Major National Research Facilities Program

Annual Report by the Australia Telescope National Facility to the Department of Industry, Science and Resources

Report Number 3, 1 July 1998 - 30 June 1999

An ATNF multi-band, millimetre- wave receiver being assembled prior to enclosure in its cryogenic dewar. The two largest feed horns cover the 12 and 9 mm bands, while the small horn is for 3.5 mm. To minimize losses and receiver-generated noise, the 3.5 mm feed and all the low-noise amplifiers and associated components in the dewar are cooled to 20 K. In operation, the 12 or 3.5 mm horn is moved to the secondary focus of an ATCA antenna using the existing turret rotator. To select the experimental 9 mm feed (or any eventual 7 mm option replacing it), the package is also linearly translated.

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Table of Contents

P J Hall, 13 September 1999

Director's Foreword

With the MNRF upgrade now in full swing and final outcomes and time-scales coming into focus, it is a good time to look at the niche we will occupy with the upgraded Australia Telescope Compact Array (ATCA). The international scientific community is now fully behind ALMA, the Atacama Large Millimetre Array in Chile, which will be built at a cost of more than half a billion US dollars and which is expected to be in operation in 2008. An enormous amount of science awaits ALMA but, in the interim period, Australia will have new and unique observational capabilities as a result of this MNRF upgrade. When the upgrade is completed in 2002, the ATCA will be the only Southern Hemisphere interferometric array and it will be able to pursue the beginning of many of the scientific investigations which will eventually be tackled with ALMA. After ALMA is in operation the ATCA will still retain an important complementary role, being the only Southern Hemisphere interferometer operating at the longer millimetre, and centimetre, wavelengths.

The decision made early in the upgrade project to extend the high frequency surface to 22 m is now looking good. The technical evaluation of performance is promising and the strategy of emphasizing large fields of view at millimetre wavelengths is becoming more important. By increasing the antenna diameter to 22 metres the gap between the antenna diameter and the shortest spacing on the Compact Array will be very much reduced, improving the quality of large field images.

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 while continuing to operate the existing instrument. This is a very healthy situation and will keep the ATNF in a good position to influence future developments in radio astronomy.

One of the results of discussion in the last meeting of the Australia Telescope Steering Committee was to acknowledge the importance of these R&D programs being conducted at the ATNF. In addition to the key performance indicators based on the operational capabilities of the ATNF, we will be including new performance indicators based on our ability to meet development milestones and to bring new systems into operation.

As well as balancing the requirements of continued National Facility operation with the development of the new capability, the ATNF staff have had to contend with some of the most serious flooding of the Narrabri site on record. Despite these setbacks I am pleased to see that most of the project milestones are still being met and the project completion is still expected by January 2002.

In conclusion, the projects described in this report are progressing well and are positioning Australia for a continued great future in radio astronomy.

Prof Ron Ekers
Program Director

Executive Summary

The Australia Telescope National Facility and the University of Tasmania are currently 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 second decade of the next century. The Australian upgrades are funded largely by the MNRF program and were begun in early 1997; the last project is scheduled for formal completion in January 2002.

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, allowing much finer detail to be discerned 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 previous year saw a number of milestones reached in the project. These include:

- completion of civil, and most electrical, engineering works for a new north spur interferometer track and for extra stations (antenna locating and connection points) on the original east-west track;

- extension of the high-frequency reflecting surface on one ATCA antenna, evaluation of the modification, and a subsequent decision to proceed with the upgrade on the remaining four closest-spaced antennas;

- construction of a prototype high-frequency receiver package, and a related decision to set October 1999 as a firm target for a two-antenna test interferometer at Narrabri;

- promising performance from a prototype optical-fibre local-oscillator distribution network and associated signal-generation electronics;

- design and laboratory prototyping of electronics for a remote-sensing system to correct the image distorting effects of atmospheric water vapour.

While the ATCA will have operational high-frequency receivers by the completion target date of January 2002, the incorporation of more sensitive receivers than envisaged originally has required some revision of MNRF Program plans (refer to Section 4). The new receivers, based on advanced indium phosphide low-noise amplifiers, are expected to be operational in final form by December 2002.

The second of the MNRF upgrades, being undertaken jointly by the ATNF and the University of Tasmania, involves expanding the Australian VLBI network. VLBI is a technique in which cosmic radio signals received by widely separated antennas are recorded, then subsequently combined electronically to produce images of the sky. These images have a level of detail similar to those from a single enormous telescope, the size of which is roughly equivalent to the largest antenna spacing in the VLBI array; in practice, the antennas can be spaced over inter-continental, or even earth – satellite, distances. The upgrade of the Australian network includes commissioning a 30 m antenna at Ceduna in South Australia, providing improved receivers and high-stability, hydrogen-maser frequency sources at a number of observatories, and installing new signal processing and recording equipment. Although some higher performance (and relatively costly) receiving systems for Ceduna and Hobart are still being designed and constructed, the VLBI upgrade is now functionally complete.

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 is 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, are being supported. Recent highlights include the upgrade of South Pole infra-red observing facilities, the commissioning of a gamma-ray observatory at Woomera in South Australia, and the establishment of innovative projects to explore techniques and technologies for the next-generation radio telescope: the square-kilometre array.

It is clear that the ATNF is operating at, or near, the technological leading edge in implementing several aspects of the MNRF Program. While the nature of agreements with R & D partners sometimes limits direct commercialization possibilities, the ATNF plays an active and visible role in disseminating new technology to international astronomy groups, including groups charged with the design and construction of next-generation telescopes. Examples of relevant technology include low-noise millimetre-wave amplifiers, efficient high-reliability cryogenic coolers, and stable signal distribution systems based on low-cost optical fibre. In MNRF-supported strategic work (related mainly to the square-kilometre array), areas such as focal plane antenna arrays and fibre-optic signal processing may have wider long-term commercialization potential, and recent intellectual property agreements with university and other partners have been framed to reflect this.

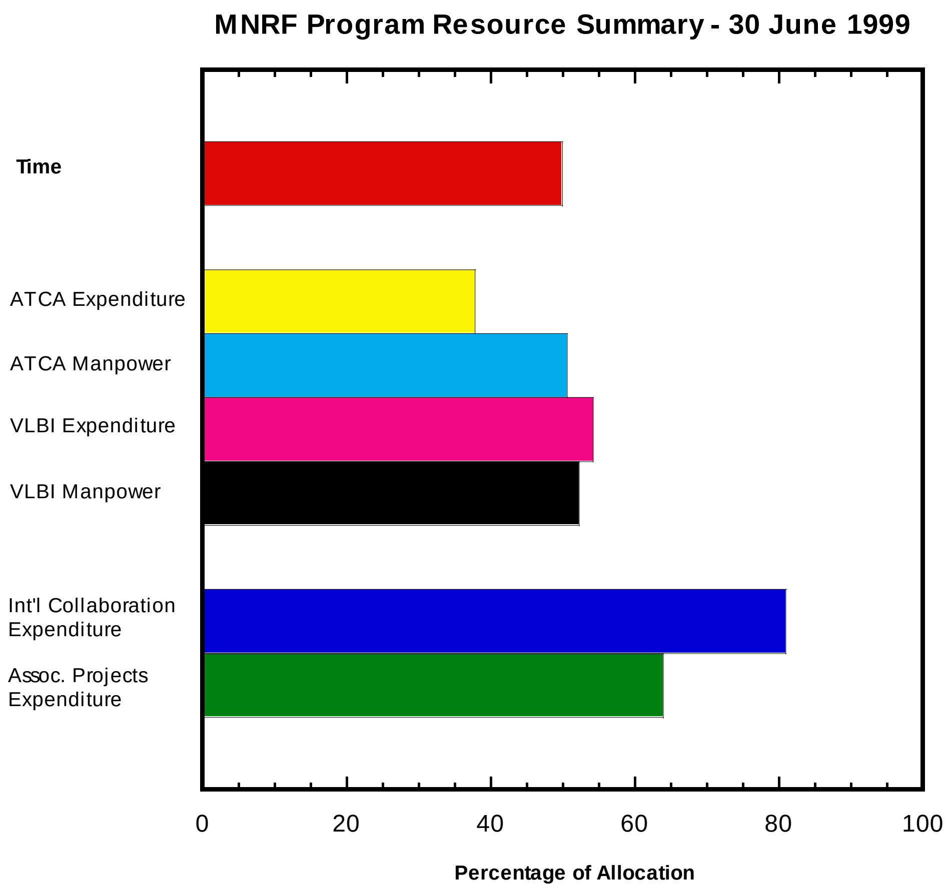
The table below summarizes the financial situation for the MNRF Program as at 30 June 1999. The category “associated projects” includes funds for ATNF strategic research, project management, manpower and test equipment.

ATNF - U. Tas. MNRF Program - Summary Financial Information as at 30 June 1999

Project	Provision	Expenditure to Date	Balance
AT Compact Array High-Frequency Upgrade	5 550 000	2 103 100	3 446 900
VLBI Upgrade (ATNF + U. Tas.)	2 040 000	1 108 118	931 882
International Astronomy Collaboration	1 260 000	1 024 500	235 500
Associated Projects	2 150 000	1 365 800	784 200
TOTAL	**11 000 000**	**5 601 518**	**5 398 482**

All amounts are in Australian dollars and, in this 1999 summary, account has been taken of unspent funds held by the University of Tasmania. Interest on those 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 five years (30 January 97 – 30 January 02) is assumed. The slightly low ATCA upgrade expenditure reflects the need to fund the remaining antenna panel installation as well as major components in the upcoming receiver production effort. Note that, as anticipated, the international astronomy collaboration funds are largely exhausted at this point. In the case of the associated projects, the effect of a plan involving full utilization of two constituent budgets (strategic research and test equipment) by June 2000 is evident.



1. Introduction

This document is the third 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 1998 to 30 June 1999. 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 MNRF Annual Report No. 2, 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

This Section contains a summary of the MNRF-related discussions held by the Australia Telescope Steering Committee at its meeting of March 25-26 1999. For an overview of the MNRF Program management, see Appendix 1.

The Steering Committee has a sub-committee to comment on progress and expenditure relating to the Program and to review annual report drafts. As noted in Appendix 2, the sub-committee now comprises Dr R Cannon, Dr R Webster, Prof J Mould, Dr P Scaife, and Prof J Storey. The sub-committee will conduct a formal review of the Program in September 1999 and will report its findings and recommendations to the Program Director, Prof R Ekers.

The Steering Committee noted that previous Annual Reports had been reviewed by the sub-committee and submitted to the Australian Government (via the then Department of Industry, Trade and Resources) in September 1997 and 1998. The reports have also been distributed to all Steering Committee members. An updated MNRF financial statement was considered by the Committee at its March 1999 meeting; the Committee noted that all projects were on target and it raised no MNRF-related issues.

In a related area, the Committee noted that, in February 1996, the CSIRO Executive developed a set of Key Performance Indicators (KPI) to be used both to assess CSIRO as a whole, as part of the Triennium Funding Agreement, and to assess individual CSIRO Divisions. The March 1996 Steering Committee meeting adopted a set of KPI which were closely based on the corporate CSIRO KPI, but modified slightly to reflect better the operation of a National Facility. This year, the Steering Committee noted that none of the performance indicators reflected the effort being put into the development of future instrumentation, such as for the MNRF program. The ATNF agreed to develop a KPI based on the actual project milestones.

4. ATNF Upgrades and Extensions

The past year has seen significant progress in all upgrade and extension projects and, indeed, the bulk of the VLBI network extension is now complete. The enhanced VLBI network has recently been made available to the astronomical community by the ATNF and the University of Tasmania. First images from the network are shown later in this report.

The AT Compact Array high-frequency upgrade is continuing, with several important milestones reached over the course of the year. Impressively, the civil works associated with the upgrade are complete, despite a year of severe flooding at Narrabri. Although some re-sequencing of the project has been necessary, the ATNF remains confident that the target completion date of January 2002 can be met.

The ATNF has successfully applied for CSIRO resources to supplement the MNRF funds obtained to upgrade the ATCA. Details are given in MNRF Annual Report No. 2 but, essentially, the CSIRO funds have permitted construction of a short north spur rail track attached to the original array east-west track, and incorporation of locally designed monolithic millimetre-wave integrated circuits (MMICs) into new ATCA receivers. The effects are to enhance greatly the imaging performance of the Telescope at high frequencies, to allow construction of stable, reproducible and maintainable receivers and, as a bonus, to provide the ATNF with a range of advanced test and measuring equipment.

No insurmountable difficulties have arisen in relation to ATNF upgrades, although the delay in obtaining a US export licence for indium phosphide (InP) MMIC devices caused some concern over the past year. While the InP devices are designed by CSIRO, US foundries are the most practical fabrication contractors. Despite the licence delay, InP devices will still be available on timescales compatible with the MNRF upgrades. To allow important aspects of the ATCA 3.5 mm upgrade to be verified this year, the ATNF is proceeding with telescope-based testing of two prototype receivers based on gallium arsenide (GaAs) MMIC devices designed and produced by CSIRO Telecommunications and Industrial Physics. These devices in fact remain a viable option for the upgrade as a whole, but it is increasingly likely that the ATCA receivers will be fitted with the higher-performance InP low-noise amplifiers by December 2002. However, a suite of sensitive receivers will be available for astronomical use at, or before, the formal contract completion date of January 2002.

In the course of the year, the ATNF seized an unexpected opportunity to transfer important aspects of receiver engineering design and construction to Australian industry, in line with the spirit of the MNRF contract. Astrowave P/L, a new Melbourne-based consultancy with links to Monash University, will produce a number of systems for the ATNF; these are outlined individually in the sub-project reports in Section 4(a) (below). This receiver work is in addition to the high-precision mechanical fabrication work already passed to local industry.

(a) High-Frequency Upgrade

This upgrade to the AT Compact Array at Narrabri will increase the angular resolution of the Telescope by an order of magnitude, allowing astronomers to see much finer detail in radio images of the sky. The upgrade will also make it possible, for the first time in the Southern Hemisphere, to produce highly detailed images of the distribution of common molecules in space. In essence, the upgrade adds two new observing bands to the Telescope: 12 mm (16 - 25 GHz) and 3.5 mm (85 – 95+ GHz). Although the new receiving equipment uses advanced electronic and electromagnetic engineering devices and techniques, the upgrade has been planned carefully to avoid increasing the ATCA operational resource requirements.

Substantial progress has been made in all areas of the high-frequency upgrade and the ATNF now has a firm target for a prototype millimetre-wave interferometer. This two-element system will be operational at Narrabri in October 1999. It will include two re-surfaced ATCA antennas; 12 mm and 3.5 mm receivers; prototype local oscillator generators and distributors; and an early version of the new antenna control computers. One month of ATCA time has been scheduled to install and test this system, and it is anticipated that invaluable design verification data will be obtained.

Reports on upgrade sub-projects are included below.

(i) 12/3.5 mm Receivers

The ATCA millimetre-wave receivers are contained in a single cryogenic dewar containing receiving electronics for 12 mm and 3.5 mm systems; provision has been made to incorporate a 7 mm (40-50 GHz) system in the future although, in fact, the first two receivers, now almost complete, may contain 9 mm (32 GHz) electronics (in lieu of 7 mm). This would allow the prototype ATCA interferometer to perform timely and scientifically valuable work relating to the cosmic microwave background radiation. This research is being conducted in collaboration with the University of Chicago, which is aiming to supply critical 9 mm electronics. For more details of the multi-band receiver package design, refer to MNRF Annual Report No. 2.

The prototype receivers, one of which is shown on the cover of this report, use fairly basic first-stage low-noise amplifiers (LNAs) but will, nonetheless, allow the overall ATCA upgrade to be demonstrated. The design of the advanced indium phosphide (InP) MMICs which form the basis of future LNAs is well advanced, with the 12 mm amplifier having already passed the foundry design-rule check stage. The next step is mask fabrication for the integrated circuits, followed by device manufacture, on-wafer testing at CSIRO, wafer dicing at the foundry and, finally, bonding and packaging at the ATNF. With the export licence issue resolved (see Section 4, Introduction), 12 mm MMIC amplifiers should be available in mid-2000. These devices will cover the full 16 – 25 GHz range and give a typical ATCA system equivalent noise temperature of 80 K. The MMIC-based amplifiers for 3.5 mm will be available a few months later and are expected to give 100 GHz system temperatures of

180 K (at the zenith) in favourable observing conditions. As a contingency against difficulties with the advanced InP devices, gallium arsenide MMIC designs have also been produced; these chips add about 30 K and 80 K to the 12 mm and 3.5 mm system temperatures respectively. It is worth mentioning that, following delivery of any MMIC chips, there is a substantial challenge in designing and testing probe assemblies which allow signals travelling in conventional waveguide to be fed to the MMIC.

To reach the point of being able to produce workable high-frequency MMIC amplifiers, the ATNF has invested substantially in training, production and testing infrastructure, and advanced software for computer-aided design of high-frequency circuits and 3D electromagnetic wave guiding structures. In particular, the Facility now has an operating electro-forming plant for the manufacture of exceedingly precise structures such as feedhorns; a new clean-room facility to allow wire bonding to MMIC chips; and a Hewlett-Packard 8510 network analyser capable of making vector (amplitude and phase) circuit measurements to at least 110 GHz. While electro-forming is the usual way of producing precise high-frequency electromagnetic elements, the ATNF is also experimenting with a metal arc spraying technique which may give similar mechanical tolerances and electrical performance with less manufacturing complexity.

In a similar vein, the ATNF has been developing its own cryogenic compressors based on a rotary “scroll”principle rather than on the traditional reciprocating action (Figure 4-1). These units offer more gas flow, improved efficiencies and increased reliabilty relative to commercial compressors. They also have the advantage of requiring no external cooling, a major cost and reliabilty advantage in the hot Narrabri summers. Tests of prototype scroll compressors have demonstrated the expected quantitative advantages and the units will be fitted to ATCA antennas as the high-frequency upgrade continues.

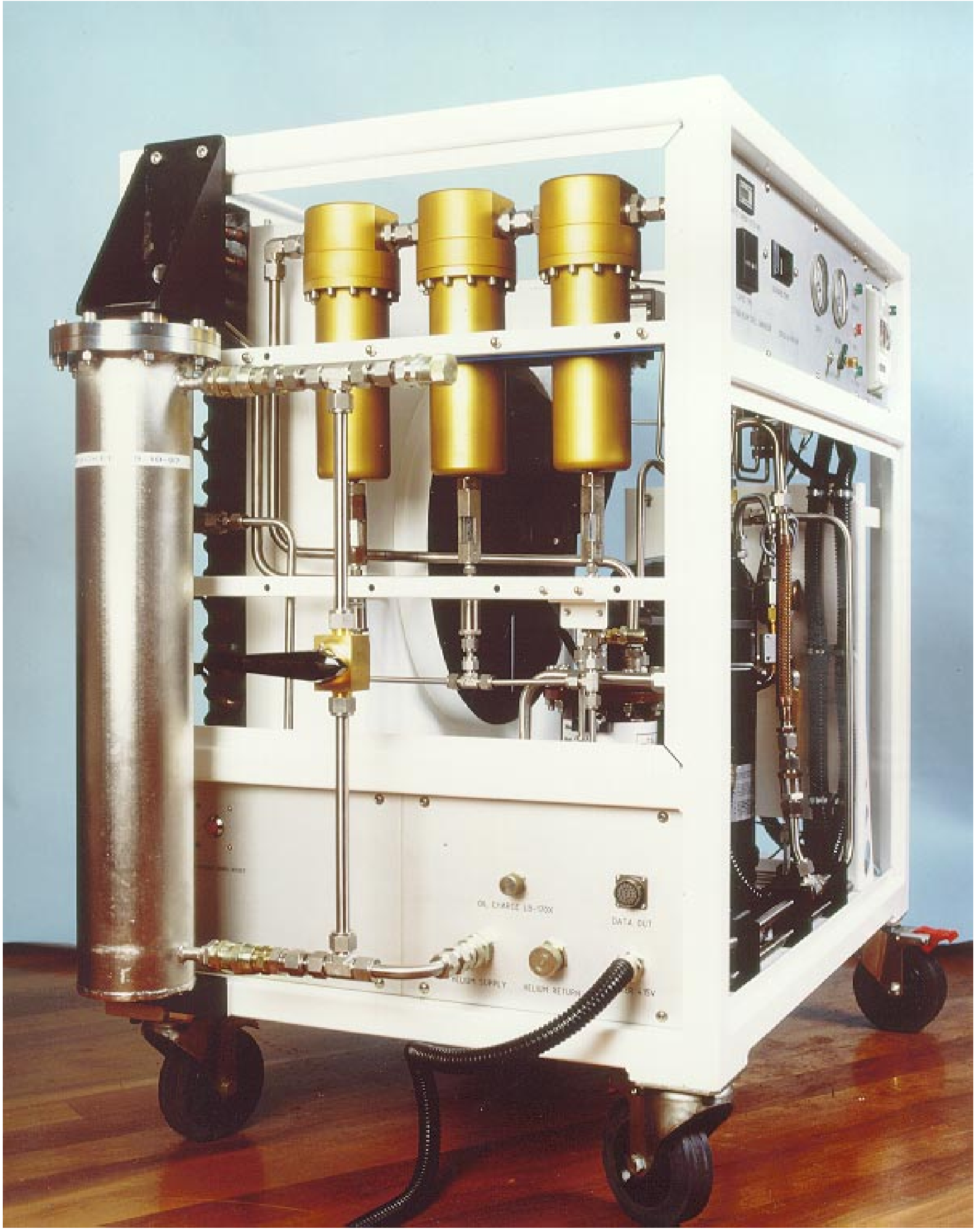


Figure 4-1 *Internal view of a new 5 kW helium compressor developed by the ATNF for use with cryogenically cooled receivers. The unit, which is cubical in form with a face dimension of 0.9 m, is based on an Hitachi, helium-modified, scroll compressor. Three coalescing filters (bronze-coloured), together with an external (cylindrical) activated-carbon filter, guarantee an exceptionally pure helium gas supply to the cryogenic refrigerators. The ATNF compressors have a lower component cost than commercial units and also offer higher gas-flow rates (up to 1.5 m^3 min^{-1}), lower running temperatures with no requirement for external cooling in the Narrabri environment, a variable-speed drive option, and easy installation and service on antennas.*

(ii) ATCA Antenna Surface Extension

The six 22 m diameter ATCA antennas were constructed originally with solid reflecting surfaces to a diameter of 15 m, but the outer 7 m section of each antenna was clad with perforated aluminium panels. The perforated material forms an effective reflector at frequencies up to 50 GHz but, to improve the efficiency of the array at higher frequencies, the MNRF Program provided funding to extend the solid reflecting surface of the five closest antennas to the full 22 m diameter. This effectively doubles their sensitivity in the 3.5 mm band and alleviates concerns relating to missing spacings in the aperture synthesis process. MNRF Annual Report No. 2 contains details of the specification and tendering process for the project; the ATNF has now engaged Evans Deakin Engineering (EDE) P/L to supply and fit the panels.

New panels were fitted to antenna CA03 in September 1998. Extensive tests showed that there were no pointing problems resulting from extra wind loading effects, verifying predictions that the performance at lower frequencies would not be compromised by the modification to increase the high frequency efficiency. Initial adjustment of the panel setting was done using simple mechanical techniques, and first-round radio holography measurements revealed setting errors up to 500 μm rms at the antenna edge. More sophisticated panel adjustment in June 1999 resulted in an overall error of <200 μm rms, giving an expected aperture efficiency of about 40% at 100 GHz. Figure 4-2 shows a working holographic image produced in the course of the tests.

Under a separate funding arrangement with the University of New South Wales, the ATNF is currently undertaking a similar surface extension for the 22 m Mopra antenna. EDE production techniques are producing panels for this upgrade with errors < 110 μm rms, the same specification adopted for the four remaining ATCA antennas. During October 1999, these antennas will also be outfitted with the new panels, and array-based performance tests will begin. To expedite the panel adjustment process, two dedicated 30 GHz holography receivers are being produced for the ATNF by Astrowave P/L. These uncooled, portable, receivers will be used in conjunction with a communications satellite beacon transmitter to allow rapid and accurate holographic measurements to be made.

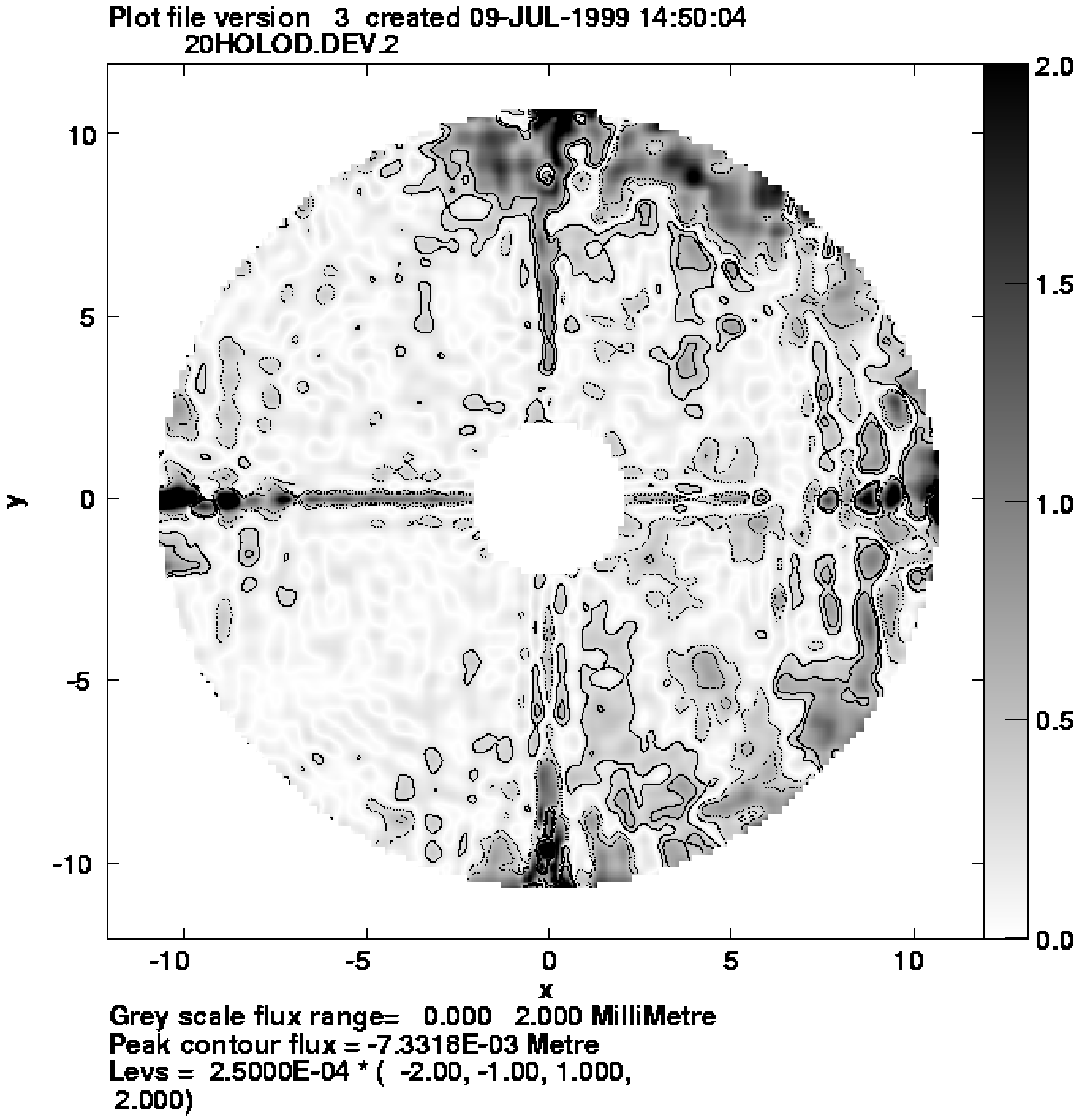


Figure 4-2 *Holographic image of the surface of ATCA antenna CA03 taken during a series of panel adjustments in June 1999. The left side of the dish has been fairly well adjusted and shows rms surface deviations of order 150 μm; final adjustment and measurement of the right-side panels are still to be done. Even so, the formal error across the whole antenna is less than 200 μm. The areas shadowed by the quadrupod support legs, and the central region blocked by the secondary reflector, are clearly visible; these areas have no significance in the holographic measurement process.*

(iii) Atmospheric Phase Correction

This remote-sensing project is delivering equipment and techniques to correct image distortion caused by wind-borne blobs of water vapour moving across the ATCA. The line-of-sight water vapour seen by each of the antennas is measured continuously by water line monitors (WLMs) sensitive to radiation from the 22 GHz water-vapour emission line. Using inversion techniques developed by the ATNF and other millimetre-wave observatories, corrections for unwanted differential delays (or phase) caused by the blobs are made prior to astronomical imaging. The effect is to greatly sharpen the images, especially at high observing frequencies where the effects of water vapour are severe.

In the past year, detailed design of the phase correction system was completed and, despite unforeseen staffing problems in the RF engineering area, two prototype systems will be delivered by the end of 1999 – a delay of six months on the original target. This delay is not expected to compromise the completion target for the high-frequency upgrade.

The prototype WLMs are being constructed by Astrowave P/L, in consultation with ATNF engineers. The systems use the feed and first RF stages of the 12 mm band astronomy receiver, followed by a channelized detection system with 4 x 1 GHz channels positioned within the 16 – 25 GHz band. Using new algorithms and simulation software developed at the ATNF, in conjunction with balloon meteorology data, the channels have been placed to minimize errors in the atmospheric water-vapour measurement while rejecting spurious brightness temperature variations from other sources (e.g. antenna pickup of ground thermal radiation).

One difficulty inherent in sensing atmospheric emission near 22 GHz is the increasing use of the band for communications, including satellite links. However, the expectation is that, with careful second-order adjustment of the channel positions, remote sensing at the ATCA site should be feasible for at least the next decade. The promise of phase correction under a range of weather conditions (including, at least, light cloud) makes the approach worth pursuing, despite the interference risk. At some very high elevation sites, sensing near the 183 GHz water vapour line may be feasible but, at Narrabri, radiation from this line is entirely saturated over the entire range of water-vapour values encountered.

(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.

To verify the design of the new LO system, extensive laboratory testing is under way using a 2 km fibre link at ATNF Headquarters in Sydney. Results show that, using a commercial 15 GHz laser diode modulator and standard single-mode optical fibre, a number of potential LO arrangements are viable. In fact, it appears most likely that a new 7 GHz high-frequency reference will be distributed, as well as a 160 MHz signal for compatibility with existing systems. Most importantly, tests show that slow length variations of fibres, caused mainly by thermal variations, can be adequately corrected using "round-trip" phase measurements on pairs of fibres in the same cable bundle. Figure 4-3 illustrates the two-fibre correction process. The design target for the total phase error (comprising contributions from the distribution network and receiver local oscillator chains) remains 5° rms at 100 GHz.

Floods and resulting civil-work delays at Narrabri have caused some slippage in the fibre installation schedule at the site. All new stations will be available for limited use after April 2000. However, five east-west stations will be operational for high-frequency interferometer tests in October 1999. The target for full operation of the entire new LO generation and distribution system is now December 2000.

Much of the performance increase of the upgraded LO distributor is predicated on having precise, robust, indoor and outdoor connectors for the single-mode fibres. The ATNF has identified a European-standard connector (Diamond 2000) which has suitable mechanical and optical performance, and which can be ruggedized for external use. While this product is a mature one, a final survey of emerging competitive products is under way prior to any final commitment to purchase some $50k worth of the Diamond connectors.

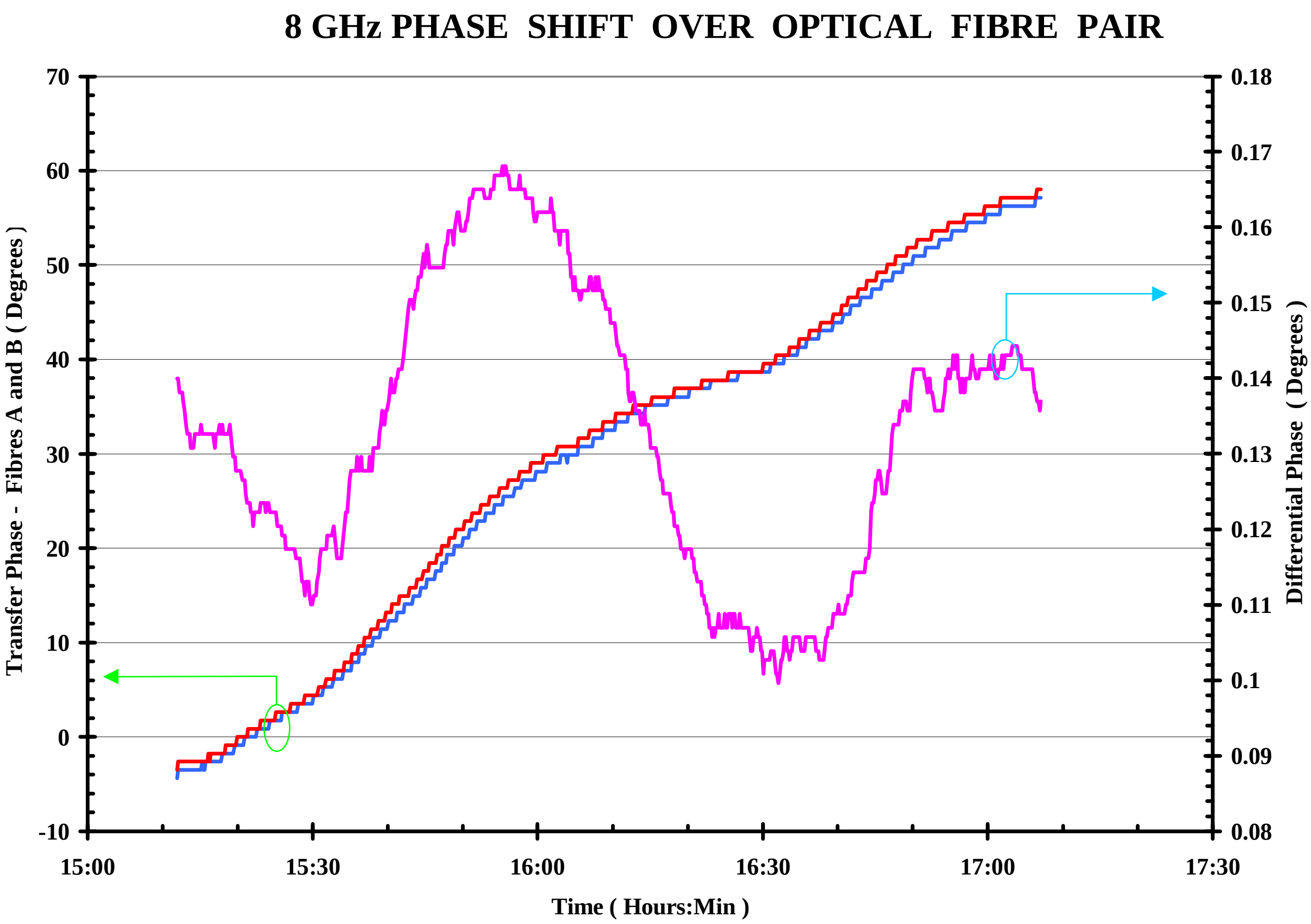


Figure 4-3 *Plots illustrating the performance of a two-fibre phase correction system operating at 8 GHz with a 2 km length of optical-fibre cable. The red and blue traces show the output phase relative to the input for the two fibres, while the purple line shows the phase difference between the fibre outputs. At 8 GHz the difference is about 0.05° peak to peak. When scaled to 100 GHz, the error amounts to only about 0.6°, verifying that, in the upgraded ATCA, it will be possible to correct adequately for fibre-length variations caused by, for example, thermal expansion or contraction.*

(v) ATCA Extra Stations

The original MNRF funding allocation was for three additional antenna stations on the 3 km east-west rail track of the ATCA. CSIRO provided additional funds to construct a 230 m north spur track, enhancing greatly the high-frequency imaging performance of the array. With a high degree of commonality between the E-W and north spur works, both projects were combined for management purposes. Details of the contract management are given in MNRF Annual report No. 2. In general, the civil works undertaken by the contractor, Barclay Mowlem Construction Limited (Railway Engineering and Construction Group), went well but were delayed substantially owing to the high rainfall and flooding in the Narrabri area. However, with the exception of some road works, the contract has been completed.

The ATNF sub-contracted separately the digging and finishing of trenches and pits for station cabling, and this work has now been completed. Antenna electrical wiring modifications to allow the re-positioning ("long-travel") drives to function in both E-W and N-S directions are well advanced, and copper and optical-fibre communications cables to the new stations will be installed shortly. Some new stations will be tested during the high-frequency interferometer trials in October 1999 and, in line with original projections, all stations should be available for use in the first half of 2000. Figure 4-4 shows a general view of the central section of the array track, together with the new spur.

(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. However, ATOMS retains the more general aim of introducing more rigorous software engineering and management techniques to the ATNF, with the ACC development being the exemplar project.

The new antenna control system is divided into a real-time antenna-based component which provides a hardware interface, and a set of additional components which incorporate higher-level processing and user-interface features. This split allows developers to capitalize on the advantages of the respective development environments.

The real-time component of the antenna servo software has been completed and is currently being tested in simulation mode. Compared with the existing ATCA servo software, this new implementation provides more accurate control and reporting of antenna positions and hardware status, as well as giving more flexibility for future observing modes. The new servo control system is implemented in the pSOS real-time operating system environment. The ACCs will be based on standard industrial PC hardware. Tests with real ATCA antenna hardware will be done in October 1999.

Figure 4-4 *Aerial view of the centre section of the ATCA. The new north spur line and central antenna turning bay are visible, as are the extensive drainage works associated with the spur. At the time the picture was taken, antenna CA03 – the first to be re-surfaced with the new solid panels – was undergoing separate tests and was being driven independently of the array.*

Developing a low-level antenna simulator has provided an excellent platform for building and testing higher-level software components, which are being written in the Java environment. This is an excellent environment for providing user interfaces and for implementing highly flexible control system components. The first result of work in this area is a set of graphical and other components which will be useful for controlling and monitoring the ACC.

Despite delays in developing core software components, a prototype ACC will be working by the end of 1999, with integration testing and production now scheduled for the first half of 2000. The new ACCs will be installed on the ATCA in mid-2000.

The next step in the more general ATOMS project is to integrate a recently developed, novel and flexible coordinate system conversion package. This software will be a test of whether "object frameworks" help designers build control systems which are simultaneously easy-to-modify and robust – common conflicting requirements with scientific research instruments such as radio telescopes.

(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 new equipment is in routine use and initial user feedback will be incorporated into a new version of the control software to be installed in August 1999. 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.

(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. The latter category has proved especially important in the past year with the growth of international interest in the square-kilometre array (SKA – previously known as the 1 kT). Relatively modest MNRF funding has made it possible to conduct vital bridging work in the fields of SKA system design and interference mitigation. These studies are maintaining Australia’s key role in the international project until much more comprehensive programs, presently being considered by the Australian Government, can be initiated – hopefully in the triennium beginning July 2000.

Brief reports on the miscellaneous MNRF areas are given below.

(i) Project Management

The geographical diversity of the MNRF Program has raised substantial project management challenges. Nevertheless, with the ATNF’s experience in operating and developing remote facilities, and using the new communications equipment mentioned in MNRF Annual Report No. 2, the Program has been kept on track (despite difficulties arising from floods at Narrabri for several months in the past year). Apart from supporting routine project management activities, MNRF funding has recently been used to provide improved lecture and presentation facilities for project specialists. A notebook PC and high-brightness video projector have made state-of-the art audio-visual presentations possible, both to CSIRO and wider audiences.

(ii) Manpower

No changes to the position noted in the MNRF Annual Report No. 2 have occurred, except that a small amount of MNRF funding has been used to extend the terms (to a maximum of 12 months) of two tertiary engineering students currently gaining professional experience with the ATNF.

(iii) Test Equipment

No additional test equipment has been purchased in the past year; an overview of the initial purchase was given in the the previous MNRF Annual Report. It is worth noting, however, that the ATNF has taken delivery of a Hewlett Packard 8510 high-frequency vector network analyser (Section 4(a)*(i)*) funded by CSIRO. This instrument will have very wide application in many areas of the MNRF upgrades.

(iv) Strategic Research

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

With the increasing pace of the SKA project, some of the seed activities initially supported by the MNRF Program have been transferred to mainstream ATNF projects. In particular, the site selection investigations mentioned in the MNRF Annual Report No. 2 are now supported directly by the ATNF. However, MNRF funds continue to support two important areas of study: broadband printed antennas, and RF phase-shifters based on integrated optics. Both these studies are being undertaken by the Department of Communications and Electronic Engineering at the RMIT University, Melbourne.

In the printed antenna study, two research directions have been followed: development of ultra-broadband aperture stacked patches (ASPs) with bandwidths in excess of two octaves, and determination of the scanning performance of ASPs in large or infinite arrays. To develop the ultra-broadband patches a simple philosophy was adopted. Two ASPs were designed, each with octave bandwidths, and a broadband diplexer was fabricated to feed the two antennas. A prototype of this ultra-broadband antenna operating in the frequency range 1 – 4 GHz was developed and tested. The antenna (and diplexer) yields two octaves of bandwidth and, importantly, a constant radiation pattern across the entire band.

To analyse an array of ASPs, a numerical analysis technique was derived; this is based on the full-wave Spectral Domain Integral Equation approach. An overall design procedure has also been developed, ensuring that broadband operation is achieved by these elements in an "infinite" array environment. The scan performance of arrays of these broadband elements was investigated and, with an octave of bandwidth, an area of $\pm 50^{o}$ in orthogonal planes could be covered with a VSWR < 2:1.

The design of a tunable RF phase-shifter was verified using a proof-of-concept device consisting of a voltage-variable optical coupler (fabricated from lithium niobate) and an optical-fibre delay line. The operating frequency was limited to a maximum of 80 MHz, as the length of the delay line was rather too long. The next stage was to build the device using semi-conductor materials, allowing the delay to be incorporated into the device itself, giving a shorter feedback loop and higher operating frequency. Early tests showed a much higher insertion loss than anticipated and, upon investigation, it was found that the high loss arose from two factors: high surface roughness, causing degradation of optical modes, and a too-thin cladding layer, causing absorption of optical power. An improved device has now been built and first test results are encouraging.

- *Interference Mitigation*

The profile of interference mitigation (IM) continues to grow within the international astronomy community. The increasing interest flows both from a realization that IM techniques will be central to the design and operation of the square kilometre array (SKA), and from the increasing level of interference to existing telescopes, particularly from new constellations of low earth-orbiting satellites.

With the increased interest and participation in IM, the ATNF has constituted a new internal program aimed at co-ordinating operational and strategic activities in relevant areas. Figure 4-5 shows the structure of the program; the activities grouped under the “Software Radio Telescope” project are supported directly by MNRF strategic funds. This exciting project, which has grown out of preliminary ATNF work in the area, incorporates a powerful computer into the actual signal path of a radio telescope, allowing experiments with IM algorithms and assessment of their effects on the astronomical performance of the instrument. It is a recognition that the SKA will incorporate flexible signal processing systems, and is a way of evaluating the performance of these systems without the expense of extensive hardware prototyping.

The project uses telescope data recorded by ATNF VLBI systems, and advanced software (much of which is written within the ATNF) and computing systems, including a supercomputer at Swinburne University of Technology. As an adjunct to the main project, the ATNF will distribute internationally a DVD-based “atlas” containing recordings of astronomical data affected by various types of interference. This compendium will be invaluable in comparing IM algorithm effectiveness. An ATNF post-doctoral fellow will spend 50% of his time working on the Software Radio Telescope project and it is expected that a substantial research result in terms of SKA system specification will be produced by December 2001.

As well as supporting the Software Radio Telescope project, MNRF funds continue to foster the development of radio frequency interference briefing material for observers at Australian radio telescopes, importantly, for SKA planners evaluating international sites for the proposed instrument. By exploiting the Australian advantage of having a single spectrum regulatory authority for an island continent, and by using a newly compiled CD database of licenced transmitters across the continent, together with a suite of custom database interrogation and visualization software developed by the ATNF, it has been possible to vastly improve our picture of the Australian electromagnetic environment. For example, Figure 4-6 shows the projected transmitter flux density for the continent, illustrating clearly low-interference regions potentially suitable as SKA sites. The work on interference databases and visualization has recently been extended to satellites; further details are available via the WWW site referenced in Figure 4-6.

The ATNF strategic IM program (Figure 4-5) formed the core of support for a program proposed by the US National Radio Astronomy Observatory (NRAO). The ATNF program allowed NRAO to demonstrate international collaboration in IM areas, an essential pre-requisite in framing their $US1M Major Research Instrumentation proposal to the National Science Foundation. Despite receiving excellent reviews, the US proposal was not funded. However, the process of defining profitable niche research areas proved invaluable, and ATNF work will continue largely as planned. In other significant interactions, a research agreement has recently been negotiated with the University of Sydney (acting in collaboration with the Australian Photonics CRC) to examine photonic grating bandstop filters. As well, CSIRO will host an international interference mitigation workshop in December 1999; this workshop is supported in part by the White conference scheme administered by the Australian Academy of Science.

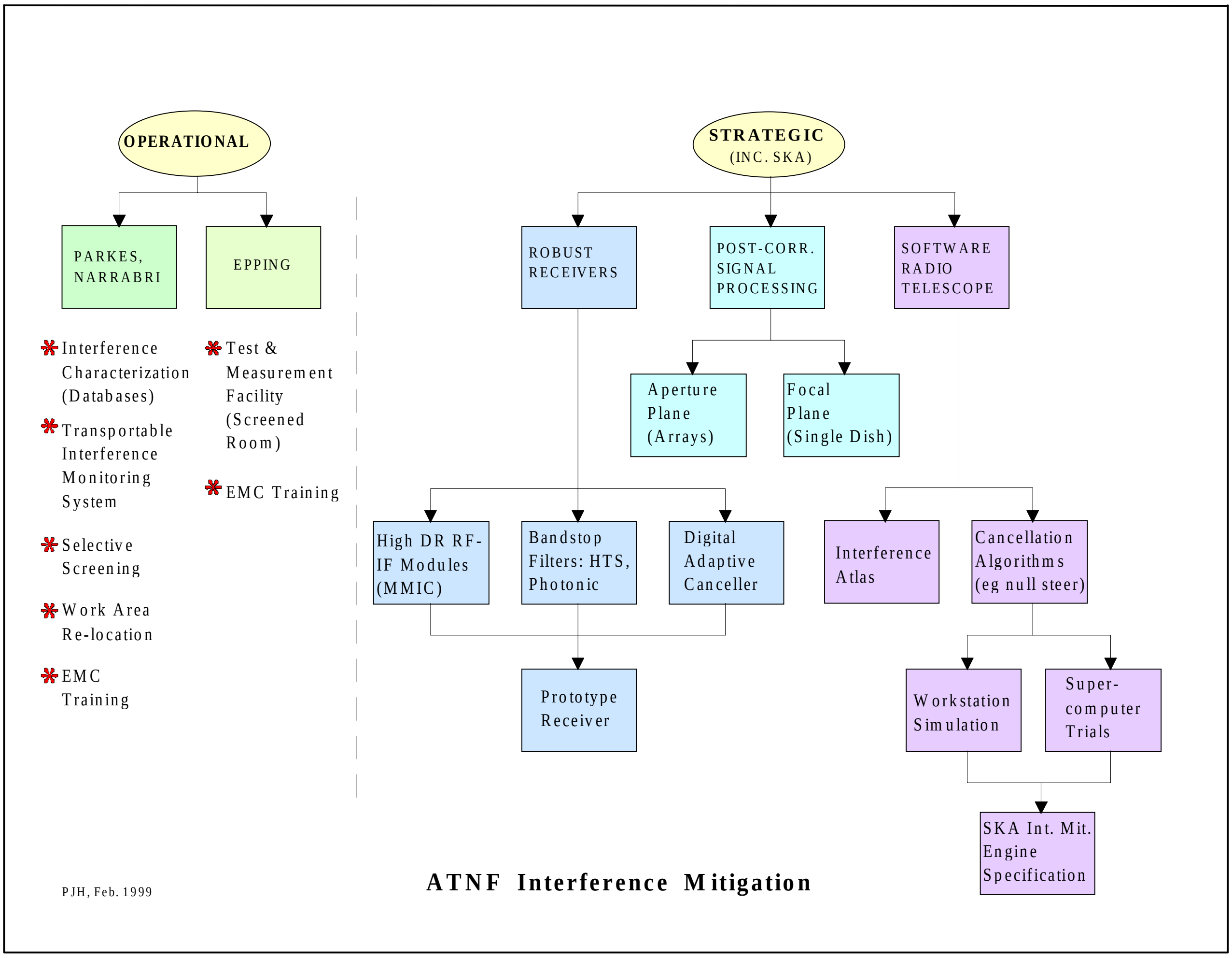


Figure 4-5 *Diagram showing the arrangement of the ATNF Interference Mitigation Program*

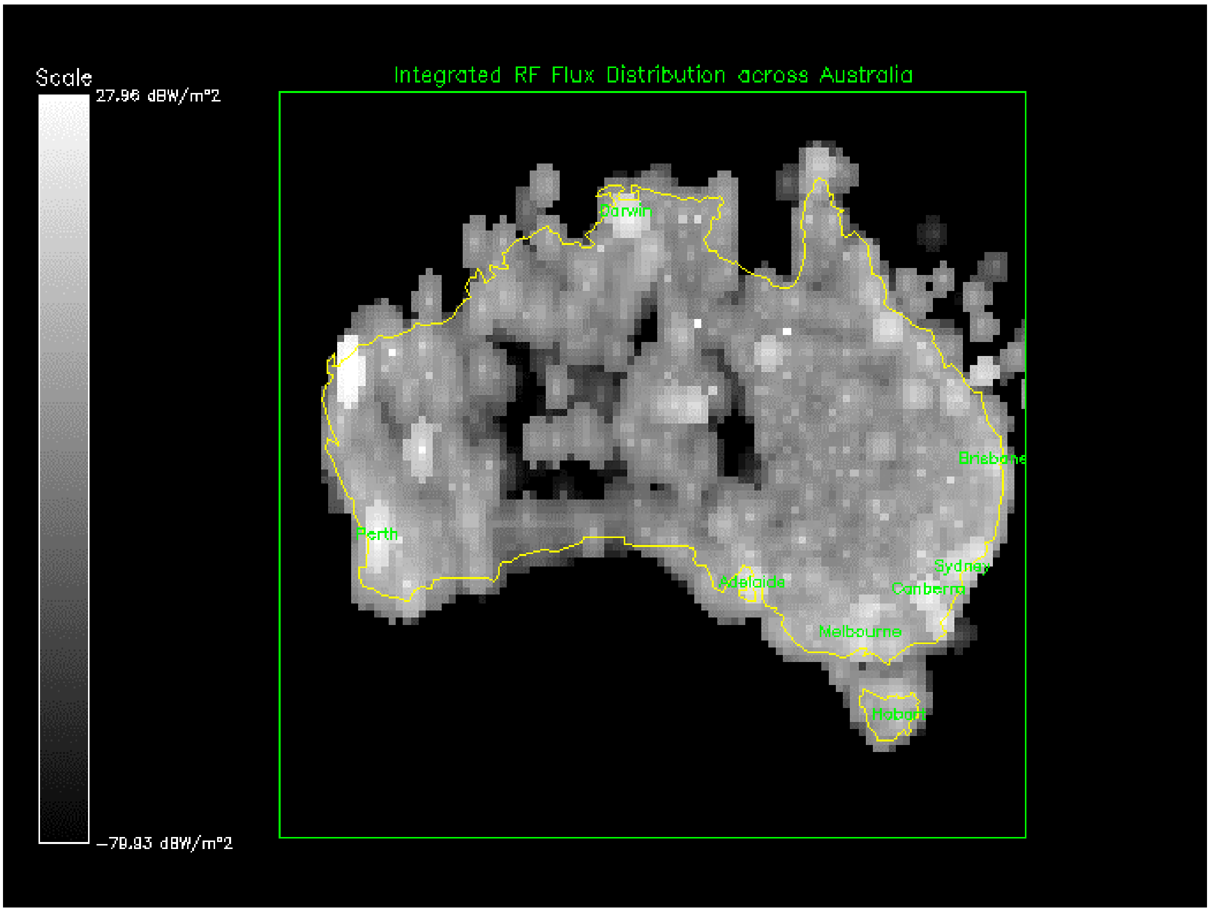


Figure 4-6 *Diagram showing the distribution of radio flux density for the Australian continent. The calculations are based on information recorded in the frequency allocation database held by the Australian Communications Authority, together with a simple (inverse-square) propagation model. The continent has been divided into cells of 100 x 100 km, and RF energy in the frequency range 50 MHz – 30 GHz has been integrated. More details of the process, together with an animation showing the map for each 100 MHz band segment, is available on the world-wide web at* http://www.parkes.atnf.csiro.au/people/jsarkiss/rfi/

(d) Program Science Report

The MNRF science team has been less active during this construction year as the main science questions were resolved and specifications were set last year, and the anticipated period of intense commissioning activity has not yet started.

(i) Calibration and phase correction

The phase correction team has continued to monitor international developments and, from recent Owens Valley Radio Observatory results, it appears that the ATNF strategy of measuring several channels around 22 GHz is likely to be successful. The prototype 22 GHz receivers will not have sufficient bandwidth to fully test this system however, and so the first receivers, although providing a good estimate of the stability of the electronics, will not be able to test the phase correction technique itself. Tests of the full system will therefore be delayed until receivers using broadband 22 GHz indium phosphide low-noise amplifiers become available (most likely in the second half of 2000).

Overseas studies have shown that there is usually a suitable calibrator source in the 3.5 mm band located within five degrees of a target source. First-round observations using a test two-element 12 mm interferometer at Narrabri have identified about 400 compact sources stronger than 0.4 Jy. Further tests are planned in late 1999 to refine the selection of calibrators, especially so far as identifying sources likely to be useful at 3.5 mm is concerned.

(ii) VLBI

It has been determined that the installation of 18/20 cm (1.6/1.4 GHz) feeds at Ceduna will be far more difficult and costly than initially envisaged (see section 5*(v)*). A discussion of the low-frequency science goals at Ceduna concluded that these wavelengths were not strongly justified by the VLBI science, and so it has been decided not to proceed with this implementation. A similar discussion was also held regarding the provision of 22 GHz at Ceduna, but in this case it was decided that the difficulty and cost of mounting a 22 GHz receiver was justified scientifically, and so this band will be included on the telescope. The decision as to whether to cool this receiver was deferred pending some investigation of alternative cryogenic systems. However, if cryogenic cooling is installed, both the 8 and 22 GHz receivers should be cooled to reap maximum scientific return.

(iii) Receivers

As the likely receiver characteristics for the upgraded ATCA become clearer, more detailed discussions have taken place on the precise parameters. For example, the science drivers for both 86 and 110 GHz dictate that the 3.5 mm receivers should be optimized for a centre frequency of 98 GHz, rather than 95 GHz as originally chosen.

5. University of Tasmania VLBI Expansion

The 30 m Ceduna antenna, acquired by the University from Telstra in 1995 and since re-furbished extensively, is now in routine use as part of the Australian VLBI network. Previous MNRF annual reports give details of the re-commissioning program. In the past year activity centred on improving the antenna performance, with a round of surface measurements and adjustments (undertaken in collaboration with the ATNF) yielding an efficient instrument with primary reflector surface errors <0.4 mm rms. Further measurements of antenna gravitational deformation show such effects to be small, making it feasible to operate the Telescope with a fixed setting of the secondary reflector, even at the highest observing frequency of 22 GHz. A recent 8.4 GHz pointing survey indicates an rms error over most of the sky of 15 arcseconds, again suggesting that good performance at 22 GHz is readily achievable.

While the development of the Observatory has been a success thus far, progressive reductions in funds available to the University make it essential to consider realistic operational limitations when considering further upgrade work at the remote Ceduna site. For example, the question of whether closed-cycle cryogenic cooling systems can be supported is currently being investigated.

Development of the Mount Pleasant Observatory near Hobart is also continuing, with plans in place to install a new prime focus cabin and receiver position translator, enhancing greatly the frequency agility of the Observatory. After the new equipment is installed in late 1999, frequency changes will be done under computer control and will take only a few minutes.

(i) Ceduna Receivers

A number of uncooled, low-noise, receivers operating in the frequency range 2 – 22 GHz have been constructed and are now in routine astronomical use. As the original tertiary (Nasmyth) optics system has been retained at Ceduna, changing observing bands involves manually changing waveguide elements. While care is required during this operation, the skills needed fall within the range of what can be expected of a trained observer. Typically, band changes are accomplished in a few hours.

(ii) 12 mm Receivers

Two new 22 GHz receivers will be constructed by the University for use at Hobart and Ceduna. The Hobart receiver will be cryogenically cooled, while the final Ceduna design depends on the outcome of an investigation into whether closed-cycle cooling is operationally feasible at the remote site.

(iii) Hydrogen Masers

These units are now operational and this section of the MNRF contract is complete; see MNRF Annual Report No. 2 for details.

(iv) Timing Units

As with the previous item, these units are operational and this section of the MNRF contract is complete.

(v) Ceduna Antenna Optics

Studies have shown that the tertiary optics arrangement used at Ceduna will not support operation below 2 GHz, making it difficult to observe in the astronomically interesting 1.6 and 1.4 GHz bands. While a design allowing low-frequency prime focus operation has been completed, the need to lower and move the secondary reflector mechanically makes the system much more complex and expensive than envisaged originally. Consideration of the scientific priorities and operational issues involved have led to a decision to abandon Ceduna operation below 2 GHz. Fortunately, some of the VLBI network science capability lost in this decision can be regained by making performance gains at Hobart, and this is now the favoured approach.

After a recent series of surface and secondary reflector adjustments at Ceduna, the Telescope efficiency was measured using reference cosmic sources. Table 5-1 (below) summarizes the results.

Table 5-1 Ceduna Telescope Efficiency

Frequency (GHz)	System Equivalent Flux Density (Jy)	System Temperature (K)	Telescope Sensitivity (Jy/K)	Telescope Efficiency (%)
2.35	370	63	5.9	68
4.80	395	67	5.9	68
6.80	530	82	6.5	62
8.20	740	106	7.0	57
22.235	5200	390	13.0	30

Note that the 22 GHz measurement was made at the water-vapour line frequency. It is expected that another round of secondary reflector adjustments will increase the efficiencies at the higher frequencies by a few percent.

Gain-elevation curves for the Telescope have been measured at the lower frequencies. The curves show that the gain is flat down to an elevation of 15°, with a rapid fall-off for smaller elevations. However, the loss in gain is most likely due to pointing degradation, rather than any significant limitations in the antenna optics.

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.

At a meeting held in August 1998 the NCA sub-committee (Prof R Ekers, Prof J Mould and Dr E Sadler) reviewed the international collaboration program and decided to continue support for overseas travel by Australian astronomers. As the original $70k travel allocation was exhausted, the Committee decided, on the basis of international project developments, to transfer $33.5k from the European LSA Project collaboration to a new travel fund. It was also noted that future adjustments may also be necessary, depending on the status of the LSA interactions and on whether the International Gemini Project itself is able to cover the cost of Australian travel associated with Gemini.

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
L Allen, 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 has been on array configuration studies and associated dynamic range issues.

In work so far, predictions have been made of how the radio sky (at 1.4 GHz) might appear at flux density limits 100 times as faint as existing surveys. Figure 6-1 shows one such simulation. A paper describing these simulations has been submitted for publication to *Proc. Astron. Soc. Pacific*, and the work was presented at the recent international meeting "Scientific Imperatives at Centimetre and Metre Wavelengths" in Amsterdam. A presentation of the early stages of this study was made (June 1998) at a scientific workshop "The Sub-MicroJansky Sky" hosted by the ATNF. A summary of that workshop was accepted for publication in *Proc. Astron. Soc. Aust.*; the early work was also presented at the International SKA Scientific Meeting in Calgary, Canada, in July 1998.

Studies of the response functions of large, many-element interferometers operating in a variety of configurations are continuing. This work is presently being consolidated, with an emphasis on providing an accessible presentation of the major issues surrounding telescope configuration studies. These include an optimisation to provide the greatest sensitivity at high resolution while still maintaining good surface brightness sensitivity, and the implications of various configurations on dynamic range.

(c) Studies of the Highest Energy Particles in Nature

Proposer: R Clay

MNRF funding has enabled University of Adelaide workers to participate in Project AUGER Collaboration Board Meetings, allowing Australians to take a high profile in the development of the Auger high-energy cosmic-ray observatory. Details of these meetings were given in MNRF Annual Report No. 2.

International funding, to the extent of $US50M, is now available, permitting construction of the first half of the Auger Observatory in Argentina. No substantial Australian funding is involved, although the MNRF seed money and small amounts from the University of Adelaide have allowed initial participation. The current status of the project is discussed in a news article in a recent issue of *Nature* (**398**(1), April 1999). Construction of an engineering test array will begin in 1999 and will allow many of the new concepts and systems developed for the Observatory to be tested. In particular, cloud-detection systems developed by the University of Adelaide will be assessed.

Owing to a misunderstanding on the status of the MNRF support, collaboration visits were not made in 1998; this is now rectified and it is hoped that the effects of lost time can be minimized.

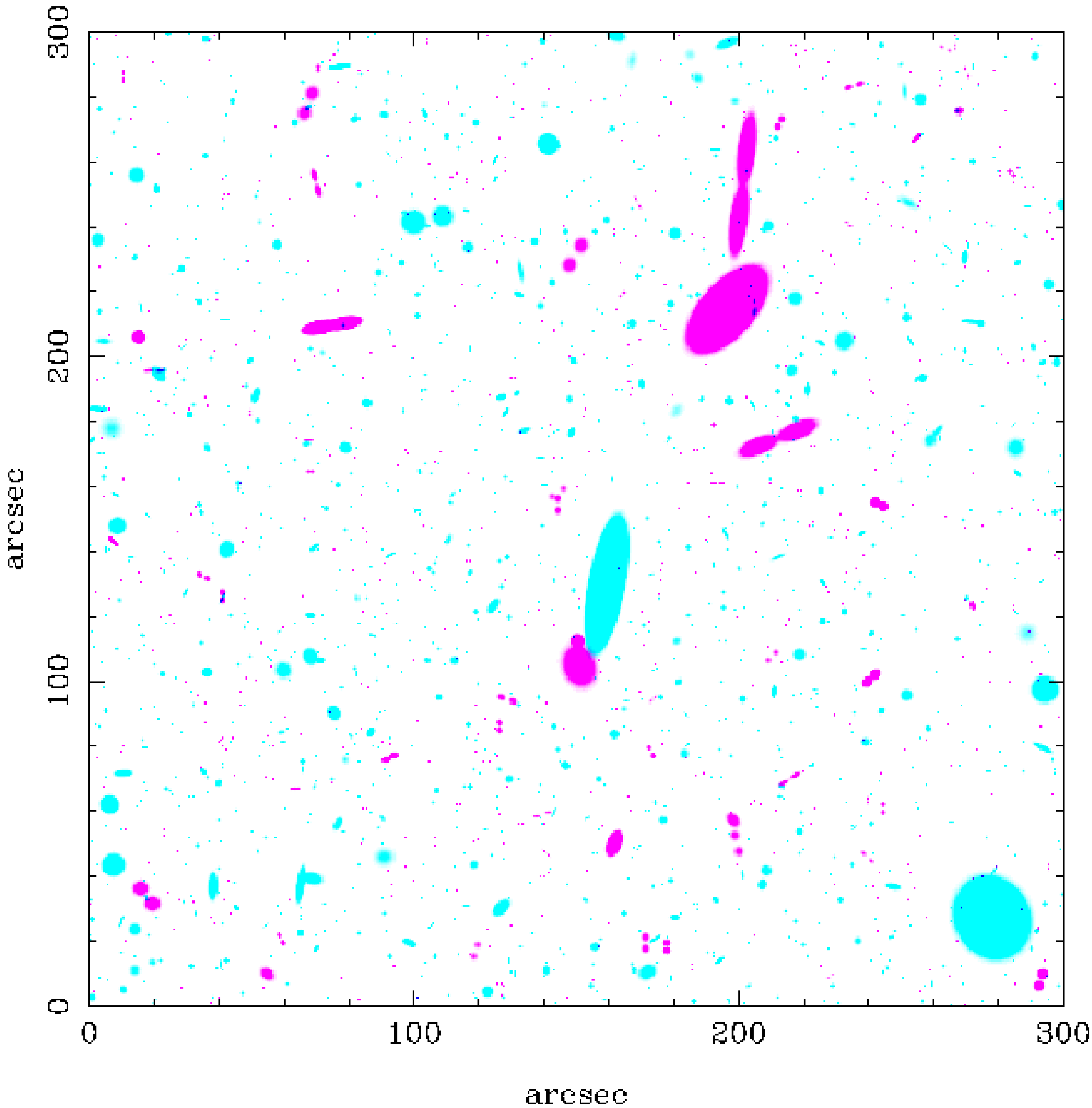


Figure 6-1 *Simulation showing a prediction of what the SKA may see at 1.4 GHz. Flux density limits are of the order of 0.1 micro-jansky - over a hundred times as faint as existing surveys. The area of sky simulated is about four times the size of the Hubble Space Telescope "Deep Field" image, and contains almost 2000 galaxies detectable through their radio emission. The colours distinguish galaxies whose radio emission is derived from active galactic nucleii sources (red) from those radiating due to star-formation processes (blue). For the first time, radio astronomers will see predominantly "normal" galaxies in their observations of the universe. This image is from A. Hopkins, R. Windhorst, L. Cram, R. Ekers, 1999, Proc. Astron. Soc. Pacific (submitted).*

(d) SPIRIT: The South Pole Infrared Imaging Telescope
Proposers: L Allen, J Storey, M Dopita, J Mould

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

The UNSW has devoted its share of the funds to upgrading the existing 60 cm SPIREX infrared telescope (operated by CARA - the US Center for Astrophysical Research in Antarctica) located at the South Pole. RSAA 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 (4000 m) Antarctic plateau.

The SPIREX upgrade consisted of the addition of a 1024 x 1024 InSb-based infrared camera, together with a number of smaller projects aimed at improving the quality of images from the telescope. The infrared camera, known as Abu, was developed by NOAO. This project has launched a joint Australian-US partnership, the end result of which is to give Australian astronomers access to a unique infrared telescope boasting the largest thermal detector array in existence.

SPIREX/Abu was put into operation in early 1998, and carried out a series of important joint US-Australian projects. In 1999 the facility is being made available to astronomers of both nations. A call for proposals in early 1999 resulted in a good response from Australian astronomers. During the year, 11 projects will be carried out on behalf of astronomers at ADFA, ATNF, the Universities of Melbourne and Sydney, and UNSW.

RSAA's report entitled "SPIRIT: The South Pole Infrared Imaging Telescope - The Phase A Engineering Study", outlines 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 and 10-12 μm observing wavelength ranges. A tip-tilt mirror (oscillating secondary) arrangement and large-format electronic detector arrays are central to the design. Significantly, the telescope is designed for largely unattended, open-air, operation in temperatures as low as -85° C. Bearing in mind the remote Antarctic location envisaged for the instrument, the design is optimized for very low power operation.

As a result of the MNRF funding, Australia not only has access to a unique observatory at the South Pole, but is well placed to take a leading role in the development and construction of a major international infrared telescope in Antarctica.

(e) γ-ray Observatory - CANGAROO Project
Proposer: J Patterson

The Universities of Adelaide and Tokyo have announced the commissioning of Cangaroo II - a new, leading-edge, telescope to detect and measure spectra of very high energy gamma ray sources near 100 GeV. While the number of such sources is comparatively small, the count includes interesting sites of relativistic energies in the universe including some active galaxies (BL Lacs), gamma-ray bursters, some young supernova remnants and pulsar plerions. Multi-wavelength observations of these objects can reveal useful information concerning their evolution, structure, magnetic fields and dynamics. The CANGAROO project is moving towards filling the gap between satellite experiments at about 20 GeV and previous TeV experiments, where many more potential sources exist.

CANGAROO II is a 10 m-diameter Mitsubishi radio telescope which has been filled to 7 m with 60 accurate carbon fibre mirrors, designed for desert conditions. Figure 6-2 shows a general view of the instrument. Shortly, 40 more mirrors be added, increasing the aperture to the full 10 m. The mirrors image Cerenkov light in the upper atmosphere, which is produced by relativistic cascades of electrons and positrons, onto a sensitive and very fast 512 pixel camera system at the focus. Cosmic ray event rates at about 10 Hz have been measured. It is hoped to increase this to more than 25 Hz as the system is refined. In 2000, a second and similar telescope will be installed nearby. Later, two more telescopes will be added, making a large instrument known as CANGAROO III. This array will provide higher angular resolution and a lower threshold than a single telescope. The total investment by Monbusho and the University of Tokyo, assisted by the Australian Research Council and MNRF, approaches A$20 million. For further information see *http://www.physics.adelaide.edu.au/astrophysics/cangaroo.html* or *http://icrhp9.icrr.u-tokyo.ac.jp/*.

Figure 6-2 *View of the 10m CANGAROO II gamma-ray telescope at Woomera, SA. The picture was taken in February, 1999, when construction was nearly complete.*

(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. To date, no alternative use of the money has been identified to support Australian participation in the project, although there have been some general discussions related to the possibility of involving Australian expertise (for example, in correlators). Such activities would be advantageous to Australia in the sense of facilitating future Australian access to the new instrument. Furthermore, with strong technology links emerging between the ALMA and square-kilometre array projects, support for Australian involvement in international SKA working groups is likely to be profitable.

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

The AUSTRALIS project involves the design and procurement of an optical/near-infrared, multi-fibre, spectrograph for the European Southern Observatory (ESO). In particular, the original proposal was for a spectrograph destined for the ESO Very Large Telescope (VLT), a multi-telescope array, based on four 8 m units, currently under construction at Cerro Paranal in northern Chile. The underlying philosophy is to provide, through the use of multiple optical-fibre light guides, a spectrograph able to observe many objects simultaneously with a wavelength resolution sufficient to resolve the internal kinematics of very distant galaxies. The main objectives of the Phase A study, as initially proposed, were to develop the original concept design (as detailed in the AUSTRALIS Concept Study) into a full optical, mechanical, electronic and software specification.

However, very early in the Phase A project, ESO requested the AUSTRALIS consortium to provide a costed proposal for the procurement of the fibre positioner for AUSTRALIS. This represented a significant subset of the Phase A study and an opportunity to incorporate the AUSTRALIS spectrograph into ESO's future VLT instrumentation plans; as a result, the study was re-scheduled. Subsequent to the MNRF submission, the AUSTRALIS positioner (now known as OzPoz) is being procured under a separate contract to ESO while, in recognition of the fact that the original Phase A study included substantial work on the positioner, half of its funds were donated to the positioner procurement contract and the study de-scoped and extended to concentrate on the critical engineering design issues surrounding the spectrograph itself.

To date, progress on the Phase A study includes the successful completion of the positioner design study, a continuing prototyping investigation into the difficult area of microlensed fibre integral fibre unit (IFU) design, and a detailed evaluation of spectrograph design options. The IR spectrograph design has in fact undergone several revisions since the last report, culminating in a design which caters for spectral resolution up to 17,000 (H-band), this being in response to the up-grading of the VLT's NIRMOS multi-slit IR spectrograph which now has R~5000 capability. A collaboration between Dutch and Australian astronomers is active in pursuing the design to the next level. Meanwhile, prototyping of the switch-yard fibre coupler is complete, and test reports are currently being prepared. The large IFU has advanced to the assembly stage, with telescope tests scheduled on the Anglo-Australian Telescope during the second half of 1999. In advancing the large IFU, a collaboration has been established with the SOAR telescope group, a consortium with US and Brazilian members. A SOAR physicist has been attached to the Australian project to be trained by project members and, subsequently, to copy the AUSTRALIS large IFU as a prototype feed to the SOAR spectrograph.

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

This project is allowing Australian participation in the planning of a proposed X-ray all-sky monitor, known as LOBSTER. The LOBSTER collaboration consists of NASA's Goddard Space Flight Center, the Los Alamos National Laboratory, and the Universities of Melbourne, Leicester and Wisconsin. The satellite is in the conceptual phase of its development and will be competing for NASA funding of over $A100M, under the "Small Explorer" scheme. In evaluations to date, the project has received excellent assessments of its scientific goals but it has been advised that its technical readiness needs to be improved if funding is to be approved.

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

This project aims to promote collaboration between Australian and Japanese astronomers, with the emphasis being on establishing informal contacts. In the past year, a particularly productive workshop entitled "Stars and Galaxies: Decipherment of Cosmic History with Spectroscopy" was organized by Professors Ando and Kajino in Hilo, Hawaii. Several Australian astronomers from the Australian National University attended and participated in the program. Arrangements have recently been concluded for up to seven Japanese astronomers to visit Australia in July 1999. The group will observe the new 2 dF system in operation on the Anglo-Australian Telescope and most of the party will attend the Annual General Meeting of the Astronomical Society of Australia in Sydney. They will also participate in technical discussions with Australian astronomers and engineers. This visit will be the last activity in the program, since funds are now exhausted.

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

The International Gemini Project (IGP) is building two 8 m optical/infrared telescopes, one in Chile and one in Hawaii. The telescopes and their instruments represent state-of-the-art technology, and will be important components of the optical astronomy programs of IGP members (US, UK, Canada, Chile, Argentina, Brazil and Australia) well into the next century.   First-light has been seen by the Hawaiian instrument and it is expected that the southern telescope will pass a similar milestone in 2000. Australia will contribute 5% of the $US193M project cost through Australian Research Council (ARC) grants; the MNRF allocation is a contribution to the ARC funding and is designed to support initial capital requests for the IGP. 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 has now completed the transfer of all Gemini MNRF funds to the University.

(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 and it has been offered to the European Southern Observatory as a test bed for Very Large Telescope Interferometer (VLTI) instrumentation and detectors. The opportunity for ESO staff to gain hands-on experience of long-baseline optical interferometry with SUSI has also been offered. To date, neither offer has been taken up.

The SUSI group is developing instrumentation of mutual interest to the SUSI and VLTI programmes. This includes improved tip-tilt mirrors (first-order adaptive optics), and group-delay tracking 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 Post-doctoral Fellow has been hired to work on the instrumental development. As part of the project, a new tip-tilt mirror system has been completed and, after extensive laboratory tests, the system is now in full operation in SUSI using existing quadrant detectors. A switch to a more versatile CCD detection system is currently being investigated. Work on a group-delay tracking system to operate at the red end of the visual spectrum is well advanced, with the design completed, components ordered, and laboratory tests planned.

7. MNRF Financial Statements

Table 7-1 summarizes the overall MNRF financial situation as at 30 June 1999. As in previous years, the statement is presented unaudited, pending dissemination by the Department of Industry, Science and Resources of guidelines for the production of audited financial and asset reports. The summary excludes interest of $76.6k which has accrued in the CSIRO account (calculated as at March 31, 1999).

In the summary related to the ATNF VLBI receiver upgrade, the $50k already spent represents the cost of constructing the initial 12 mm receiver now in routine use at Mopra. The remaining funds in the budget will be used to construct a multi-band millimetre-wave receiver (similar to the new ATCA receivers) for the Mopra antenna.

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 1998-99; MNRF Annual Report Numbers 1 and 2 contain full details of earlier grants. Note the transfer of funds from the European LSA project to the travel allocation (refer to Section 6 for details).

Table 7-1 MNRF Financial Summary as at 30 June 1999

Projects	Provision	Expenditure to Date	Balance
ATNF High Frequency Upgrade			
12/3.5 mm ATCA	2860000	661600	2198400
Atmospheric phase correction	160000	48500	111500
ATCA antenna surface extension	910000	300600	609400
New E-W stations for ATCA	440000	423400	16600
ATCA local oscillator upgrade	750000	182200	567800
ATOMS	200000	185500	14500
Parkes conversion system	230000	301300	-71300
ATNF VLBI Upgrade			
12 mm receiver	200000	50000	150000
VLBI improvements	336000	334500	1500
Strategic Research			
Array technology	123200	63300	59900
Interference Excision	76800	15100	61700
Project Management			
Infrastructure	300000	202100	97900
Test Equipment	400000	380900	19100
Manpower	1250000	704400	545600
Payments to University of Tasmania[2]	1504000	1214000	290000
International Collaboration	1260000	1024500	235500
TOTAL	**$11000000**	**$6091900**	**$4908100**

Notes

1. All amounts in Australian dollars (rounded to the nearest one hundred dollars).
2. The University of Tasmania has unspent reserves of $524562, of which $34180 is accumulated interest.

Table 7-2 MNRF International Collaboration Projects - Summary as at 30 June 1999

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	$15k		Dec. ’97 - 100% travel support for invited workshop speakers.	$14,962
B MacA Thomas (ATNF)	The One Kilometre Square Telescope (1kT)	$191.8k	$87k	$45k	2 yr post-doc position; possible extension to 3 yrs; salary overheads from Strategic Research project.	$40,901
R W Clay (U Adel)	Studies of the Highest Energy Particles in Nature	$198k	$6k	$24k	Travel support grant.	$6,000
LE Allen/ JW Storey (UNSW) M Dopita/J Mould (ANU RSAA)	SPIRIT ‘The South Pole Infrared Imaging Telescope’ - NOAO/CARA collaboration	$255k	$225k		Progress payments to UNSW.	$225,000
J Patterson (U Adel)	γ-ray Observatory - Cangaroo Project	$90.5k	$30k		Seed money for Japanese collaboration.	$30,000
JB Whiteoak (ATNF)	Phase 2 Activities of European Large Southern Array (LSA) Project	$100k	$56k	$10.5k	Funding amount reduced; $33.5K transferred to international travel.	$782
K Taylor (AAO)/M Colless (ANU RSAA)	Australis Phase A Study	$400k	$320k			$320,000
K Nugent/R Webster (U Melb)	LOBSTER X-Ray Satellite Project	$141k	$58k		Salary Research Fellow + travel.	$58,000
M Bessell (ANU RSAA)	Australia-Japan Collaborative Workshops	$115k	$20k		Seed money for Japanese collaboration.	$20,000
M Brennan (ARC)	Gemini partnership	$200k	$200k		Contribution to the 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	$60k		Research Fellow salary for 2 years	$30,000
	Travel related to international collaboration; & misc. establishment costs		$103.5k		$33.5K transferred to travel from LSA project. Direct reimbursements from ATNF to 30/6/99	$78,899
	TOTALS		**$1,1805k**	**$79.5k**		**$1,024,544**

Total Commitment : $1,180.5k
Reserved: $79.5k
Total Budget: $1,260.0k

Table 7-3 International Collaboration Funding - Overseas Travel Summary For Financial Year 1998-99

Name	Institution	Travel Dates	Destination	Purpose	Travel funding Committed
Dr G S Da Costa	ANU RSAA	8/9/98 – 16/9/98	Hilo, Hawaii	Gemini Director's review and Instrument Forum meetings	$2822.69
Dr K Taylor	AAO	11/9/98 - 15/9/98	Hilo, Hawaii	Gemini Instrument Forum meetings	$987.42
Dr P McGregor	ANU RSAA	11/9/98 – 13/9/98	Hilo, Hawaii	Gemini Instrument Forum	$2877.00
Dr C Smith	Australian Defence Force Academy	17/9/98 – 18/9/98	Gainesville, Florida	Gemini Instrument Design Review for thermal infrared imaging system	$1214.00
Professor L Cram	U Syd	9/10/98 – 12/10/98	Hilo, Hawaii	Gemini Finance Committee Meeting	$2229.63
Dr G S Da Costa	ANU RSAA	18/10/98 – 24/10/98	Hilo, Hawaii	Gemini Science Advisory Committee	$2418.13
Professor L Cram	U Syd	16/11/98 – 21/11/98	Hilo, Hawaii	Gemini Board Meeting	$2234.66
Dr P D Wood	ANU RSAA	10/12/98 – 12/12/98	Hilo, Hawaii	Gemini meeting on top-level science and laser beacon adaptive optics systems	$2607.10
Dr A Hopkins	U Syd, ATNF	7/4/99 – 9/4/99	The Netherlands	Collaboration on deep source work	$1500.00
Dr R P Norris	ATNF	7/4/99 – 14/4/99	The Netherlands	SKA science and technical meetings	$2000.00

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.

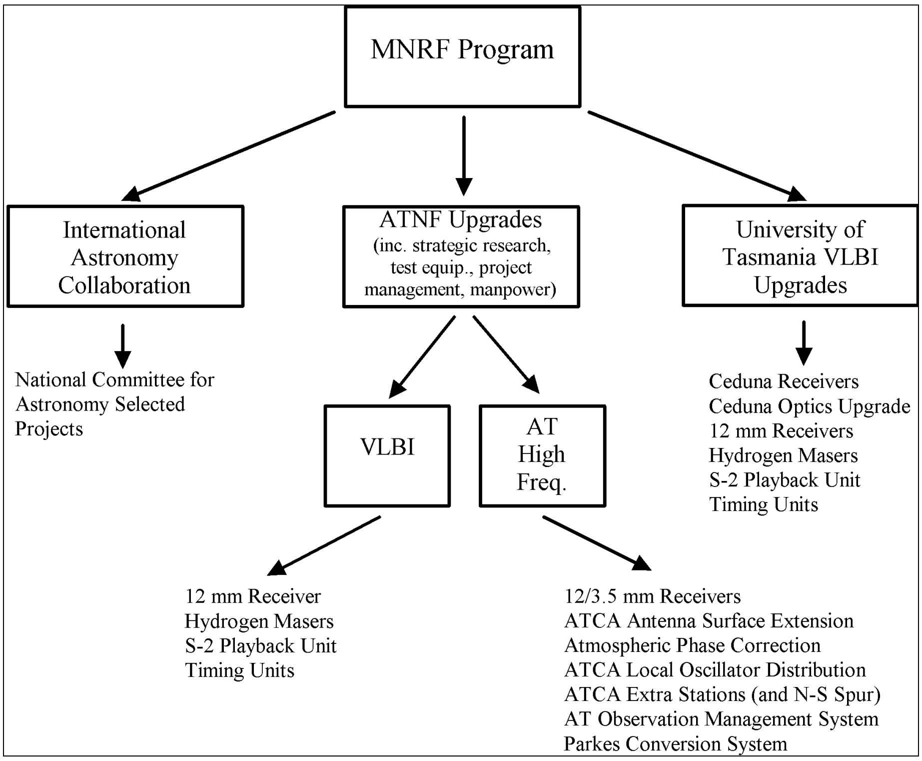


Figure A1-1 *MNRF Program Structure*

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.

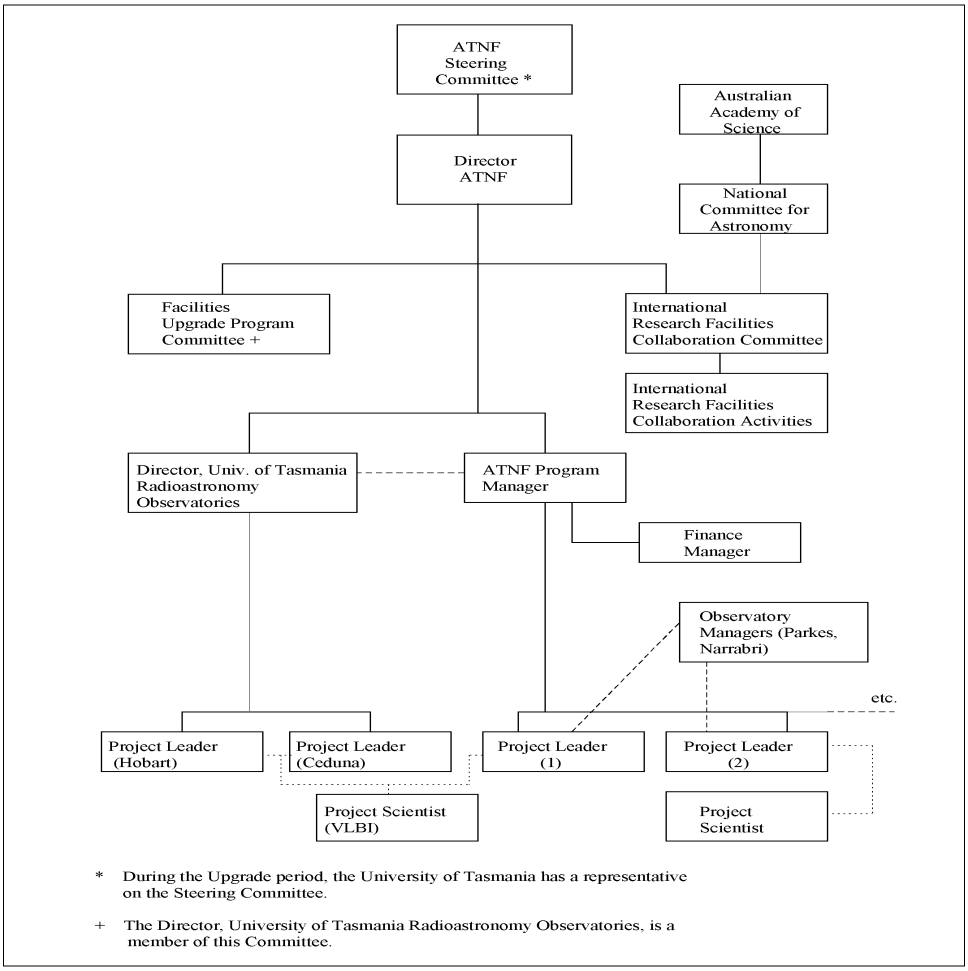


Figure A1-2 *MNRF Program Management and Overall Structure*

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.

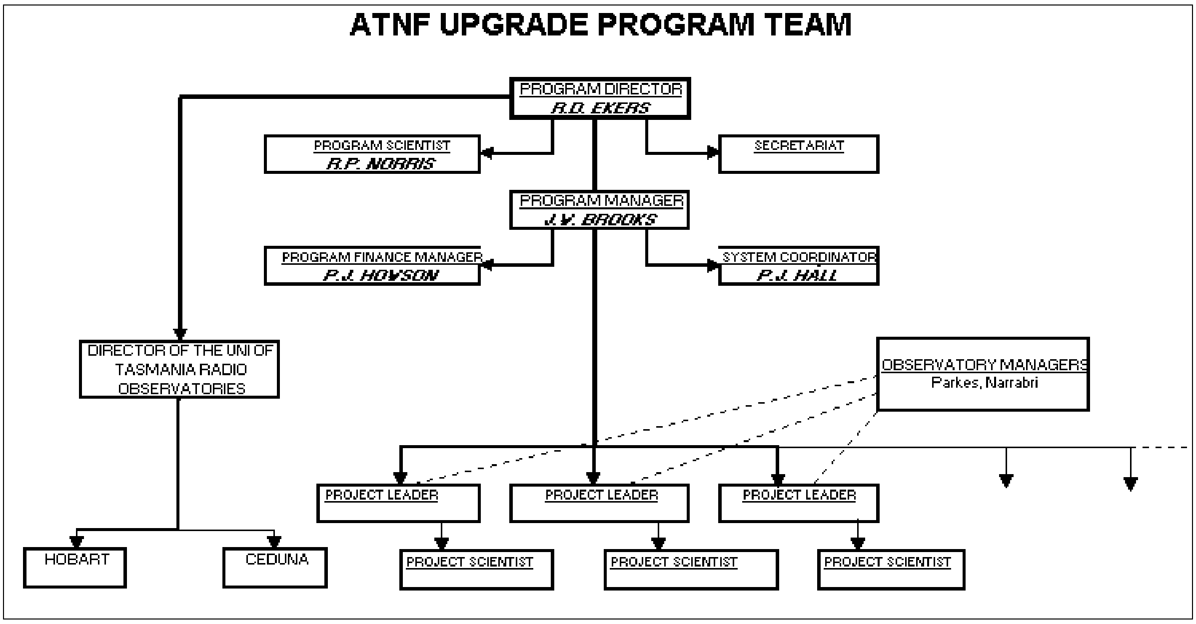


Figure A1-3 *MNRF Executive and Program Structure*

Appendix 2 - ATNF Steering Committee Membership, 1999

CHAIRMAN
***Dr R Cannon**, Anglo-Australian Observatory

Deputy Chair
***Dr R Webster,** University of Melbourne

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 Frater, Deputy CEO, CSIRO
Prof P McCulloch, Director, University of Tasmania Radio Astronomy Observatories

Astronomers
Dr R Price, Officer-in-Charge, Parkes Observatory, CSIRO ATNF
***Prof J Mould**, Director, Mt Stromlo and Siding Spring Observatories
***Prof J Storey**, University of New South Wales

International Advisors
Dr J Bergeron, European Southern Observatory, Munich, Germany
Dr 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
Dr J O'Sullivan, Director of Technology, News Limited

* 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	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 T Bourke, M Burton (UNSW), P Hall, B Koribalski (chair), R Norris, and J Whiteoak.
2. Mr G Carrad is the Project Engineer.

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.

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 has recently revised the World Wide Web site describing the MNRF Program and its progress. The site URL remains *http://www.atnf.csiro.au/mnrf/mnrf.html* As well as being a repository for Program summaries, the Web is proving 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, in press, JEEEA.
2. 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 in Radio Astronomy: Technologies for Large Antenna Arrays", Dwingeloo, April 1999.
3. Ekers, R. D., The Square Kilometre Array Radio Telescope, in Proc. ESO Workshop "Looking Deep in the Southern Sky", Springer, 1999.
4. Ekers, R. D., Plans for the Square Kilometre Array, Proc. Intl. Conf. "Perspectives in Radio Astronomy: Scientific Imperatives at cm and m Wavelengths", Amsterdam, April 1999.
5. 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.
6. 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.
7. Hopkins, A., Summary of the Sub-MicroJansky Radio Sky Workshop, Proc. Astron. Soc. Aust., Vol. 16, No. 2, July 1999.
8. Hopkins, A., Windhorst, R., Cram, L. and Ekers, R., What Will the Next-Generation Radio Telescope Detect at 1.4 GHz?, submitted, Proc. Astron. Soc. Pacific.
9. Hopkins, A., Windhorst, R., Cram, L. and Ekers, R., What Will the SKA See at 1.4 GHz?, Proc. Intl. Conf. "Perspectives in Radio Astronomy: Scientific Imperatives at cm and m Wavelengths", Amsterdam, April 1999.
10. Norris, R. P., The MNRF Upgrade to the Australia Telescope, in Proc. ESO Workshop "Looking Deep in the Southern Sky", Springer, 1999.

11. Norris, R. P., $H_2 0$ Megamasers and the SKA, Proc. Intl. Conf. "Perspectives in Radio Astronomy: Scientific Imperatives at cm and m Wavelengths", Amsterdam, April 1999.
12. Thomas, B. M., SKA: Matching the Specifications and Antenna Technologies, Proc. Intl. Conf. "Perspectives in Radio Astronomy: Technologies for Large Antenna Arrays", Dwingeloo, April 1999.
13. 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. Ekers, R. D., Interference Excision in Radio Astronomy Measurements, Proc. 1 kT International Technical Workshop, Sydney, Dec. 15 - 18, 1997.
2. 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.
3. 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.
4. Kesteven, M. J., ATCA Upgrade - Pointing Considerations, AT/39.3/081.
5. Kesteven, M. J. and Parsons, B. F., Mechanical Stability of the AT Subreflectors, AT/39.3/070.
6. Kesteven, M. J. and Parsons, B. F., Antenna on the Rail Observations, AT/39.3/072.
7. Kewley, L., Interference Excision Using the Parkes Multibeam Receiver, Proc. 1 kT International Technical Workshop, Sydney, Dec. 15 - 18, 1997.
8. Norris, R. P., Scheduling the ATCA at Millimetre Wavelengths, ATNF Report. Sept. 1997.
9. Norris, R. P., Notes from ATCA Calibration Meeting, ATNF Report, Oct. 1997.
10. Sault, R., Cross-Correlation Approaches to Interference Elimination, Proc. 1 kT International Technical Workshop, Sydney, Dec. 15 - 18, 1997.
11. Thomas, B. MacA., Planning the Next International Radio Telescope, submitted to Engineers Aust., 1999.
12. Thomas, B. MacA., The 1 kT - Application of Phased Array Technology, AT/39.3/064.
13. 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.
14. Thomas, B. MacA., Interference Mitigation - An R & D Strategy for the 1 kT Array, ATNF Workshop on Electromagnetic Compatibility, Sydney, April 27, 1998.
15. Thomas, B. MacA., Focal Plane Arrays – Some Basic Characteristics and an Application to HF SKA, AT/39.3/095.

Books and Theses

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, 10-12 December 1997. R. Morganti and W. Couch (ed.), Springer, 1999. ISBN 3-540-65286-8.

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.

Presentations

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 ATNF MNRF Upgrade - A Progress Report, Anglo-Australian Telescope and ATNF Joint Symposium, Canberra, March 19,1998.
4. Koribalski, B., The Millimetre-Wave Upgrade of the Australia Telescope Compact Array, Workshop on Applications of Radio Science (Aust.), Barossa Valley, September 21 - 23, 1997.
5. Norris, R. P., The MNRF Upgrade to the Australia Telescope, Astronomical Society of Aust., July 7, 1997.
6. Norris, R. P., Radio Astronomy into the Next Millenium, Conference "Astronomy and Space Science", Mafraq, Jordan, May 5, 1998.
7. 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.
8. Thomas, B. MacA. and Ekers, R. D., The 1 kT Project, Department of Industry Science and Tourism, May 26, 1998.

Education and Outreach Activities

ATNF staff continue to be active in educating the astronomy community about the potential of the National Facility upgrades. For example, under the terms of a recent memorandum of understanding, the University of NSW will operate the ATNF's Mopra 22 m radio telescope for three months of each year, giving enthusiastic 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 the exploiting the full scientific potential of the upgraded ATCA.

In the VLBI area, ATNF staff have supported the University of Tasmania by giving occasional lectures and tutorials dealing with contemporary science issues and VLBI techniques. At the more strategic level, the ATNF was an award-winning exhibitor at Manufesto 98, a forum for industry and its research partners. Part of the ATNF display featured the square-kilometre array (SKA) work being supported by the MNRF Program (see Section 4(c)).

Appendix 5 - MNRF 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. It is likely that the Committee will meet again in early 2000, following trials of prototype high-frequency systems at Narrabri.