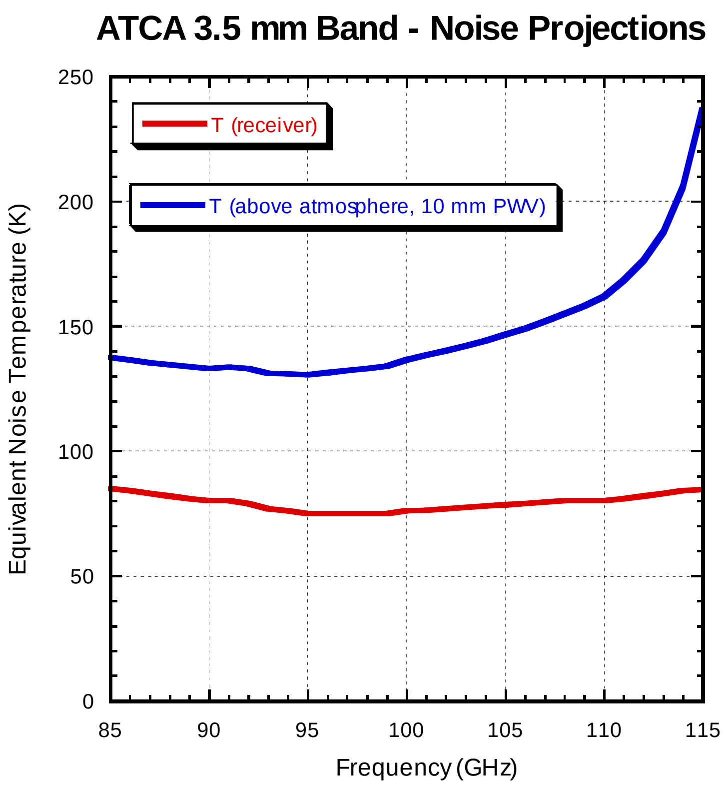


Figure 4-1 *Plots showing the expected variation in ATCA equivalent noise temperature as a function of frequency in the 12 and 3.5 mm bands. The red traces show the receiver (flange) noise temperatures, while the blue lines show indicative above-atmosphere system temperatures with 10 mm of precipitable atmospheric water-vapour - a common value during Narrabri winters.*

(i) 12/3.5 mm Receivers

Design and construction overviews for these cryogenically-cooled receivers (contained in a common dewar) are given in Annual Reports No. 2 and 3; this note gives a production status report and projections for system performance based on initial measurements.

At present, production of the new receiver packages is in progress, with precision metal components being manufactured by both ATNF staff and commercial contractors. A variety of advanced techniques are being used to produce the large number of very high precision waveguide components needed in the receivers. These include techniques such as wire electro-discharge cutting, laser machining, water cutting, electro-discharge machining, electrolytic deposition plating, and copper electro-forming.

As mentioned above, cryogenic low-noise amplifier (LNA) development is now reliant on interactions with TRW Inc. LNAs for both 12 and 3.5 m have been tested on-wafer at ambient temperature and performance is close to that predicted by circuit simulation. The yield rate for operationally useful chips is about 50%. Wafers containing many chips will shortly be returned to TRW for scribing and dicing, giving individual LNAs suitable for packaging at the ATNF (Figure 4-2). These amplifiers will be tested further and, in particular, their performance at cryogenic temperatures (<20 K) will be assessed. If tests are satisfactory, LNA production will begin in earnest in early 2001. However, it is expected that sample amplifiers will be available for use in 3.5 mm interferometer tests at Narrabri in late 2000.

Manufacture of the scroll helium compressors described in MNRF Annual Report No. 3 is continuing, with several of these units now in service at the ATCA. Two units have also been delivered to the University of Tasmania for use at the Hobart and Ceduna radio observatories.

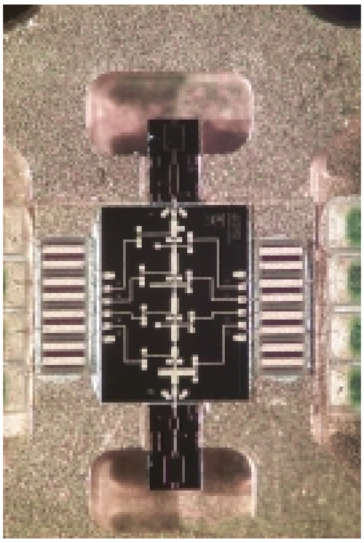


Figure 4-2 *Early prototype 3.5 mm MMIC low-noise amplifier assembled in a waveguide mounting. The central integrated-circuit region is about 3 x 2 mm.*

(ii) ATCA Antenna Surface Extension

Five of the six ATCA antennas now have solid reflecting surfaces extending to the full 22 m dish diameter (Figure 4-3). ACTA antenna CA06, which is less likely to be useful in 100 GHz observations, retains its original mix of solid and perforated surfaces; the perforated surface covers the outer 3.5 m dish radius and ceases to reflect efficiently at frequencies above 50 GHz. The surface extension project has doubled the sensitivity of the 100 GHz ATCA and alleviated substantially the "missing spacing" problem during 3.5 mm aperture synthesis; this would have been much more severe with 15 m dishes at the 30 m ATCA minimum spacing. As well as the five ATCA antennas, the ATNF 22 m Mopra radio telescope (near Coonabarabran) has also been upgraded under a separate (non-MNRF) funding arrangement with the University of NSW.

Earlier annual reports have described contractual and manufacturing issues relating to the surface extension, as well as initial tests on CA03 - the first antenna to be extended. With six new surfaces in place in the past year, a program of first-pass measurement and adjustment has been done using 12 GHz microwave holography. A new holography signal processing unit, developed and constructed for the ATNF by Astrowave P/L, has been an important part of these tests.

All antennas have now been adjusted such that the rms surface error is 250 μm rms (average for all antennas). With the delivery of a 30 GHz holography receiver scheduled for October 2000, it is expected that a final rms error of ~150 μm can be obtained, yielding the 40% aperture efficiency target for the upgraded ATCA operating at 100 GHz.

Figure 4-3 *Five antennas of the ATCA showing solid surfaces extending to the full diameter of 22 m*

(iii) Atmospheric Phase Correction

This remote-sensing project aims to correct image blurring caused by the motion of blobs of water-vapour in the atmosphere above the ATCA. Emission from water-vapour in the line-of-sight of each antenna is measured continuously, and corrections are made to compensate for the extra time-delay introduced when cosmic radio waves encounter the blobs. The procedure is the radio analogue of de-blurring using adaptive optics in visible-light astronomy.

Water-vapour sensing is done using a channelized 22 GHz radiometer, co-located with the astronomical receiver in each ATCA antenna. Refer to earlier MNRF annual reports for more technical details. A minor design change has been made, prompted by the availability of moderate-cost 22 GHz low-noise RF amplifiers. It is now likely that the sensing radiometers will use entirely separate feeds and RF electronics, rather than sharing first-stage, cryogenically-cooled, astronomy components. The separation of the astronomy and sensing functions gives greater design flexibility and less chance of gain instability due to cryogenic refrigerator cycling. It is expected that radiometer system temperatures of ~ 150 K will be achieved, allowing phase correction to < 10° rms.

Figure 4-4 shows the arrangement of the four sensing channels in the prototype ATCA water-vapour radiometers. The channels are placed so as to maximize the sensitivity to water-vapour emission, while allowing greatest rejection of spurious emission from clouds (containing liquid water), ground pickup and other sources of unwanted radiation.

One radiometer has been completed and is currently undergoing laboratory tests. It is expected that a second unit will be finished by October 2000, allowing trial interferometric phase correction at Narrabri. If the performance is satisfactory, a further three units will be constructed, outfitting the five ATCA antennas to be used for 3.5 mm observing.

The ATCA water-vapour radiometers are being designed and constructed by Astrowave P/L, in consultation with ATNF engineers and system scientists.

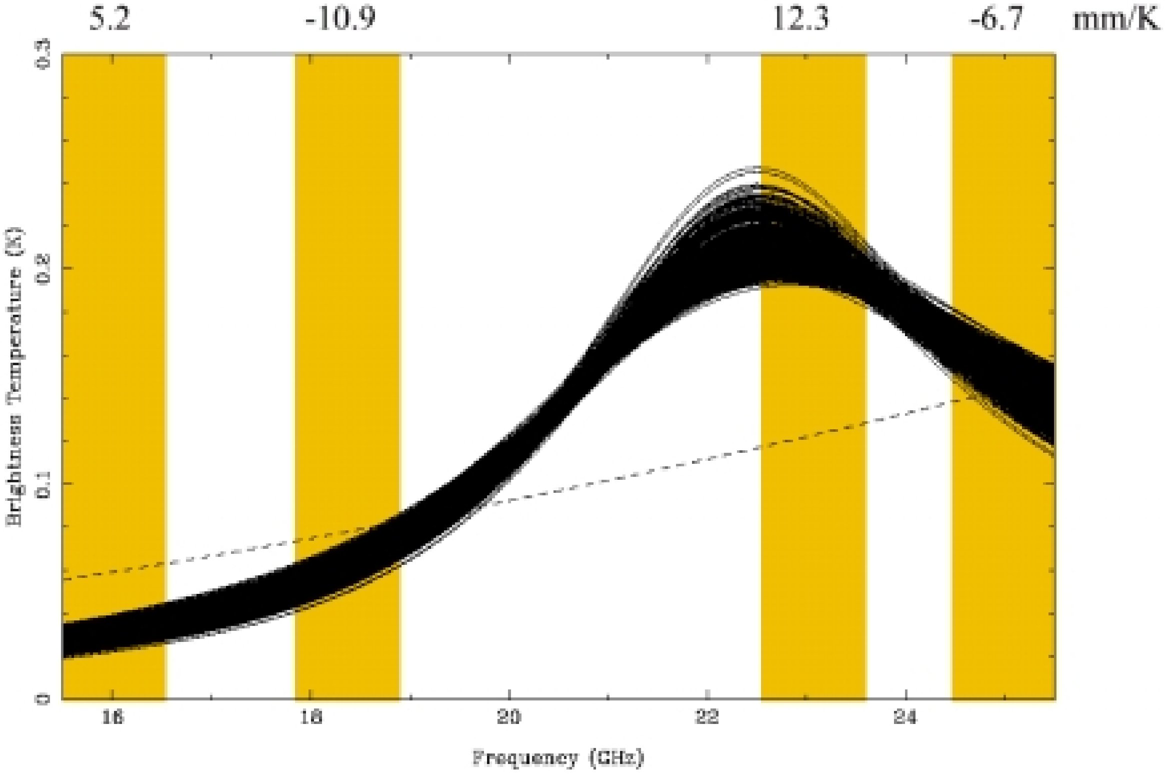


Figure 4-4 *Plot showing the position and width of the water-vapour sensing bands in the prototype ATCA radiometers (vertical yellow shading). The solid traces indicate the predicted change in atmospheric emission temperature, given a 1 mm change in electrical path due to water-vapour. The different traces are for different meteorological conditions. The dashed line shows the form of the emission from a liquid water (clouds). The nominal relative weight used in combining the channel measurements are given at the top, in mm/K.*

(iv) ATCA Local Oscillator Distribution Upgrade

The local oscillator (LO) in a synthesis telescope is the master reference signal to which all receivers are frequency-locked, and against which variations in signal phase (caused, for example, by structure in cosmic sources) are measured. Local oscillator signals at each antenna must be as close to identical as possible, and the LO signal distribution system must be robust in the face of many make – break cycles, flowing from frequent array re-configurations. The ATCA LO upgrade will replace a troublesome “daisy chain” style co-axial cable distributor with a “star” optical-fibre network. It will also provide new equipment capable of generating the stable, pure, signals needed for high-frequency observing.

Experiments described in the last MNRF Annual Report have been vital in completing the new LO design. In the ATCA arrangement, a reference signal in the range 13 -15 GHz will be distributed to each antenna via single-mode optical fibre. The reference will directly-modulate a solid-state laser (λ = 1310 nm) and will be multiplied by either two or eight, for 12 mm or 3.5 mm observing. To ensure compatibility with existing receivers, a second optical signal (λ = 1550 nm) modulated at 160.05 MHz will be multiplexed on to the same fibre. A "round-trip" phase measurement system, designed to measure phase change due to small variations in fibre length, will be used to provide compensation at both reference frequencies.

Tests in the last year have involved evaluation of the phase noise on an experimental 2 km fibre link, assessment of LO-induced de-correlation in an interferometer using two ATCA antennas fed by a fibre-distributed, high-frequency, reference signal, and checks to ensure backwards-compatibility with receivers requiring a 160.05 MHz reference.

At present, about half the required fibre-optic cables have been installed at Narrabri; the remaining cable installation will be complete by August 2000. Fibre termination is a major task and is being done by CSIRO technical staff based at Narrabri. To ensure that the required quality control is maintained, a mobile splicing van (giving a clean, temperature-stable environment) has been constructed and staff have received intensive training in the exacting splicing and termination operations.

It is now expected that the new LO system will be operational in April 2001, about four months later than originally envisaged.

(v) ATCA Extra Stations

The original MNRF funding allocation was for four extra antenna stations on the 3 km east-west rail track of the ATCA. CSIRO provided additional funds to construct a five station, 230 m, north spur track, enhancing greatly the high-frequency imaging performance of the array. These projects, and associated works, are now complete; refer to MNRF Annual Report No. 3 for details, as well as a photograph of the upgraded array.

(vi) AT Observation Management System (ATOMS)

The stringent demands of high-frequency observing, the expansion of ATCA control and monitoring requirements, and concerns about the reliability of the present antenna control computers (ACCs), have combined to make delivery of a new-generation ACC a priority of the ATOMS project.

The new antenna control implementation was outlined in MNRF Annual Report No. 3. In the past year, the project has suffered substantial delays, including some related to the resignation of the original project leader. However, a replacement leader has now been appointed from within the ATNF (see Appendix 3) and intensive efforts are underway to ensure installation of the new ACCs by mid-2001, about one year later than forecast.

A substantial fraction of the ACC design has now been tested, with important servo functionality being demonstrated at Narrabri in October 1999. A major software component dealing with communications within antennas has also been completed, as have many necessary modifications to existing ATCA array-control software. Problems with the development environment for the pSOS real-time operating system have slowed progress, but most of these difficulties have now been resolved and work is proceding well on remaining software components. Two new Linux-based computers were installed recently at Narrabri and, in the short term, one of these will support the Java environment used in the new ACC-related array control architecture. In the longer term, the machines will also replace the functionality of existing VMS-based on-line computers.

(vii) Parkes Conversion System

This four-channel frequency conversion system, designed primarily to improve the performance, versatility and ease of control of the 64 m Parkes telescope, is now complete. The Parkes hardware and observing software is now much more compatible with new equipment and techniques developed under the MNRF program for use at other ATNF observatories. A substantial software development effort over the past year has ensured that the versatility of the hardware is well-utilized by observing software suites.

(b) ATNF VLBI Upgrade

In addition to supporting the provision of high-frequency capabilities on ATNF instruments, the MNRF Program funding provides for extension and improvement of the Australian VLBI network and, in particular, facilities managed by the ATNF and the University of Tasmania. The following four projects, identified in the MNRF contract, are now complete and the systems are in routine operation (refer to MNRF Annual Report No. 2 for technical details):

- 12 mm (22 GHz) receiver;
- hydrogen-maser frequency standards;
- S-2 playback unit;
- timing units.

(c) Associated ATNF Projects

In addition to the high-frequency and VLBI upgrades, the ATNF has contractual responsibility for several smaller areas identified under the MNRF agreement headings of project management, manpower, test equipment, and strategic research.

Brief reports on the miscellaneous MNRF areas are given below.

(i) Project Management

Apart from funding continuing Program management expenses (including the review described in Section 3), only small-scale activities were supported in this area during the last year. The most significant was the funding of poster production and travel expenses for a group of six ATNF engineers attending the Workshop on the Applications of Radio Science, held at Beechworth (Victoria) in April 2000. Details of the work presented are given in Appendix 4.

(ii) Manpower

No new appointments have been funded in the past year from MNRF allocations.

(iii) Test Equipment

No new test equipment has been purchased in the past year.

(iv) Strategic Research

In late 1999 CSIRO made a $1.5M allocation to its radio astronomy sector for research involving the Square Kilometre Array (SKA). The earlier MNRF strategic funding for work in SKA systems and interference mitigation allowed ATNF and allied researchers to demonstrate their capacity and influence in the international SKA project arena. In large measure therefore, the MNRF support laid the foundation for the new CSIRO program and, hopefully, the new program will itself be the basis of much more Australian SKA involvement, perhaps culminating in the siting of the telescope in this country.

With the CSIRO program now operational, the remaining MNRF-supported activities have been incorporated into the program; minor changes in direction have ensured better focus in the wider SKA context. Relevant parts of the CSIRO SKA program management structure are shown in Table A3-3. MNRF interference mitigation funds will be essentially exhausted by July 2000 but some SKA systems funding will continue to augment CSIRO funds in the 2000-01 financial year.

- *Square Kilometre Array (SKA, or 1 kT) Systems Project*

Following the successful completion of a PhD research project, work previously being carried out by the Department of Communications and Electronic Engineering at the RMIT University (Melbourne) on wide bandwidth focal-plane arrays ended in September 1999.

Support of the Western Australia SKA site search project (previously funded entirely by the ATNF) has been expanded, with employment of Dr Michelle Storey in a part-time support role. The WA investigations are important case studies, leading to the refinement of SKA siting criteria. While an SKA site decision will not be made before 2005, the Australian work is highlighting general siting issues and, in addition, is promulgating within the international scientific community the advantages of possible Australian sites.

As well as continuing progress in the technical aspects of the project, an outreach program, aimed particularly at the WA rural and aboriginal communities, has been developed. Since July 1999, four visits to Perth and specific areas in the Gascoyne and Mid-West have been made to review possible sites (an area of about 50 x 50km), and to participate in planning discussions with Western Australian Government agencies. These agencies include the Departments of Commerce and Trade, Conservation and Land Management, Minerals and Energy, Land and Administration, and the Native Title Unit of Ministry of the Premier and Cabinet. In addition, contact has been made with the Yamatji Land and Sea Council, and as part of the science outreach to secondary students, the High Schools in Carnarvon and Geraldton.

To compile a short-list of possible sites, three studies are proceeding under the auspices of the WA Government. These are:

- evaluation of the broad suitability of some lease-hold properties acquired on behalf of the WA Government by the Department of Conservation and Land Management for conservation purposes;

- preliminary evaluation by the WA Department of Minerals and Energy of the above sites to determine whether these sites are devoid of significant mineral or petroleum deposits, thereby gauging their compatibility with requirements for a "Radio-Quiet Reserve";

- preparation of tender documentation for a contractor to undertake the first stage of high-sensitivity measurements of the electromagnetic spectrum on a possible site.

A substantial continuing input from the ATNF is required for all these activities and, in large measure, this input has been supported to date by MNRF SKA Systems funds.

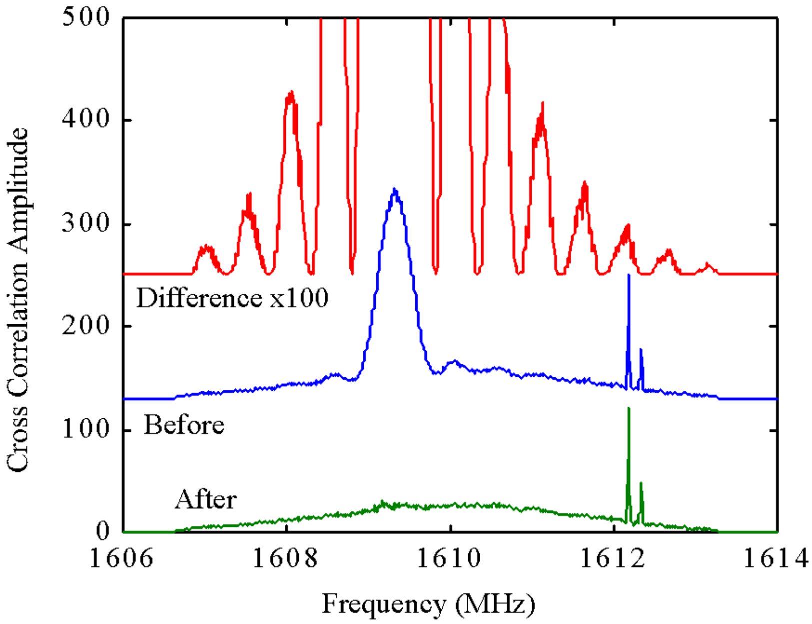
- *Interference Mitigation (IM)*

The organizational structure for the MNRF-supported IM work (outlined in Annual Report No. 3) has given an immediately-workable framework for a range of IM projects within the new CSIRO SKA program. Broadly speaking, the three main IM studies are robust receivers, post-correlation processing, and a software radio telescope project. Only the last two studies have been active to date but, from July 2000, all three projects will be supported by the new SKA program.

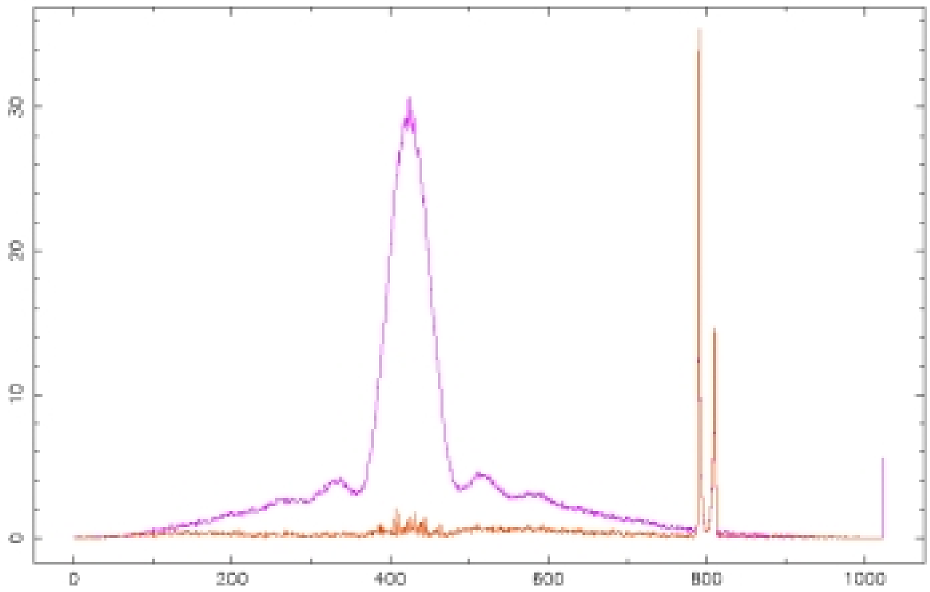
Technical results from the IM projects have been excellent, with both software telescope strategies and post-correlation techniques successfully demonstrating effective suppression of certain classes of unwanted radio signals, including those from navigation satellites and terrestial fixed-point data links. Figure 4-5(a) shows how a new digital signal processing technique has been applied to actual data recorded from antennas of the ATCA. Radio-frequency interference from a GLONASS navigation satellite has been effectively removed, and the astronomy signal has not been corrupted by the IM adaptive filtering operation. In Figure 4-5(b), a new post-correlation approach is illustrated. Here, interference from GLONASS has been removed using a post-correlation algorithm operating on data of the type routinely recorded at the ATCA. Both the adaptive filter and post-correlation approaches are likely to form part of the IM hierarchy in the SKA.

In allied work, a collaborative project with the School of Electrical and Information Engineering at the University of Sydney has resulted in a detailed report outlining ways of realizing photonic interference filters. This work has considerable application in existing radio telescopes which use analog optical fibre signal transmission links and is potentially valuable for the SKA.

As the global IM effort grows, fuelled by both astronomy and communications demands, the strong links between the ATNF and international groups are of increasing importance. As an example, real data from Parkes and the ATCA are now distributed to specialist signal processing workers, serving in some cases as benchmark data for new algorithms and techniques. CSIRO also hosted an international gathering organized under the Australian Academy of Science's E. and F. White conference scheme. Held in Sydney in December 1999 and attended by about 50 people, the conference was supported in part by MNRF interference mitigation funds. The gathering was highly successful in fostering collaborations and, indeed, the results shown in Figure 4-5 flow from conference interactions.



(a)



(b)

Figure 4-5 *Examples of interference mitigation techniques applied to ATCA data. In (a), a coherent (pre-correlation) adaptive processing scheme has been applied to 1609 MHz spread-spectrum interference from an orbiting Russian navigation satellite; after processing, the satellite interference is effectively removed without corrupting the cosmic maser signal near 1612 MHz. In (b), a related post-correlation approach involving vastly less computation substantially reduces the effect of the satellite; this approach is applicable directly to data recorded routinely from the ATCA. (In this second example, the horizontal axis is labelled in ATCA correlator channel numbers; in both (a) and (b) the vertical axes are arbitrary linear scales).*

(d) Program Science Report

(i) 22 GHz Test Observations

- *Imaging An LMC Supernova Remnant*

Figure 4-6 shows an image of N157B (also known as 30DorB) at 22 GHz. The image was made in November 1999 as an early test of the performance of the ATCA at 22 GHz. Only three prototype receivers were available and 22 GHz operation will be improved further when receivers of an upgraded design, and the new local oscillator system, are installed on all six antennas in 2002. Nevertheless, the image demonstrates the potential of the ATCA at higher frequencies.

N157B is a supernova remnant similar to the well-known Crab nebula. However, whereas the Crab nebula is a nearby remnant in the northern part of our own Galaxy, N157B is 25 times as distant, being embedded in our companion southern galaxy, the Large Magellanic Cloud. First suggestions that N157B was like the Crab nebula were made more than 20 years ago (Mills, Turtle & Watkinson 1978 MNRAS 185, 263 and Milne, Caswell & Haynes 1980 MNRAS 191, 469), but simple radio maps at that time were unable to reveal the detailed shape of the source seen here. N157B has apparently expanded to a somewhat larger size than the Crab, and is thus perhaps several millennia old (in contrast to the Crab which exploded in 1054AD).

Considerations leading to N157B as a test object were: a total flux density that remains high at short wavelengths; an angular size small enough to fit within the ATCA primary beam, yet large enough for the synthesised beam to reveal structure; and a very southern location so that it is above the horizon for long periods.

- *Calibration of Millimetre Wave Observations*

Progress is being made on two connected paths in addressing phase calibration issues for high frequency observing. A water-vapour radiometer system is being developed to directly measure changes in phase caused by fluctuations in the atmospheric water-vapour content along the line of sight (Section 4(a)*(iii)*). One radiometer is complete and is being tested; a second is scheduled to be ready in August 2000. Using these two radiometers, interferometric tests to measure the effectiveness of the system will be undertaken in late 2000. The design target is to achieve accuracies of 100 μm of differential atmospheric delay (i.e., 10° of phase at 3.5 mm). Assuming the tests prove successful, three more radiometers will be constructed.

The radiometers form, in a real sense, a phase flywheel which is calibrated by observations of astronomical sources. The flywheel allows phase corrections to be determined on shorter timescales than the normal source/calibrator cycle time. As with conventional and `fast-switching' phase calibration, the calibrator sources should be as near as possible to the astronomical source of interest, so a dense grid of calibrators is needed. The job of developing a list of high frequency calibrators for the ATCA is progressing well, with both literature searches and 22 GHz observing sessions of candidate calibrators being underway. To date, 1874 observations of 1238 candidates have been done.

Naturally, the list of candidates includes all sources from the current ATCA (15% of candidates) and VLA (27% of candidates) calibrator manuals. The list also includes large HII regions, water-vapour masers, and many sources which will ultimately prove to be of no use as calibrators.

In addition to being useful for array calibration, the emerging source list is proving interesting to two international teams involved in cosmic microwave background (CMB) experiments at 32 GHz. Discrete radio sources are contaminants in CMB experiments but, provided the source flux is know, this contamination can be corrected. Understanding the population of sources at these frequencies will also allow statistical estimates to be derived of the errors in the CMB observations of large regions of the sky where contaminating sources cannot be removed directly.

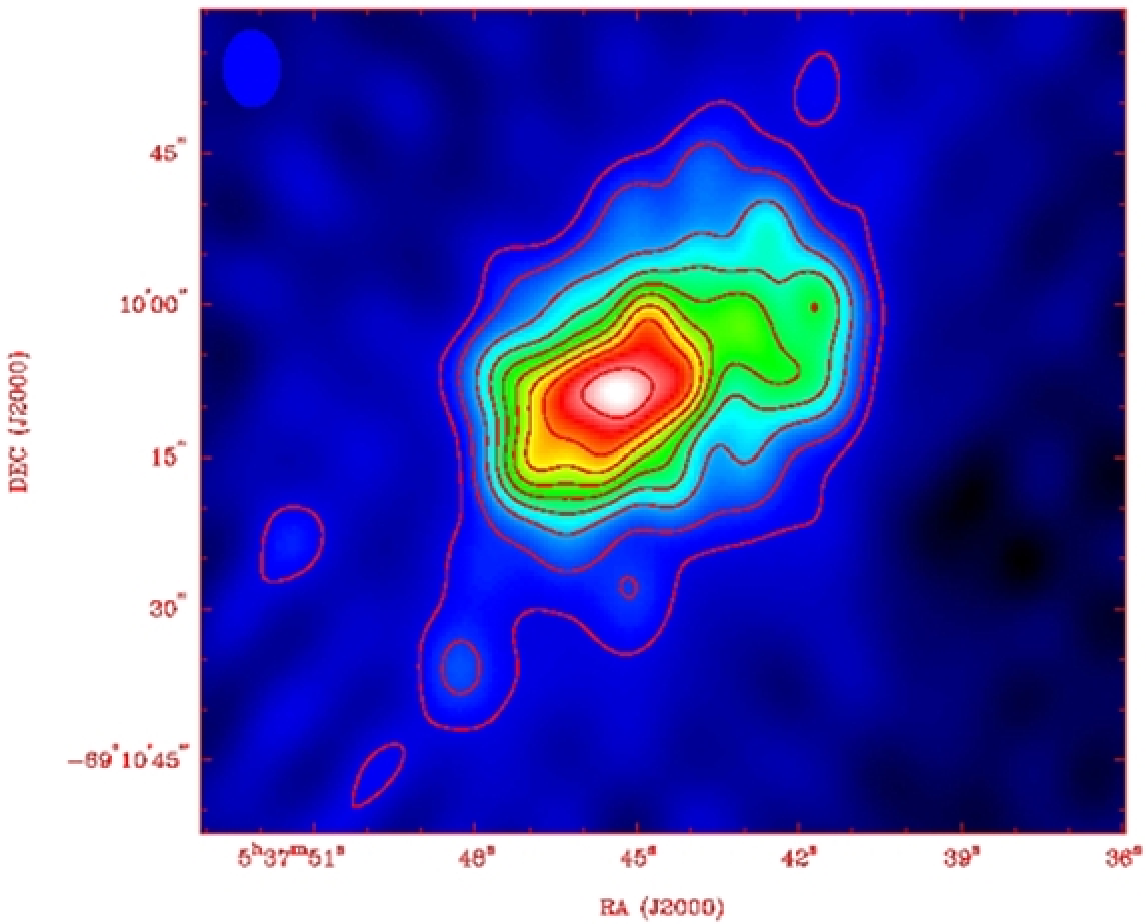


Figure 4-6 *The first astronomical image produced using the upgraded Australia Telescope Compact Array (ATCA) operating in the 12 mm (22 GHz) observing band. Three prototype receivers were used to make the observation in November 1999. The picture is of the supernova remnant N157B in the Large Magellanic Cloud. An angular resolution of better than 10 arcsecond is evident - consistent with the 300 m maximum separation of the three ATCA antennas in use.*

(ii) VLBI

- *Ceduna Antenna Tests and Centaurus A Observations*

With the practical completion of much of the VLBI upgrade, the University of Tasmania's 30 m Ceduna antenna is now making a significant contribution to VLBI in the Southern Hemisphere.

Since being officially opened in October 1997, Ceduna has contributed to VLBI observations with other antennas in Australia, South Africa, Asia, and the USA, as well as the HALCA space VLBI antenna in Earth orbit. It has significantly improved the imaging capability of Southern Hemisphere, global, and space VLBI arrays.

The Southern Hemisphere VLBI team has also undertaken a systematic series of observations to verify the Ceduna antenna performance and to investigate the improved imaging capability; these tests used an array of Australian antennas. The project aims to observe well-known and scientifically interesting radio sources in the Southern Hemisphere, including the closest active radio galaxy, Centaurus A.

Centaurus A, at a distance of only 3.4 Mpc (11 million light years), gives VLBI astronomers a chance to observe an AGN radio jet at high spatial resolution (1 milli-arcsec corresponds to approximately 0.02 parsec); it is also an object best observed from the Southern Hemisphere since it lies at a declination of -43°.

On December 20, 1999 Centaurus A was observed at a frequency of 6.6 GHz as part of the Ceduna verification program. Figure 4-7 shows the u-v coverage obtained from these observations; the improvements due to the Ceduna antenna are immediately obvious. The inner north-south baselines involving the Australia Telescope Compact Array (ATCA), Mopra, and Parkes antennas can be seen at the centre of the u-v coverage. The sweeping outer arcs of the u-v coverage are the baselines from the ATCA, Mopra, and Parkes to the Ceduna antenna. These long Ceduna baselines give a higher angular resolution, and their east-west to north-south coverage circularizes the beam and provides better phase-closure triangles, strengthening the constraints available to the imaging process.

The cover picture of this report shows the image obtained from the 6.6 GHz VLBI observations and places it in the context of the overall structure of the Centaurus A radio source. The low and intermediate resolution images from the Parkes antenna, the Very Large Array (VLA), and the ATCA show an unresolved nucleus and the extended jets and lobes of the source. The VLBI image resolves the nucleus into a core and jet, zooming in on the region where the jet is first produced and collimated. The VLBI image is the first to be produced at 6.6 GHz and has an angular resolution of approximately 3 x 6 milli-arcsec. These observations have detected the faint counter-jet emission as well as the complex structure of the main jet. To put this result into context, the resolution and quality of image obtained with this four-antenna observation exceeds that which is possible using twice as many antennas from the Northern Hemisphere Very Long Baseline Array (VLBA). VLBA observations have had great difficulty detecting the counter-jet features at this resolution, due to the limited north-south u-v coverage of that array at southern declinations.

The 6.6 GHz observing frequency is also highly significant from a scientific viewpoint. This is the first observation of Centaurus A at this frequency and will add considerably to our knowledge of the physics of the source. The Centaurus A nucleus is partially obscured by a screen of ionised gas which absorbs radio emission as a function of frequency, absorbing more at lower frequencies. The core of the source is completely absorbed below 2.3 GHz, while much of the jet structure is diminished above 8.4 GHz due to intrinsic spectral index effects. These two constraints mean that to investigate the frequency dependant effects of absorption effectively, observations must be made between 2.3 and 8.4 GHz. Previously only three frequencies have been available for this use: 2.3, 4.8, and 8.4 GHz; this is the absolute minimum required to separate the effects of the absorbing screen and absorption intrinsic to the source. The addition of VLBI imaging at 6.6 GHz, coupled with the longer baselines to Ceduna, provides a critical fourth frequency in this range, allowing models for the absorption to be over-constrained and more robust.

These Centaurus A observations illustrate the success and importance of the addition of the Ceduna antenna to the Southern Hemisphere VLBI network coverage.

- *Space VLBI*

In February 1997 the first dedicated VLBI radio antenna in space, designated HALCA, was placed into orbit by the Japanese Institute for Space and Astronautical Science (ISAS). Australian antennas have provided crucial support for this pioneering mission throughout both the check-out and operational phases. In particular, the antennas at Ceduna, Hobart and Mopra have seen extensive use as ground elements of the mission 5 GHz Survey program. The Survey analysis is not yet complete, but the preliminary results to date are proving particularly interesting. Figure 4-8 shows the weighted mean of the normalized flux density versus baseline length distribution for the sources presently analysed (Lovell et al., Proc VSOP Symposium "Astrophysical Phenomena Revealed through Space VLBI, Eds. H. Hirabayashi, P.G. Edwards & D.W. Murphy, 183-188 (2000). The data reveal for the first time the presence of a previously unexpected new ultra-compact component in the core of the "average" source. This component is most likely associated with the micro-arcsecond core components whose presence has been discovered through the presence of intra-day variability (Kedziora-Chudczer et al., 1997, ApJ Letters).

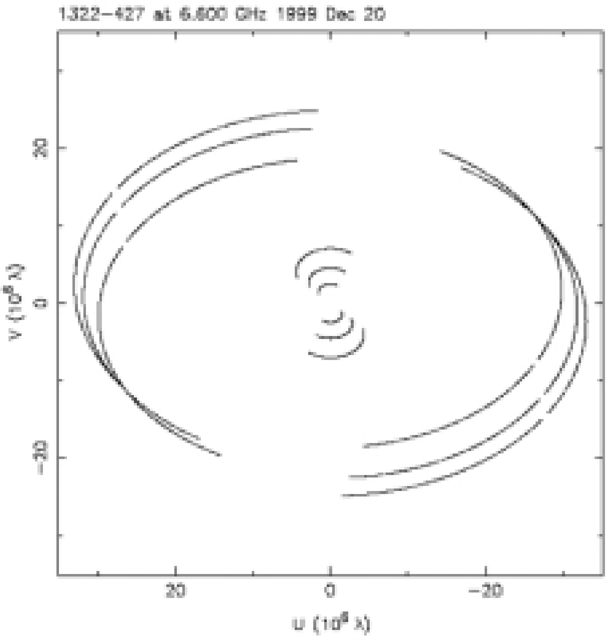


Figure 4-7 *U-V plane coverage of the Australian VLBI network during December 1999 observations of Centaurus A at 6.6 GHz. The sweeping outer arcs are due to baselines from Ceduna to ATNF antennas at Narrabri, Mopra and Parkes. The addition of Ceduna improves substantially the imaging quality of the network.*

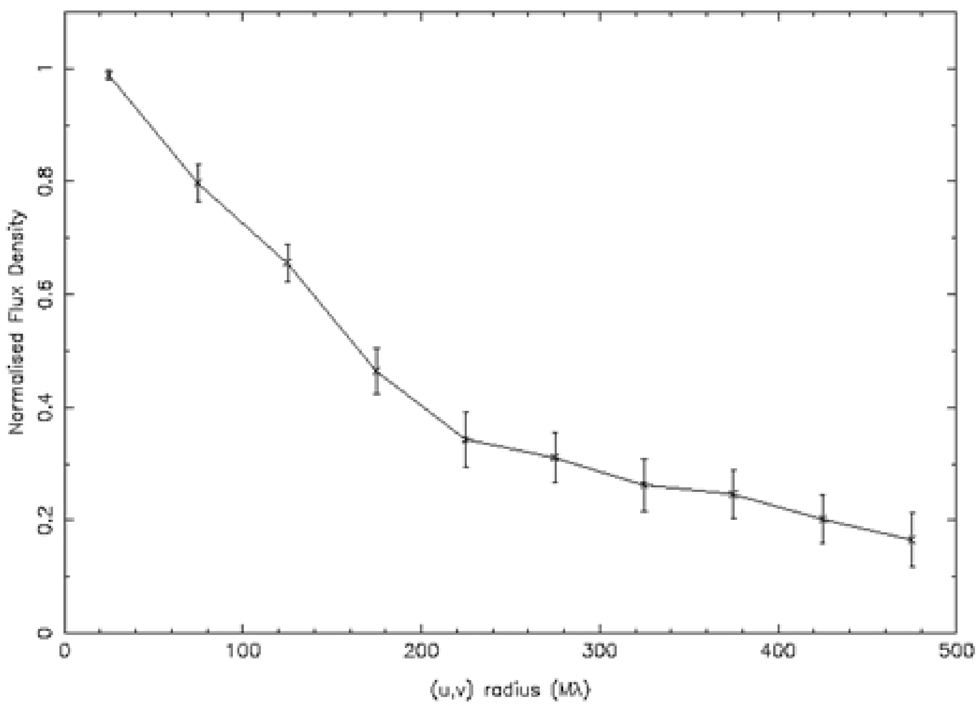


Figure 4-8 *Preliminary results of the 5 GHz space VLBI survey. The plot shows the weighted mean of the normalised flux density distribution for the survey sources analysed to date.*

5. University of Tasmania VLBI Expansion

As noted in MNRF Annual Report No. 3, the bulk of the University of Tasmania VLBI upgrade is complete, with both the Hobart and Ceduna antennas now in routine astronomical use. This Section outlines the status of outstanding items and describes minor changes in project direction; most of these changes were canvassed in Report No. 3.

Unexpected delays in the delivery of major components, the desirability of a further survey of the Ceduna antenna surface, and the revision and extension of some aspects of the upgrade have resulted in some aspects of the project missing the original completion target of March 2000. Coupled with the likelihood that final-version Tasmanian 22 GHz receivers will utilize ATNF MMIC components, it is now estimated that the whole upgrade will be complete and the facilities fully operational in final form by December 2002.

The upgraded Hobart and Ceduna antennas have been used in a series of national and international VLBI experiments. Results (see Section 4(d)*(ii)*) demonstrate the capabilities of the expanded Australian VLBI network and provide several exciting new scientific outcomes. The successful first year of operation demonstrates the value of the upgraded VLBI facilities to the Australian astronomy community.

The mid-term review of the MNRF program (Section 3) considered the resources that would be needed to operate the Hobart and Ceduna facilities, as well as a number of associated safety issues. The review agreed to a series of changes to the remaining VLBI upgrade program; these changes are summarized below.

- No low frequency (1.3 to 1.8 GHz) capability will be provided at Ceduna. There is no satisfactory solution available at the tertiary focus and a prime focus alternative is too expensive; prime focus operation also poses unacceptable operational and maintenance demands.

- Operation in the 22 GHz band at Ceduna will use a fixed subreflector. Investigations indicate that an overall efficiency in excess of 30% can be obtained for elevation angles greater than 20 degrees.

- Receivers at Ceduna will be ambient temperature devices at all frequencies except 8.4 and 22 GHz. For these frequencies, receivers will be cryogenically-cooled within a single dewar but room-temperature spare systems will also be provided.

- The 22 GHz upgrade at Hobart will be expanded. The original upgrade required three-dimensional positioning of the feed for optimal efficiency; it was agreed that this will be expanded to provide a larger feed translator on which several receivers could be located. This will enable computer selection of receivers, significantly increasing the efficiency of the observatory while reducing operational costs.

(i) Hobart Upgrade

A feed translator capable of housing four receiver packages has been designed with the help of ATNF staff. The translator was constructed by Sydney Engineering and delivered to the University in October 1999. Software to control the positioning of the translator in all three axes is now available. A new focus cabin was built for the Hobart antenna, providing additional space to house the receiver packages. The focus cabin and feed translator were installed on the antenna in May 2000 and tested in a 22 GHz VLBI experiment on June 18.

Improved receiver packages are now under construction; these will provide operation in seven frequency bands: 1.3-1.8 GHz, 2.2 GHz, 4.8 GHz, 6.7 GHz. 8.4 GHz, 12.2 GHz and 22 GHz. High-gain dual mode feeds have been built for 4.8, 6.7, 8.4 and 12.2 GHz; stepped waveguide feeds have been designed by CSIRO and built by the University of Tasmania for the two lower frequencies. The five highest-frequency receivers will be housed in a single cryogenic dewar. Figure 5-1 shows the feed translator, focus cabin and part of the new receiver systems prior to installation.

(ii) Ceduna Receivers

Commercial low-noise amplifiers for 2.2 GHz and 4.5 - 6.8 GHz were ordered in June 1999. Unfortunately, the 2.2 GHz amplifiers were only delivered in June 2000, while the 4.5- 6.8 GHz amplifiers are still delayed. However, the 2.2 GHz amplifiers have excellent ambient temperature performance, with a noise temperature of about 25 K being measured. Amplifiers for the 8.4 GHz cryogenic system have been built and are ready for incorporation in the dual-frequency dewar. Orders have been placed for amplifiers to be used in the 22 GHz cryogenic and room temperature systems.

(iii) Ceduna Antenna Optics

This upgrade is essentially complete, with all feed systems now on site. The antenna surface has been adjusted using conventional tape and theodelite surveying techniques. A further improvement in efficiency will most likely be achieved after a holographic survey of the surface. A 12 GHz holography feed has been designed and built by the ATNF, and low-noise amplifiers have been constructed by the University. The survey and associated panel adjustments are expected to take place during the second half of 2000.

(a)

(b)

(c)

Figure 5-1 *Front (a) and rear (b) views of the partially-assembled focus cabin and feed translator for the Hobart antenna. A local rigging firm was engaged to lift and fit the new assembly to the prime-focus (c).*

6. International Astronomy Collaboration

The MNRF Program funding included an allocation of $1.26M to enhance international collaboration by Australian astronomers. MNRF Annual Report No. 2 contains a summary of the call for proposals and the subsequent selection process by a sub-committee appointed by the National Committee for Astronomy. Table 6-1 lists all funded projects, and reports received from successful proposers are presented, in edited form, in the ensuing Sections. Disbursement details from a separate $70k allocation for international travel are given in MNRF Annual Reports Numbers 1 and 2.

Following exhaustion of the initial $70k travel allocation, an August 1998 meeting of the NCA sub-committee reviewed the international collaboration program; the sub-committee transferred $33.5k from the European Large Southern Array (LSA) Project to provide continued international travel support for Australian astronomers. In July 2000 the full NCA reviewed funding for the European LSA project and, in the light of changes described in Section 6(f), decided to re-allocate the remainder of the funds to support international astronomy travel, with emphasis on millimetre-wave collaborations. A new project will appear in the MNRF International Collaboration list in the 2000-2001 annual report. The NCA will be the proposer and an amount of $65,718 has been reserved to operate the project. The process of the ATNF Director approving international travel funding applications will continue.

In Section 7, Table 7-2 summarizes the financial position of the MNRF International Astronomy Collaboration projects, and Table 7-3 gives separate details of international travel supported by the scheme in the last financial year.

Table 6-1 International Collaboration Projects

Proposer	Affiliation	Proposal
R Morganti, E Sadler	ATNF, U. Sydney	A Joint ESO/Australia Workshop: “Looking Deep in the Southern Sky”
B Thomas	ATNF	The One Kilometre Square Telescope (1 kT)
R Clay	U. Adelaide	Studies of the Highest Energy Particles in Nature
M Ashley, M Burton, J Storey/M Dopita, J Mould	UNSW/ANU (RSAA)	SPIRIT: “The South Pole Imaging Telescope” (NOAO-CARA Collaboration)
J Patterson	U. Adelaide	γ-ray Observatory – CANGAROO Project
J Whiteoak	ATNF	Phase 2 Activities of European Large Southern Array (LSA) Project
K Taylor, M Colless	AAO, ANU (RSAA)	Australis Phase A Study
K Nugent, R Webster	U. Melbourne	LOBSTER X-ray Satellite
M Bessell	ANU (RSAA)	Australia-Japan Collaborative Workshops
M Brennan	Australian Research Council	Gemini Partnership – Contribution to the Capital Cost of Australia’s Participation in the Gemini Project
J Davis	U. Sydney	Collaboration with ESO on Instrumentation for the VLTI

(a) A Joint ESO/Australia Workshop “Looking Deep in the Southern Sky”
Proposers: R Morganti and E Sadler

This meeting was held 10-12 December 1997 in Sydney; a detailed report was included in MNRF Annual Report No. 2. The Proceedings, edited by the Proposers, have now been released and full publication details are given in Appendix 4 of this report.

(b) The Square Kilometre Array Telescope (SKA, previously 1kT)
Proposer: B Thomas

The SKA is the next-generation centimetre-wave radio telescope currently being planned by an international collaboration; an overview of the participants and co-ordinating bodies is given in MNRF Annual Report No. 2. The SKA will have a collecting area of 10^6 m^2, making it at least an order of magnitude more sensitive than any existing instrument.

Planning has advanced considerably in the past year, principally as the result of major science and technology forums held in the Netherlands in April 1999.

The ATNF is presently contributing to the SKA project via two MNRF mechanisms: a post-doctoral appointment supported largely by the International Astronomy Collaboration fund, and a larger commitment from the Strategic Research allocations (refer to Section 4(c)*(iv)*). The focus of the post-doctoral work was originally on array configuration studies and associated dynamic range issues. In recent months, the MNRF post-doctoral support has been shifted towards interference mitigation work, also described in Section 4(c)*(iv)*.

(c) Studies of the Highest Energy Particles in Nature

Proposer: R Clay

MNRF funding has enabled University of Adelaide workers to continue to participate in the PIERRE AUGER project Collaboration Board meetings, and to take a high profile in the development of the high-energy astrophysical observatory. The last two meetings were held at the observatory site in Mendoza Province, Argentina.

Eventually, the observatory will consist of both a southern and a northern site. The southern site, in Argentina, is to be built first and its funding is now essentially committed at a level of a little over US$50M. Fifty-three research groups from twenty countries are participating in this venture.

Construction on site has now begun. The first communication towers are on site (the observatory covers 3000 square kilometres), the first radiation detectors for the engineering test array are in place, and works for the first of four fluorescence telescope sites (costing US$1.5M) have begun. The University of Adelaide has shipped its first batch of cloud detectors to the site. REIF funds are being requested to complete the cloud detection system for this international facility. The engineering array should be operational by the end of 2000. Provided that no major changes are required as a result of experience with the engineering array, the observatory should be fully operational in a further three years although it will provide valuable scientific data well before then.

The only current major impediment to the project is difficulty with entry of equipment into Argentina, given the various customs formalities involved. This is being addressed at high diplomatic levels.

(d) SPIRIT: The South Pole Infrared Imaging Telescope

Proposers: M Ashley, M Burton, J Storey, M Dopita, J Mould

The MNRF funding allocation in this area is shared equally between UNSW and RSAA (formerly MSSSO).

The aim of this project was to secure Australia's role in Antarctic astronomy. Two parallel activities were undertaken: participation in the SPIREX/Abu project at the South Pole

(UNSW) and development of the enabling technologies to build a low-temperature telescope (ANU).

SPIREX/Abu was a 60 cm infrared telescope with a 1024x1024 pixel detector array. As part of a larger collaboration with the US, the UNSW rebuilt the telescope optics, developed a fast tip-tilt secondary mirror, and provided a thermal management system for the instrument. SPIREX/Abu operated for two winters (1998 and 1999) and provided a wealth of data for the principal investigators and for US and Australian guest observers. The first scientific papers from this work are now in press.

ANU efforts have centred on producing a Phase A engineering study for a new 2.5 m class telescope to be located at the remote Dome C site on the high (5000 m) Antarctic plateau. For this study, RSAA completed a detailed report entitled "SPIRIT: The South Pole Infrared Imaging Telescope - The Phase A Engineering Study". The report outlined optical, mechanical and project management considerations for a 2.5 m telescope capable of yielding almost diffraction-limited images at 2.4 μm. The telescope is a wide-field design, operating primarily in the 2-4 μm and 10-12 μm observing wavelength ranges. A tip-tilt mirror (oscillating secondary) arrangement and large-format electronic detector arrays were central to the design. Significantly, the telescope was designed for largely unattended, open-air, operation in temperatures as low as -85 degrees C. The design was optimised for low power operation.

Early in 2000 the prototype ANU telescope mount (the G/Mount) was delivered to the South Pole with the assistance of CARA, the US Center for Astrophysical Research in Antarctica. The G/Mount was attached to the CARA tower and the ANU ADIMM and UNSW AFOS instruments were mounted on it. These instruments measure astronomical seeing and panchromatic transmission respectively. Control of the instrument and monitoring of functions is possible over the internet. Performance of the G/Mount azimuth axis has been nominal, but the altitude axis seized in February 2000, severely impairing use of the facility. A review was held at Mount Stromlo Observatory in July 2000, and the reviewers recommended a diagnosis and repair mission in November. The mission will be facilitated by CARA but modest additional funding will be required; this will be requested from the MNRF travel allotment

Overall, the South Pole activities have been extremely successful, and have helped to establish Australia as a major player in Antarctic astronomy.

(e) γ-ray Observatory - CANGAROO Project

Proposer: J Patterson

In March 2000, the CANGAROO II ten metre telescope for high energy astrophysics was completed by the addition of 54 additional 80 cm mirrors, making 114 mirrors in all. As well, additional fast phototube light detectors were added in the imaging camera, taking the total number of tubes to 552. An upgrade of the data acquisition system was also undertaken. On May 9, the telescope was formally opened by His Excellency, the Ambassador for Japan, Mr Masaji Takahashi. The ceremony and luncheon was hosted by the Vice Chancellor of Adelaide University, Prof Mary O'Kane.

The University of Tokyo, which is responsible for much of the funding through a Centre of Excellence, was represented by the Director of the Institute for Cosmic Ray Research, Prof Yoji Totsuka. Components of the funding also came from the Australian Research Council and the MNRF International Collaboration scheme.

The ceremony also launched the CANGAROO III expansion: four gamma-ray telescopes to operate as a combined system reaching 100 GeV, thereby breaking into the last gap in the electromagnetic spectrum coverage. When complete, the total value of the project will be over A$15 million and it will involve astrophysicists from Adelaide and ANU, as well as nine Japanese universities.

An instrument test period is now underway, involving studies of known sources such as the Crab Nebula, Vela pulsar and PSR 1706-44, as well as monthly monitoring of telescope performance. Shortly, a program to search for southern, low-redshift BL Lacs (blazars), supernova remnants and young energetic pulsars will commence.

Negotiations are currently underway with the Department of Immigration to ameliorate the effect of white lights at a detention centre located about eight kilometres from the CANGAROO site.

Details of the CANGAROO project and future developments can be found on the Web at *http://www.physics.adelaide.edu.au/astrophysics/CangarooII/cangaroo.html*

(f) Phase 2 Activities of European Large Southern Array Project
Proposer: J Whiteoak

In 1998 an amount of $56k was committed to support Australian participation in Working Groups associated with the Large Southern Array (LSA) project. Since then the project has been completely restructured and, as a result of a recent agreement, has now been formally combined with the US Millimetre Array (MMA) project to form the Atacama Large Millimeter Array (ALMA). During the manoeuvres the original Working Groups were disbanded, and no further meetings have been held. As reported in the introduction to this Section, the LSA funds have now been re-allocated by the National Committee for Astronomy to support international travel by Australian astronomers, with preference to be given to collaborations involving millimetre-wave astronomy.

(g) AUSTRALIS Phase A Study
Proposers: K Taylor and M Colless

The AUSTRALIS proposal was for an optical/infrared multi-fibre spectrograph for the European Southern Observatory (ESO) Very Large Telescope (VLT). Following the conceptual design of AUSTRALIS, further work was funded, via the AUSTRALIS phase A MNRF funding, to study key areas of the instrument design: evaluation of integral field units (IFUs), switchyards, and design of the robotic fibre positioner.

The fibre positioner is now known as the OzPoz project and is being built by the Anglo-Australian Observatory, under contract to ESO, as part of the VLT wide-field fibre facility (FLAMES). Half of the MNRF funds were allocated to the fibre positioner contract. The OzPoz fibre positioner has passed its final design review and the final stages of manufacture are underway. The instrument is expected to be accepted by ESO in May 2001 after laboratory trials.

The study of IFUs and switchyards is now complete and the conclusions of the study were presented at the March 2000 SPIE instrumentation conference in Munich. The technology developed for the AUSTRALIS large-IFUs has led to the construction of two IFUs. The SPIRAL IFU has been successfully commissioned on the Anglo-Australian Telescope and has excellent performance. A second IFU was constructed as a collaboration between the AAO and the SOAR telescope consortium. The SOAR-IFU is due to be commissioned on the Brazilian 1.6 m telescope in late 2000.

The combination of robotics and IFU experience gained as a result of MNRF funding places Australia in a strong position to be involved in future instrumentation projects.

(h) LOBSTER X-ray Satellite
Proposer: K Nugent and R Webster

The LOBSTER project received one-off MNRF funding to support the development of a new Australian-based approach to an all-sky X-ray telescope. This project was part of a large international collaboration between the University of Melbourne, Los Alamos National Laboratory, NASA Goddard Space Flight Laboratory and the University of Leicester.

The project commenced some important optical development work and, under its current non-MNRF funding, is an integral part of the optics evaluation component of the LOBSTER satellite program. It is hoped that Australia will be able to remain a part of this important space science initiative.

(i) Australia - Japan Collaborative Workshops
Proposer: M Bessell

This project is now complete; the final report appeared in MNRF Annual Report No. 3.

(j) Gemini Partnership - Contribution to the Capital Cost of Australia's Participation in the Gemini Project
Proposer: M Brennan

The Gemini Project is an international partnership formed to construct and operate two 8.1 metre telescopes designed for optimal performance in optical and infrared astronomy. The telescopes are located at superb observing sites, one at Mauna Kea on Hawaii, and the other at Cerro Pachon, in the Chilean Andes. The North telescope was dedicated on June 25, 1999 and is now coming on line for regular scientific use. Construction of the Gemini South telescope is approximately one year ahead of schedule. Membership of Gemini gives Australian Astronomers access to the most advanced optical-infrared facilities in the world, helping to ensure the continuing success of Australia's astronomical research.

Australia became a partner in the Gemini Project in 1998. Our contribution to the capital cost of the facilities is $US9.2M. MNRF funds for International Collaborations of $A200,000 were a component of this contribution. Membership of Gemini requires an annual contribution to the operating costs; this contribution is funded jointly by the ARC, several Universities (ANU, UNSW, USyd, UMelb) and the ATNF. Following advice from the Department of Education, Training and Youth Affairs advising that the University of Sydney is the lead Australian university involved in the IGP and is acting as an intermediary for payment of funds to the US National Science Foundation, the ATNF completed the transfer of all Gemini MNRF funds to the University in the financial year 1998-99.

(k) Collaboration with ESO on Instrumentation for the VLTI

Proposer: J Davis

The Sydney University Stellar Interferometer (SUSI) is a working long-baseline optical interferometer carrying out a programme of scientific observations of single and binary stars. The European Southern Observatory (ESO) is developing the Very Large Telescope Interferometer (VLTI) for installation at Paranal in Chile, and SUSI has been offered to the ESO as a working facility for testing instrumentation and detectors for the VLTI. An offer has also been made to provide ESO staff with hands-on experience of long-baseline optical interferometry with SUSI. Neither offer has been taken up to date but the University of Sydney group has been approached by ESO to assist with the commissioning programme for the VLTI.

The SUSI group has continued the development of instrumentation of mutual interest to the SUSI and VLTI programmes. This includes improved tip-tilt mirrors (first-order adaptive optics) and wavefront tip-tilt detection, group-delay tracking, fringe scanning techniques and correlation measuring systems operating at the red end of the visual spectrum. With the assistance of MNRF funds, matched by University of Sydney funds, a Postdoctoral Fellow has been supported to work on aspects of these instrumental developments. A new tip-tilt mirror system has now been in successful operation in SUSI, using existing quadrant detectors, for a year. A detection system, based on a fast, low read-out noise, CCD, is in an advanced stage of development in the laboratory and will be installed in SUSI during 2000. Development of a group-delay tracking system to operate at the red end of the visual spectrum has continued and an investigation into a fringe scanning technique that promises a significant improvement in sensitivity has commenced.

7. MNRF Financial Statements

Table 7-1 summarizes the overall MNRF financial situation as at 30 June 2000. The summary excludes interest of $133,500 which has accrued in the CSIRO account.

An audit of the MNRF program was recently completed by BDO Nelson Parkhill. The audit covered the period from the start of the program to 30 June 2000 and was in accordance with the guidelines issued by DISR.

The final reports have not yet been received but discussions with the auditors indicate that a successful outcome was achieved and that, in their opinion, the MNRF grant is being administered in accordance with the contract specifications. A similar audit is currently underway at the University of Tasmania (using auditors KPMG).

Table 7-2 is a summary of international astronomy collaboration projects funded under the MNRF Program, while Table 7-3 shows details of international travel requests supported in the financial year 1999-2000; previous MNRF Annual Reports contain full details of earlier grants.

Table 7-1 MNRF Financial Summary as at 30 June 2000

Projects	Provision	Expenditure to Date	Balance
ATNF High Frequency Upgrade			
12/3.5 mm ATCA	2,860,000	1,046,200	1,813,800
Atmospheric phase correction	160,000	135,100	24,900
ATCA antenna surface extension	910,000	717,200	192,800
New E-W stations for ATCA	440,000	427,300	12,700
ATCA local oscillator upgrade	750,000	420,200	329,800
ATOMS	200,000	247,000	-47,000
Parkes conversion system	230,000	302,400	-72,400
ATNF VLBI Upgrade			
12 mm receiver	200,000	150,000	50,000
VLBI improvements	336,000	337,200	-1,200
Strategic Research			
Array technology	123,200	92,500	30,700
Interference excision	76,800	49,200	27,600
Project Management			
Infrastructure	300,000	218,300	81,700
Test Equipment	400,000	380,900	19,100
Manpower	1,250,000	888,600	361,400
Payments to University of Tasmania[2]	1,504,000	1,424,000	80,000
International Collaboration	1,260,000	1,105,400	154,600
TOTAL	**$11,000,000**	**7,941,500**	**3,058,500**

Notes

1. All amounts in Australian dollars (rounded to the nearest one hundred dollars).
2. The University of Tasmania has unspent reserves of $384,810 of which $59,508 is accumulated interest.

Table 7-2 MNRF International Collaboration Projects - Summary as at 30 June 2000

Proposer	Proposal	Requested	Committed	Reserved	Comments	Payments
R Morganti (ATNF) E Sadler (U Syd)	A Joint ESO/Australia Workshop "Looking Deep in the Southern Sky"	$20K	$11,884	$3,116	Dec. '97 - 100% travel support for invited workshop speakers.	$11,884
B MacThomas (ATNF)	The One Kilometre Square Telescope (1kT)	$191.8K	$87,000	$45,000	2 yr post-doc position; possible extension to 3 yrs; salary overheads from Strategic Research project.	$73,945
R W Clay (U Adel)	Studies of the Highest Energy Particles in Nature	$198K	$16,640	$13,360	Travel support grant.	$16,640
MCB Ashley/MJ Burton/JWV Storey (UNSW) & M Dopita/J Mould (RSAA)	SPIRIT 'The South Pole Infrared Imaging Telescope' - NOAO/CARA collaboration	$255K	$225,000		Progress payments to UNSW.	$225,000
J Patterson (U Adel)	γ-ray Observatory - Cangaroo Project	$90.5K	$30,000		Seed money for Japanese collaboration.	$30,000
JB Whiteoak (ATNF)	Phase 2 Activities of European Large Southern Array (LSA) Project	$100K	$782		Transferred to travel ($33,500 & mm astro travel of $65,718)	$782
K Taylor (AAO)/ M Colless (RSAA)	Australis Phase A Study	$400K	$320,000			$320,000
K Nugent/R Webster (U.Melb)	LOBSTER X-Ray Satellite Project	$141K	$58,000		Salary Research Fellow + travel.	$58,000
M Bessell (RSAA)	Australia-Japan Collaborative Workshops	$115K	$20,000		Seed money for Japanese collaboration.	$20,000
M Brennan (ARC)	Gemini partnership	$200K	$200,000		Contb'n to capital cost of Australia's participation in the Gemini project.	$200,000
J Davis (U Syd)	Collaboration with ESO on instrumentation for the VLTI	$67K	$60,000		Research Fellow salary for 2 years	$60,000
	Travel related to international collaboration; misc. establishment costs		$103,500		$33,500 transferred from European LSA project in 1999. Direct reimbursements from ATNF to 30/6/00	$89,148
National Committee for Astronomy	International collaboration travel with emphasis on millimeter projects			$65,718	Remainder of funds transferred from European LSA project.	
	TOTALS		**$1,132,806**	**$127,194**		**$1,105,399**

Total Commitment: $1,132,806 Reserved: $127, 194 Total Budget: $1,260,000

Table 7-3 International Collaboration Funding - Overseas Travel Summary For Financial Year 1999-2000

Name	Institution	Travel Dates	Destination	Purpose	Travel Funding Committed
Dr Wim Brouw	ATNF	26/3/00	Munich, Germany	Square Kilometer Array (SKA) International Steering Committee workgroup. The meeting was attached to the SPIE large astronomical facilities conference.	$2513.90
Dr Wim Brouw	ATNF	3/8/2000-5/8/2000	NRAL, Jodrell Bank, Macclesfield, UK	SKA International Steering Committee meeting	$1550.00

Appendix 1 – MNRF Program Management Overview

Figure A1-1 is a diagram illustrating the placement of various specific projects and sub-projects in the MNRF Program.

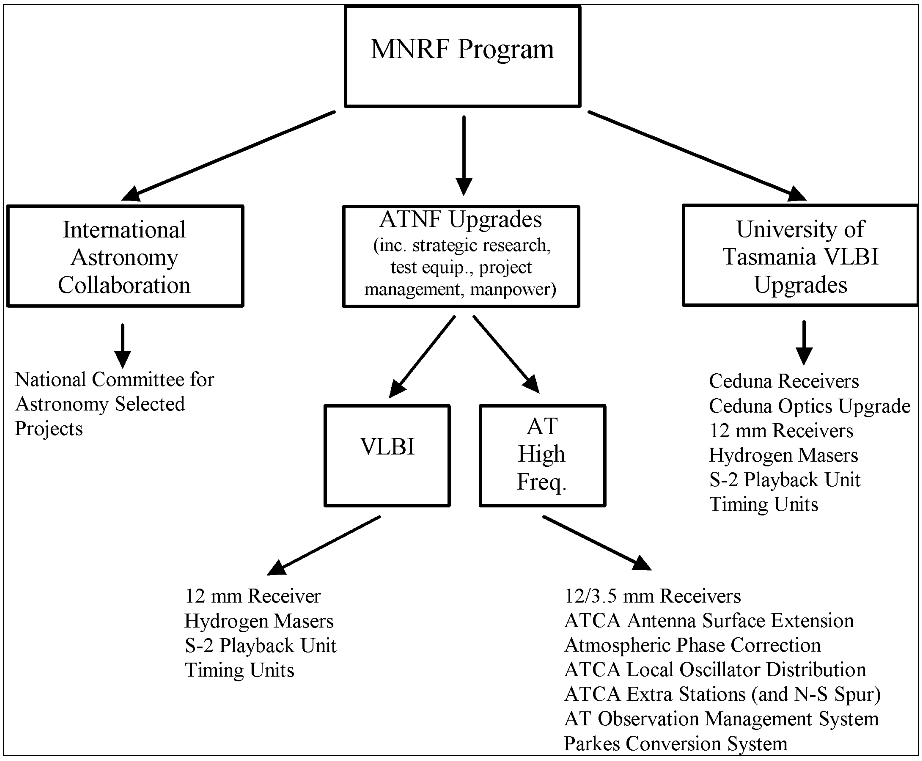


Figure A1-1 *MNRF Program Structure*

Figure A1-2, extracted from the MNRF upgrade contract, shows the overall structure of the MNRF Program. The ATNF Steering Committee (Appendix 2) is the principal policy body advising the ATNF Director. It is an independent body appointed by the Minister responsible for CSIRO. Annex 3.1 to the MNRF-upgrade contract details the operation of the Committee in terms of its role in overseeing ATNF operation and reporting to the CSIRO Executive and Minister for Science. In the MNRF context, the Steering Committee has no direct management function but is responsible for Program guidance and annual report submission. To expedite the reporting process, the Steering Committee has established a sub-committee (Appendix 2) charged with reviewing the MNRF Program progress and expenditure as presented in the draft annual reports.

Schedule 5 of the MNRF-upgrade contract details the operation of two working committees: the Facilities Upgrade Program Committee and the International Research and Collaborations Committee. In addition, the Schedule specifies the responsibilities of the Program Manager and executive staff. Committee members and senior Program personnel are listed in Appendix 3.

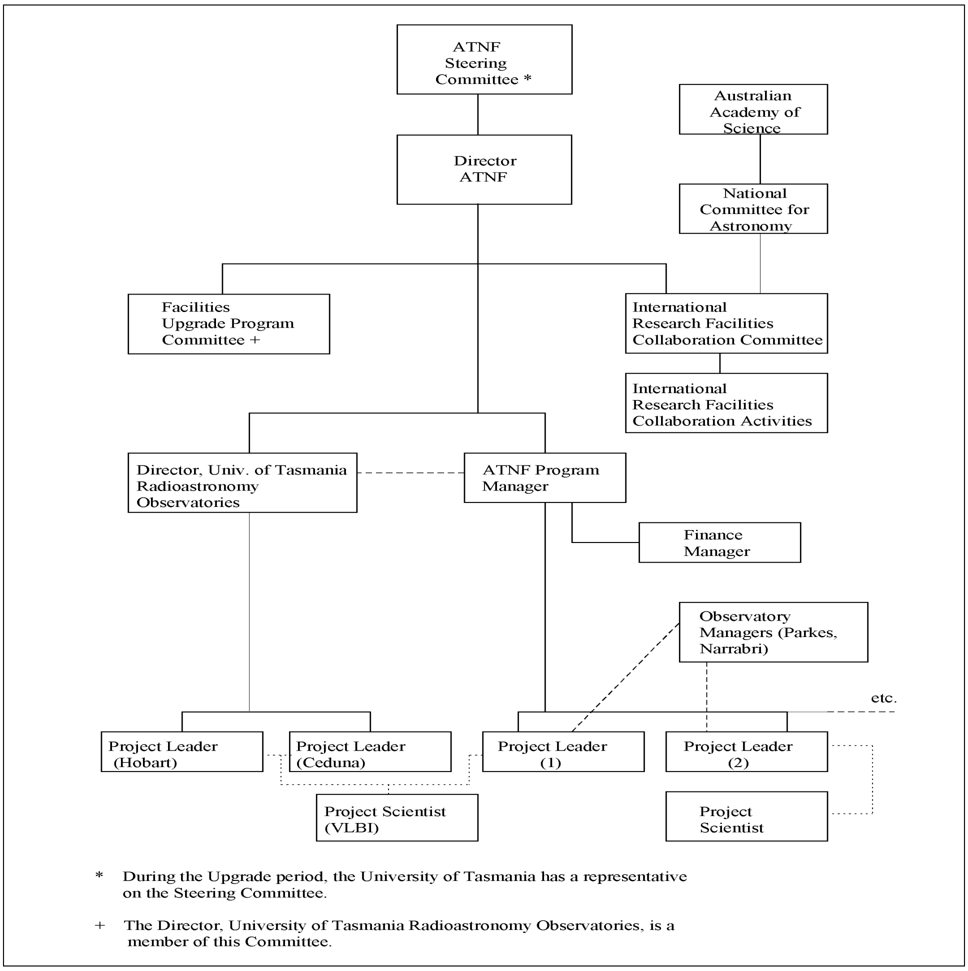


Figure A1-2 *MNRF Program Management and Overall Structure*

Figure A1-3 shows the MNRF-upgrade management in more detail; note that the ATNF Director is also the MNRF Program Director. For a complete list of senior personnel, refer to Appendix 3.

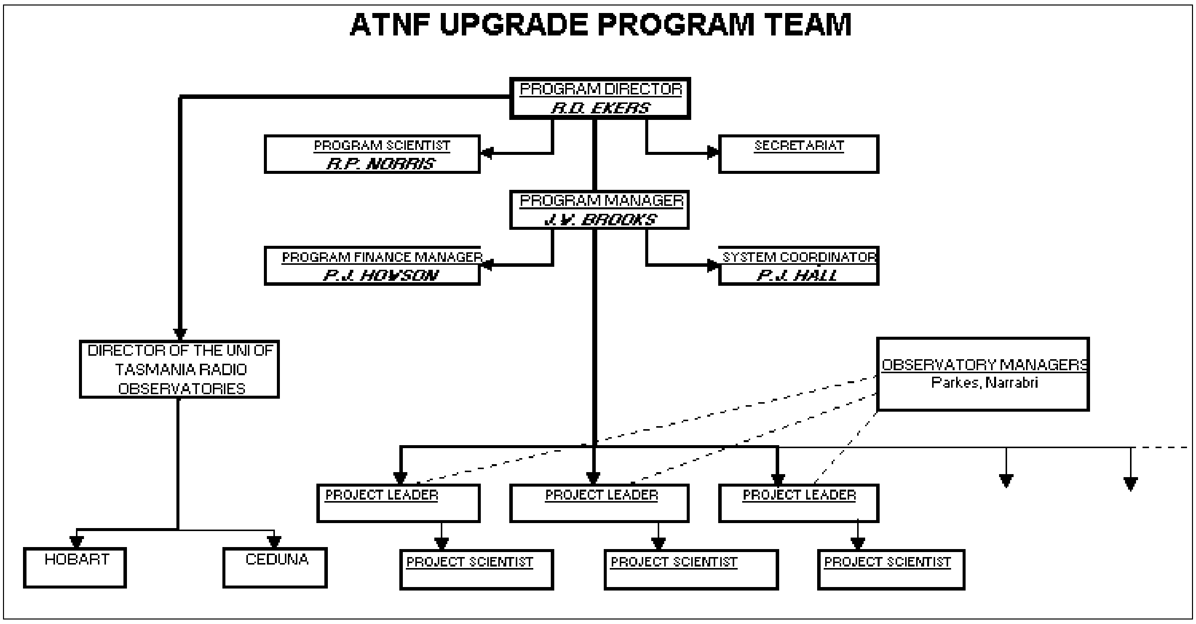


Figure A1-3 *MNRF Executive and Program Structure*

Appendix 2 - ATNF Steering Committee Membership, 1999

CHAIRMAN
*__Dr R Cannon__, Anglo-Australian Observatory

MEMBERS
Ex-officio
Prof R Ekers, Director, CSIRO Australia Telescope National Facility
Dr B Boyle, Director, Anglo-Australian Observatory
Dr D Cooper, Chief, CSIRO Telecommunications & Industrial Physics
Dr R Sandland, Deputy CEO, CSIRO
Prof P McCulloch, Director, University of Tasmania Radio Astronomy Observatories

Astronomers
Dr E Sadler, University of Sydney
*__Prof J Storey__, University of New South Wales

International Advisors
Prof K Menten, Director, Max-Planck-Institut fur Radioastronomie, Germany
Prof P Goldsmith, Director, National Astronomy and Ionosphere Center, Cornell University, USA
Prof Kwok-Yung (Fred) Lo, Director, Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan

Industry
***Dr P Scaife,** Centre for Sustainable Technology, University of Newcastle
Dr R H Frater, Vice-President Innovation, ResMed, Sydney

* Denotes membership of the sub-committee responsible for MNRF Program annual reports.

Appendix 3 - Senior MNRF Program Personnel

Facilities Upgrade Program Committee

Prof R D Ekers, ATNF Director
Mr J W Brooks, ATNF Program Manager
Prof P M McCulloch, Director, Univ. of Tasmania Radio Astronomy Observatories
Dr R P Norris, Program Scientist
Mr P J Howson, ATNF Divisional Secretary and Finance Manager

International Research Facilities Collaboration Committee

Prof R D Ekers, ATNF Director
Mr P J Howson, ATNF Divisional Secretary
Prof J Mould, Chairman, National Committee for Astronomy
Dr E Sadler, Astronomy Community Representative (NCA appointee)

Table A3-1 MNRF Program (Executive)

Executive Position	Officer
Program Director	Prof R D Ekers (Director, ATNF)
Program Manager	Mr J W Brooks (Assistant Director and Engineering Manager, ATNF)
Program Scientist	Dr R P Norris (ATNF Group Leader, Astrophysics and Computing)
System Co-ordinator	Dr P J Hall (ATNF Principal Research Scientist)
Program Finance Manager	Mr P J Howson (ATNF Divisional Secretary)

Table A3-2 ATNF Projects (Senior Personnel)

Project	Project Leader	Project Scientist(s)
12/3.5 mm ATCA Receivers	Mr M Sinclair	Dr R Manchester (12 mm) Dr B Koribalski [1] (3.5 mm)
ATCA Antenna Surface Extension	Dr M Kesteven	Dr B Thomas
Atmospheric Phase Correction	Dr P Hall	Dr R Sault Dr M Wieringa Mr G Carrad [2]
ATCA Local Oscillator Distribution Upgrade	Dr W Wilson	Dr R Subrahmanyan
ATCA Extra Stations	Mr J Brooks	Dr J Caswell
AT Observation Management System	Mr D Loone [3] Dr M Wieringa	Dr D McConnell
Parkes Conversion System	Mr G Graves	Dr J Caswell
VLBI 12 mm Receiver	Mr M Sinclair	Dr D Jauncey
VLBI, Other Projects	Dr W Wilson	Dr A Tzioumis

Table A3-2 Notes

1. The 3.5 mm Receiver project has special status and has a science team consisting of Drs R Belasubrahmanyam (UNSW), P Hall, M Kesteven, B Koribalski (chair), R Norris, R Sault, R Subrahmanyan, and J Whiteoak.
2. Mr G Carrad is the Project Engineer.
3. Mr D Loone resigned in April 2000.

University of Tasmania Projects (Senior Personnel)

The management of all University of Tasmania projects is undertaken by Prof P M McCulloch, Director, University of Tasmania Radio Astronomy Observatories.

Table A3-3 ATNF Square Kilometre Array Program Personnel (MNRF-Related Projects)

Position	Officer
Program Leader	Dr P J Hall (Principal Research Scientist)
SKA Site Study Project Leader	Dr B MacA Thomas (Chief Research Scientist)
Interference Mitigation Project Leader	Dr R J Sault (Principal Research Scientist)

Appendix 4 - Publications and Related Material

The following publications and communications have been produced by ATNF staff and associates since the beginning of the MNRF upgrade program.

Web Site

The ATNF maintains a World Wide Web site describing the MNRF Program and its progress. The site URL is *http://www.atnf.csiro.au/mnrf/* As well as being a repository for Program summaries, the Web is invaluable in the dissemination of briefing and discussion material to the ATNF user community.

Publications in Refereed Journals or Conference Proceedings

1. Abbott, D. A. and Hall, P. J., A Stable Millimetre-Wave Water-Vapour Radiometer, J. Elec. Electron. Eng. Aust., Vol. 19, No. 4, pp. 213 - 226, 1999.
2. Brooks, J. W., Hall, P. J., Sinclair, M. W., Wilson, W. E. and Kesteven, M. J., The Australia Telescope Millimetre-Wave Upgrade, submitted to Proc. Workshop on Applications of Radio Science (Aust.), Beechworth, 2000.
3. Bell, J., Hall, P., Ekers, R., Wilson, W., Ferris, R., Kesteven, M., Smegal, R., van Straten, W., and Bailes, M., Software Radio Telescope: Interference Atlas and Mitigation Strategies, Proc. Intl. Conf. "Perspectives on Radio Astronomy: Technologies for Large Antenna Arrays", Dwingeloo, April 1999.
4. Ekers, R. D., The Square Kilometre Array Radio Telescope, in Proc. ESO Workshop "Looking Deep in the Southern Sky", Springer, 1999.
5. Ekers, R. D., Plans for the Square Kilometre Array, Proc. Intl. Conf. "Perspectives on Radio Astronomy: Science with Large Antenna Arrays", Amsterdam, April 1999.
6. Ellingson, S. W., Bunton, J. D. and Bell, J. F., Suppression of GLONASS Signals Using Parametric Signal Modelling, submitted to Proc. Workshop on Applications of Radio Science (Aust.), Beechworth, 2000.
7. Hall, P. J., The Square Kilometre Array, submitted to Proc. Workshop on Applications of Radio Science (Aust.), Beechworth, 2000.
8. Hall, P. J. and Brooks, J. W., The Australia Telescope Millimetre-Wave Upgrade, in "Millimeter and Submillimeter Astronomy at 10 Milli-Arcseconds Resolution", Proc. Japan - US joint workshop (Tokyo), NRO Report No. 430, 1997.
9. Hall, P. J., Brooks, J. W., Sinclair, M. W., Wilson, W. E. and Kesteven, M. J., The Australia Telescope Millimetre-Wave Upgrade, Proc. Workshop on Applications of Radio Science (Aust.), Barossa Valley, pp. 65 - 70, 1997.
10. Hopkins, A., Summary of the Sub-MicroJansky Radio Sky Workshop, Proc. Astron. Soc. Aust., Vol. 16, No. 2, July 1999.
11. Hopkins, A., Windhorst, R., Cram, L. and Ekers, R., What Will the Next-Generation Radio Telescope Detect at 1.4 GHz?, accepted, Experimental Astronomy, 2000.

12. Hopkins, A., Windhorst, R., Cram, L. and Ekers, R., What Will the SKA See at 1.4 GHz?, Proc. Intl. Conf. “Perspectives on Radio Astronomy: Science with Large Antenna Arrays”, Amsterdam, April 1999.
13. Leach, M. R., Upgrade of the Australia Telescope Compact Array Local Oscillator Reference System, submitted to Proc. Workshop on Applications of Radio Science (Aust.), Beechworth, 2000.
14. Norris, R. P., The MNRF Upgrade to the Australia Telescope, in Proc. ESO Workshop “Looking Deep in the Southern Sky”, Springer, 1999.
15. Norris, R. P., Masers and the SKA, Proc. Intl. Conf. “Perspectives on Radio Astronomy: Science with Large Antenna Arrays”, Amsterdam, April 1999.
16. Sault, R. J., Carrad, G. J., Hall, P. J. and Crofts, J., Radio Path-Length Correction Using Water-Vapour Radiometry, submitted to Proc. Workshop on Applications of Radio Science (Aust.), Beechworth, 2000.
17. Thomas, B. M., SKA: Matching the Specifications and Antenna Technologies, Proc. Intl. Conf. “Perspectives on Radio Astronomy: Technologies for Large Antenna Arrays”, Dwingeloo, April 1999.
18. Thomas, B. M., Hall, P. J. and Brooks, J. W., The Australia Telescope Large-Array Research Project, Proc. Workshop on Applications of Radio Science (Aust.), Barossa Valley, pp. 136 - 138, 1997.

Internal Reports or Un-refereed Papers

1. Bell, J. F., Ekers, R. D., Hall, P. J., Smegal, R., Wilson, W. E., Hopkins, A., Thomas, B. M., Adaptive Interference Mitigation Strategies for the SKA, Proc. URSI 26 General Assembly, Toronto, 1999, pp. 828.
2. Ekers, R. D., Interference Excision in Radio Astronomy Measurements, Proc. 1 kT International Technical Workshop, Sydney, Dec. 15 - 18, 1997.
3. Ghorbani, K. and Waterhouse, R., Investigation of RF Phase Shifting Using Optical Technology and Broadband Printed Antennas for the 1 kT Project, RMIT Department of Communications and Electronics Engineering, Internal Report, March 1998.
4. Ghorbani, K. and Waterhouse, R., Investigations of components suitable for the SKA project, Report No. 3 to CSIRO ATNF, October 1999.
5. Hall, P. J., Mohan, A. S. and Soretz, R. S., Interference Characteristics of Australian Astronomy Sites, Proc. 1 kT International Technical Workshop, Sydney, Dec. 15 - 18, 1997.
6. Hall, P. J., Brooks, J. W., Sinclair, M. W., Wilson, W. E. and Kesteven, M. J., The Australia Telescope Millimetre-Wave Upgrade, Proc. URSI 26 General Assembly, Toronto, 1999, pp. 592.
7. Hall, P. J., Sault, R. J. and Carrad, G. C., Atmospheric Phase Correction for the Millimetre-Wave Australia Telescope, Proc. URSI 26 General Assembly, Toronto, 1999, pp. 841.
8. Kesteven, M. J., ATCA Upgrade - Pointing Considerations, AT/39.3/081.
9. Kesteven, M. J. and Parsons, B. F., Mechanical Stability of the AT Subreflectors, AT/39.3/070.
10. Kesteven, M. J. and Parsons, B. F., Antenna on the Rail Observations, AT/39.3/072.

11. Kewley, L., Interference Excision Using the Parkes Multibeam Receiver, Proc. 1 kT International Technical Workshop, Sydney, Dec. 15 - 18, 1997.
12. Norris, R. P., Scheduling the ATCA at Millimetre Wavelengths, ATNF Report. Sept. 1997.
13. Norris, R. P., Notes from ATCA Calibration Meeting, ATNF Report, Oct. 1997.
14. Sault, R., Cross-Correlation Approaches to Interference Elimination, Proc. 1 kT International Technical Workshop, Sydney, Dec. 15 - 18, 1997.
15. Storey, M., Opportunity for Siting the SKA telescope in WA, AT/43.16/075.
16. Thomas, B. MacA., Planning the Next International Radio Telescope, submitted to Engineers Aust., 1999.
17. Thomas, B. MacA., The 1 kT - Application of Phased Array Technology, AT/39.3/064.
18. Thomas, B. MacA., The 1 kT Project: Optimum Phased-Array Element Configuration for Forming a Large Co-sited Collecting Area (Station), AT/39.3/078.
19. Thomas, B. MacA., Interference Mitigation - An R & D Strategy for the 1 kT Array, ATNF Workshop on Electromagnetic Compatibility, Sydney, April 27, 1998.
20. Thomas, B. MacA., Focal Plane Arrays – Some Basic Characteristics and an Application to HF SKA, AT/39.3/095 (and Addendum 1, August 1999).
21. Thomas, B. MacA., The Square Kilometre Array, WA Site Study No. 1, AT/43.16/063.
22. Thomas, B. MacA., Searching for Suitable Central Sites for the SKA: Stage 2 (Jan. 2000), AT/43.16/074.

Books, Theses and Web Proceedings

1. Correcting Atmospheric Distortion in Short-Wavelength Radio Observations from Tropospheric Water-Vapour Soundings, D. A. Abbott, Ph. D. thesis, University of Sydney, 1998.
2. Looking Deep in the Southern Sky: Proceedings of the ESO/Australia workshop held at Sydney, Australia, Dec. 10-12 1997. R. Morganti and W. Couch (ed.), Springer, 1999. ISBN 3-540-65286-8.
3. Radio Frequency Interference Strategies: Proceedings of the Elizabeth and Frederick White Conference held at Sydney, Australia, Dec. 15-16, 1999. URL: *http://www.atnf.csiro.au/SKA/intmit/atnf/conf/index.html*

Workshops and Symposia

1. “Looking Deep In the Southern Sky”, Joint ESO-Australia Workshop, Sydney, Dec. 10 - 12, 1997.
2. “The URSI Large Telescope Working Group Meeting and the 1 kT International Technical Workshop”, Sydney, Dec. 15 - 18, 1997.
3. “The Sub-MicroJansky Radio Sky”, Sydney, June 17, 1998.
4. "Radio Frequency Interference Mitigation Strategies", Elizabeth and Frederick White Conference sponsored by the Australian Academy of Science, the ATNF and CTIP, Sydney, Dec.15-16, 1999.

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1. Ekers, R. D., The ATNF Upgrade, Joint Discussion 9, International Astronomical Union General Assembly, Kyoto, Japan, August 22, 1997.
2. Ekers, R. D., Director’s Presentation to CSIRO Board, April 28, 1998.
3. Hall, P. J., The Square Kilometre Radio Telescope, Combined Engineering Institutions Lecture Series, Sydney, April 13, 2000.
4. Hall, P. J., The Square Kilometre Radio Telescope, Invited Presentation, Workshop on Applications of Radio Science (Aust.), Beechworth, April 27 - 29, 2000.
5. Hall, P. J., The ATNF MNRF Upgrade - A Progress Report, Anglo-Australian Telescope and ATNF Joint Symposium, Canberra, March 19,1998.
6. Koribalski, B., The Millimetre-Wave Upgrade of the Australia Telescope Compact Array, Invited Presentation, Workshop on Applications of Radio Science (Aust.), Barossa Valley, September 21 - 23, 1997.
7. Norris, R. P., The MNRF Upgrade to the Australia Telescope, Astronomical Society of Aust., July 7, 1997.
8. Norris, R. P., Radio Astronomy into the Next Millenium, Conference “Astronomy and Space Science”, Mafraq, Jordan, May 5, 1998.
9. Thomas, B. MacA., Possible Siting of the 1 kT in Australia, Western Australian Department of Commerce and Trade; Department of Conservation and Land Management; and Gascoyne and Mid-West Development Commissions, May 12 - 15, 1998.
10. Thomas, B. MacA. and Ekers, R. D., The 1 kT Project, Department of Industry Science and Tourism, May 26, 1998.

Appendix 5 - Promotion, Training and Outreach

Promotion

In the past year material compiled by ATNF staff has highlighted the MNRF upgrades at two major engineering science meetings. In August 1999, poster papers and verbal reports describing the Australian millimetre-wave and VLBI upgrades were presented to the International Union of Radio Science (URSI) general assembly in Toronto, Canada.

In April 2000, six ATNF staff attended the Workshop on the Applications of Radio Science, in Beechworth (Victoria). This meeting was held under the auspices of the URSI Australian chapter. A number of papers dealing with ATNF engineering science were presented; most of the featured activities formed part of the MNRF program. Dr Peter Hall of the ATNF gave an invited presentation entitled "The Square Kilometre Array" to this gathering.

Papers presented at these two meetings are listed in Appendix 4.

Education and Training

ATNF staff are active in educating the astronomy community about the potential of the National Facility upgrades. For example, the University of NSW now operates the ATNF's Mopra 22 m radio telescope for three months of each year, giving students and other researchers (from within and outside the UNSW) the opportunity to do "hands on" millimetre-wave astronomy in a supportive and guiding environment. ATNF astronomy, engineering and support staff are contributing to this facility sharing, thereby encouraging the growth of an Australian millimetre-wave astronomy community outside the ATNF. Such a community will be invaluable in exploiting the full scientific potential of the upgraded ATCA.

The ATNF also conducts a formal post-graduate education scheme, with graduate students being co-supervised by ATNF staff. While this is linked mainly to astrophysics education, one MNRF-related engineering science PhD has been awarded. The ATNF Annual Report for 1999 details the present status of the scheme. It is worth noting that, as the MNRF-sponsored upgrades move into commissioning and first astronomy stages, Australian graduate students will be exposed to leading-edge systems via the ATNF's graduate training scheme.

In the area of undergraduate engineering education, the MNRF upgrades have allowed the ATNF to offer challenging work experience projects. Most notably, the Facility supports at least one student from "sandwich" courses each year and, since the inception of the MNRF Program in 1997, these positions have been devoted to radio frequency and digital systems work allied with the ATNF upgrades.

Outreach

ATNF outreach activities are described in the Facility Annual Report for 1999. In the MNRF context, the main work has centred on the SKA outreach program developed for WA rural and aboriginal communities (see Section 4(c)*(iv)*).

Appendix 6 - Industry Links

Background

The transfer or commercialization of leading-edge technology from the MNRF Program has been somewhat restricted by two factors:

- end-usage agreements with local and international R&D partners (in the case of, e.g., radio-frequency MMIC amplifiers);
- the absence of significant Australian industry capacity in key areas (such as millimetre-wave electronic systems).

Despite these limitations, there has been a significant involvement by external contractors in a number of MNRF-related areas. For reference, Table A6-1 summarizes this involvement from the Program commencement.

Table A6-1 Summary of Major Upgrade Contracts

Activity	**Period**	**Company or Industry Group**	**Value ($A'000)**
ATCA Antenna Upgrade Studies	1997-1998	Connell Wagner P/L	20
ATCA Panel Manufacture & Installation	1998-1999	Evans Deakin Engineering P/L	750
ATCA Extra Stations & North Spur	1998-1999	Connell Wagner P/L, Barclay Mowlem Construction Ltd	1350(1)
Preliminary Design of Ceduna Focus Mechanism	1998	Connell Wagner P/L	10
Design and Manufacture of New Focus Translator for Hobart Antenna	1999	Sydney Engineering (Sales) P/L	42
Precision Metal Forming for Millimetre-Wave Receivers	1999-2000	Seven Sydney Machining, Plating and Cutting Companies	100
Holography Test Receivers	1999-2000	Astrowave P/L	53
Water Line Monitor (Prototype)	1999-2000	Astrowave P/L	65
TOTAL			2390

Note 1:
Of the amount shown, approximately $950k was contributed by CSIRO, augmenting MNRF funds and permitting construction of a north spur interferometer track.

Appendix 7 - MNRF Technical Advisory Committee

To ensure that the ATCA millimetre-wave upgrade proceeds according to best international science and engineering practice, the ATNF has established an Advisory Committee comprising four radio scientists and astronomers recognized internationally for their expertise in the field of millimetre-wave astronomy. The Committee members are:

Dr Stephane Guilloteau, Deputy Director, Institut de Radioastronomie Millimetrique (France), an expert in millimetre-wave aperture synthesis, system and software design, array operations, and astronomy.

Dr Peter Napier, National Radio Astronomy Observatory (USA), Project Manager for the US Millimeter Array, expert in antenna engineering and optics;

Dr Rachel Padman, Assistant Director of Research, Department of Physics, University of Cambridge, expert in millimetre-wave receiver design, observing techniques and astronomy;

Dr Alan Young, Portfolio Manager, Mobile Systems and Networks, CSIRO Telecommunications and Industrial Physics, expert in electronics and signal distribution;

Dr Nick Whyborn, Space Research Office of The Netherlands, expert in millimetre-wave receiver design and antenna optics.

Dr Whyborn was unavailable for the first meeting, being replaced by Dr Guilloteau. Dr Guilloteau has now agreed to contribute indefinitely. Following its first meeting in September 1997, the Committee issued an advisory report, re-printed as Appendix 5 in MNRF Annual Report No. 2. With the advancement of the MNRF Program, it is likely that the ATNF will now refer specific engineering and science projects to individual Committee specialists for review. This process will begin in early 2001, following trials of high-frequency systems at Narrabri.

Appendix 8 - ATNF Professional Staff (MNRF-Related Activities, 1999-2000)

Refer also to Appendix 3 for a tabulation of senior MNRF Program personnel.

Sydney

JW Brooks (Assistant Director and Engineering Manager)
WN Brouw (Astrophysics/Computing)
GJ Carrad (Receivers)
JL Caswell (Astrophysics)
ER Davis (Electronics)
RD Ekers (ATNF Director)
RH Ferris (Electronics)
RG Gough (Receivers)
GR Graves (Receivers)
PJ Hall (Head, SKA Program)
A Hopkins (USyd/ATNF Post-Doctoral Fellow)
PJ Howson (Divisional Secretary)
MJ Kesteven (Astrophysics/Computing)
NEB Killeen (Astrophysics/Computing)
BS Koribalski (Astrophysics)
MR Leach (Electronics)
DG Loone (Computing)
RN Manchester (Astrophysics)
RP Norris (Head, Astrophysics, and Head, Computing)
M Oestreich (Electronics)
PP Roberts (Electronics)
RJ Sault (Astrophysics/Computing)
HL Sim (Scientific and Community Liaison)
MW Sinclair (Head, Receivers)
LG Staveley-Smith (Astrophysics)
BM Thomas (Eng. Research)
AK Tzioumis (Astrophysics/LBA Support)
JB Whiteoak (Deputy Director and Head, National Facility Support)
WE Wilson (Head, Electronics)

Narrabri

GP Baines (Systems Engineering)
RJ Beresford (Electronics)
SJ Cunningham (Computing)
J Giovannis (Computing)
TJ Kennedy (Manager, Visitors Centre)
D McConnell (Officer-in-Charge)
R Subrahmanyan (Astrophys/Electronics)
RM Wark (Operations)
MH Wieringa (Computing)

Parkes

AJ Hunt (Electronics/Servo Systems)
JE Reynolds (Officer-in-Charge)
JM Sarkissian (Operations)
MR Smith (RF Systems)

Canberra

JF Bell (ARC Fellow/Astrophysics)
DL Jauncey (Astrophysics)
JEJ Lovell (Astrophysics)

Appendix 9 - List of Main Abbreviations and Acronyms

ACC	Antenna Control Computer
ANU	Australian National University
ARC	Australian Research Council
ATCA	Australia Telescope Compact Array
ATNF	Australia Telescope National Facility
ATOMS	Australia Telescope Observation Management System
CCD	Charge-Coupled Device
CMB	Cosmic Microwave Background
CSIRO	Commonwealth Scientific and Industrial Research Organization
DISR	Department of Industry, Science and Resources
ESO	European Southern Observatory
IGP	Inernational Gemini Project
IM	Interference Mitigation
LNA	Low-Noise Amplifier
LO	Local Oscillator
MMIC	Monolithic Millimetre-Wave Integrated Circuit
MNRF	Major National Research Facilities
NCA	National Committee for Astronomy
PWV	Precipitable Water-Vapour
RSAA	Research Centre for Astronomy and Astrophysics
SKA	Square Kilometre Array
SUSI	Sydney University Stellar Interferometer
UNSW	University of New South Wales
VLA	Very Large Array
VLBI	Very Long Baseline Interferometry
VLTI	Very Large Telescope Interferometer