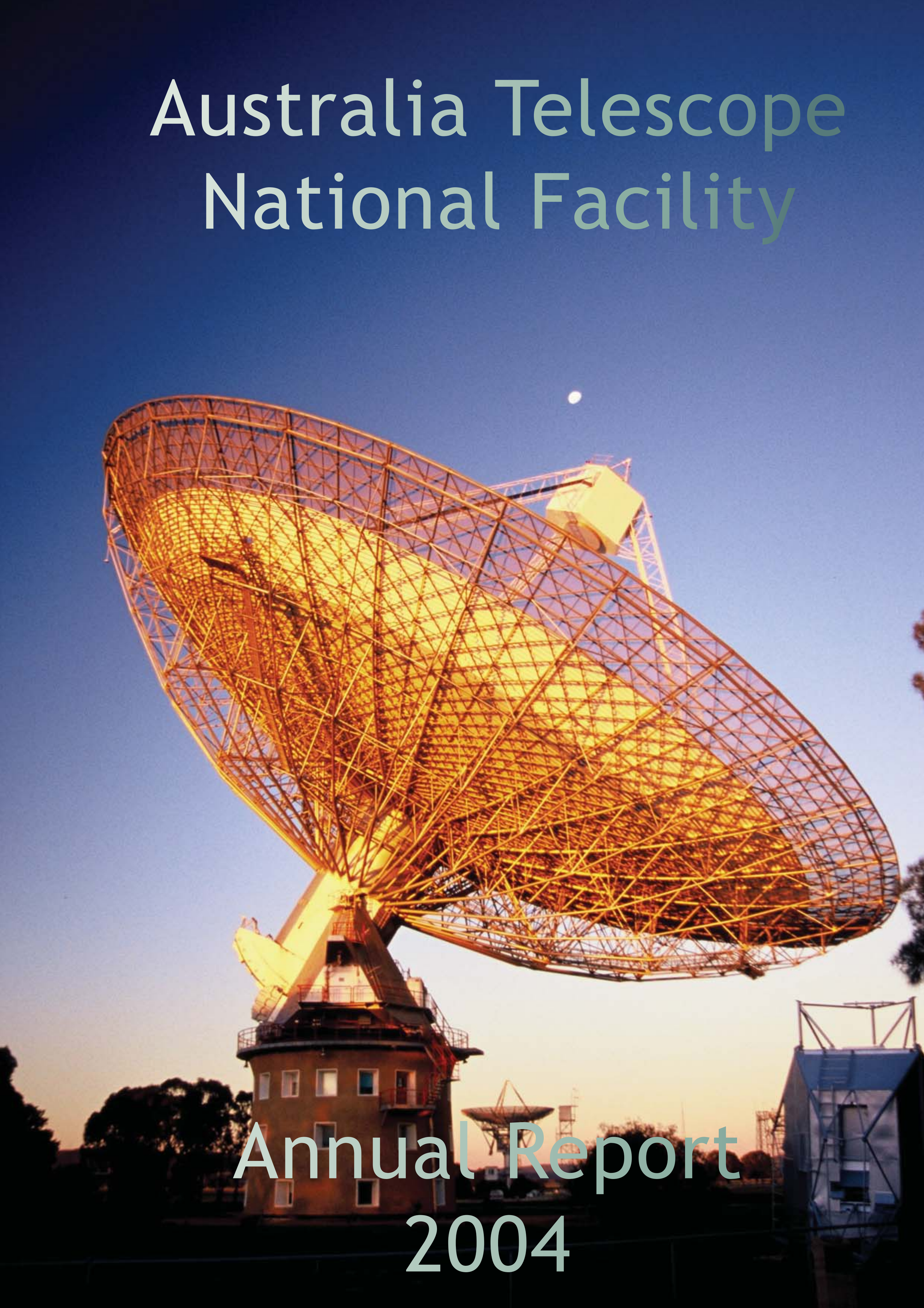
Australia Telescope National Facility



Annual Report 2004

Annual Report 2004
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This is the report of the Steering Committee of the CSIRO Australia Telescope National Facility for the calendar year 2004.

Editor: Dr Jessica Chapman, Australia Telescope National Facility

Design and typesetting: Vicki Drazenovic, Australia Telescope National Facility

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Cover image: The Parkes radio telescope at sunset
Photo: © John M. Smith, CSIRO

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Image: Sunrise at the ATCA
Photo: © Shaun Amy, CSIRO

Chairman's report

Professor Matthew Bailes,
Chair AT Steering Committee

The Australia Telescope National Facility has a long and proud history in radio astronomy. It now faces many new challenges as this sub-discipline of Australian astronomy looks towards the next generation of radio telescopes.

Radio astronomy in the next decade will perhaps benefit more from the extraordinary growth in computational power from both conventional computers and Field Programmable Gate Arrays than any other area of astronomy. It will soon be possible to observe with dozens of beams per antenna, digitally capture the signals and correlate enormous bandwidths with much higher numbers of baselines than has ever been possible before. It has long been recognised that arrays consisting of large numbers (N) of small diameter (D) telescopes give more information about the sky than a single large aperture dish of the same collecting area. But for too long the computational penalty paid by constructing "large-N, small-D" arrays has prohibited their construction.

ATNF scientists and engineers are now preparing to build one of the most novel instruments yet seen in radio astronomy over the coming years to exploit the computational power provided by modern electronics. The extended new technology demonstrator (xNTD) will be built in the West Australian desert in a "radio quiet zone". The xNTD is a natural response to Moore's law which predicts an ever-increasing capacity to record and store data. It will probably consist of approximately twenty 15-m parabolic dishes with focal plane arrays, but require unprecedented processing power to image the sky. There is no doubt this instrument will face great challenges in its construction, but these are exactly those faced by the Square Kilometre Array: terabit per second data rates, teraflop correlator modules, focal plane arrays, interference rejection and comprehending the output. I wish the engineers and scientists well in this endeavour.

As you look through this report, you will see that the ATNF manages and maintains telescopes greatly sought after by astronomers from Australia and around the world. The discovery of the double pulsar at Parkes was recognised as one of the top ten discoveries of 2004, and the ATNF instruments continue to have an impact across many areas of discovery. Millimetre-wave astronomy is set to take off at the Compact Array with the completion of the new systems.

Finally I commend John Reynolds and his staff at the Parkes Observatory for their awards that recognise the transformation that has occurred at the Parkes telescope in terms of service and efficiency, the engineers responsible for the Arecibo multibeam system, and Dick Manchester for his award recognising his contributions to pulsar research.

Director's report

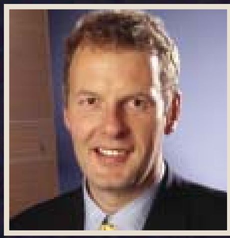
Professor Brian Boyle, Director of the ATNF

This has been a year of highlights and new beginnings. Highlights in 2004 included the successful delivery of world-class instrumentation both at home and overseas, in particular with the commissioning of the 3-mm systems at the Compact Array, and the completion of a multibeam receiver built for the Arecibo radio telescope. Both systems immediately began producing high-impact science; a testament not only to the engineering of these systems but also to the important and long-anticipated scientific niche they have filled. Other highlights were the completion of the Mars tracking program at Parkes and the Deep Space Network design study, both part of an ongoing strategic collaboration between CSIRO ATNF and NASA.

New beginnings were represented by the ATNF's decision to embark on the development of an antenna plus focal plane array solution for the Square Kilometre Array (SKA) New Technology Demonstrator program, a move that quickly gained the support of Australia's broad SKA stakeholder base as the important next step on the roadmap to the SKA. During the year it was particularly encouraging to see the growth of the cross-divisional nature of the NTD program with strong support from the CSIRO ICT Centre. New beginnings also include the ATNF's engagement in, and support for, the MIT-led Low Frequency Demonstrator; a proposal which, together with the NTD, will see the opening up of a new front in radio astronomy in Western Australia.

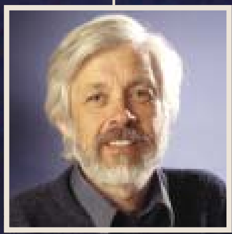
Partnership has been a common thread in all these endeavours. As the ATNF increasingly focuses on the pathway to the international Square Kilometre Array over the coming years, enhanced collaboration with both national and international partners will be essential. The successes in 2004 wrought through collaboration augur well for a successful future.

ATNF Senior Management and Federation Fellows in December 2004



Director
Brian Boyle
Photo: © Kristen Clarke

Deputy Director
Ray Norris
Photo: © Kristen Clarke



General Manager
Dave McConnell
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Head, Astrophysics
Lister Staveley-Smith
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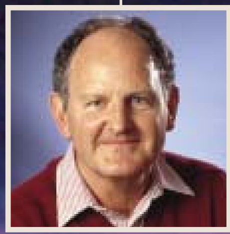

Head, Engineering
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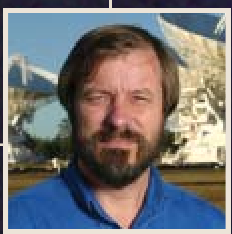
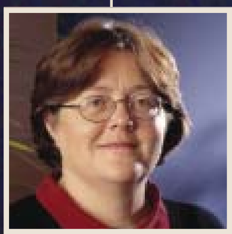


OIC Narrabri
Bob Sault
Photo: © David Smyth



Head, National Facility Support
Jessica Chapman
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OIC Parkes
John Reynolds
Photo: John Sarkissian © CSIRO

Deputy OIC Narrabri
Brett Hiscock
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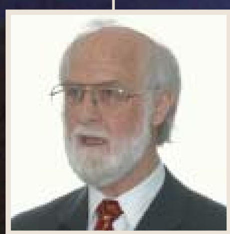
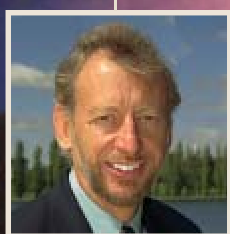
Deputy OIC Parkes/ ATNF HR Manager
Lewis Ball

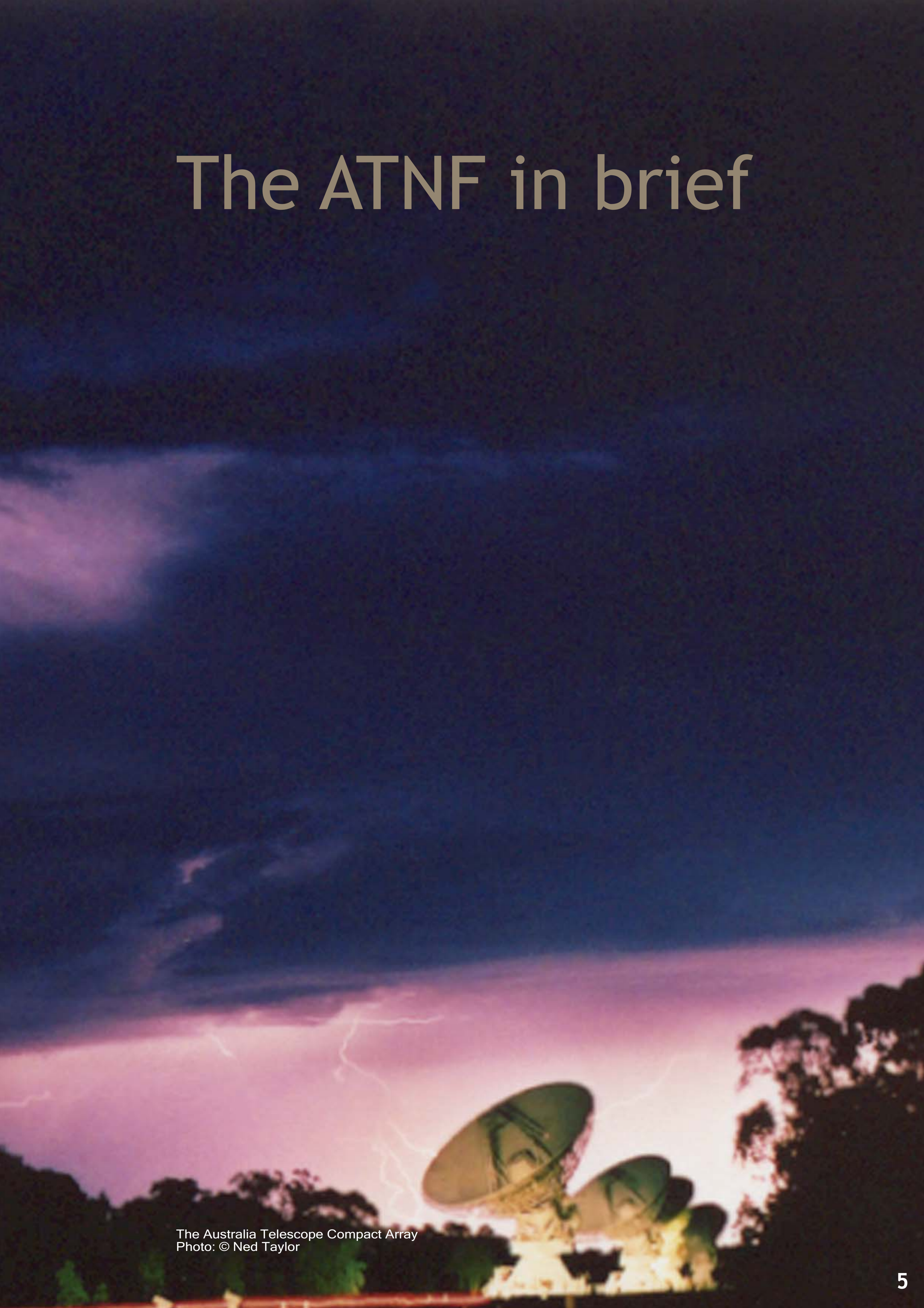


Federation Fellow
Ron Ekers
Photo: © David Smyth



Federation Fellow
Dick Manchester
Photo: © Australian Research Council

The ATNF in brief



The Australia Telescope Compact Array
Photo: © Ned Taylor

The ATNF supports Australia's research in radio astronomy, one of the major fields of modern observational astrophysics. It operates the Australia Telescope, comprising the Compact Array at Narrabri, the Mopra 22-m antenna near Coonabarabran, and the famous Parkes 64-m radio relescope at Parkes in New South Wales.

Mission

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

Size and funding

The ATNF employs approximately 180 staff. In 2003 – 2004 the organisation's total expenditure budget was A$24.5M, of which A$14.6M was direct appropriation from CSIRO.

Status within CSIRO

The ATNF is managed as a National Facility by Australia's largest national research institution, CSIRO. Formerly part of the CSIRO Division of Radiophysics, it became a separate division in January 1989.

Status as a National Facility

The ATNF became a National Facility in April 1990. As a National Facility, the Australia Telescope provides world-class observing facilities in radio astronomy for astronomers at Australian and overseas institutions. The Australia Telescope is operated as a National Facility under guidelines originally established by the Australian Science and Technology Council.

Users of ATNF telescopes

Observing time on the ATNF's telescopes is awarded to researchers on the basis of the merits of their proposed research programs by a Time Assignment Committee appointed by the Steering Committee. Approximately 90% of the telescopes' users come from outside the ATNF.

The ATNF in the Australian context

The ATNF is the largest single astronomical institution in Australia. Approximately 90% of Australian radio astronomy is carried out through the ATNF. The organisation has strong links with its primary user base, the university community. The interests of telescope users are represented by the Australia Telescope Users Committee.

The ATNF's Sydney headquarters are co-located with those of the Anglo-Australian Observatory, an independent bi-National Facility that provides world-class optical and infrared facilities. This close association is unique, in world terms, and promotes valuable collaboration between the two organisations.

The ATNF in the global context

Of the fields of modern astronomy—X-ray, ultraviolet, optical, infrared and radio—Australia makes one of the most significant contributions to world astronomy through radio astronomy. This is a result of Australia's early lead in the field, continuous technological advances, and southern hemisphere location. The Australia Telescope is the only major radio telescope of its kind in the southern hemisphere, and thus can view part of the sky which is out of reach of northern hemisphere telescopes. It provides one of the most powerful radio astronomy facilities in the world.

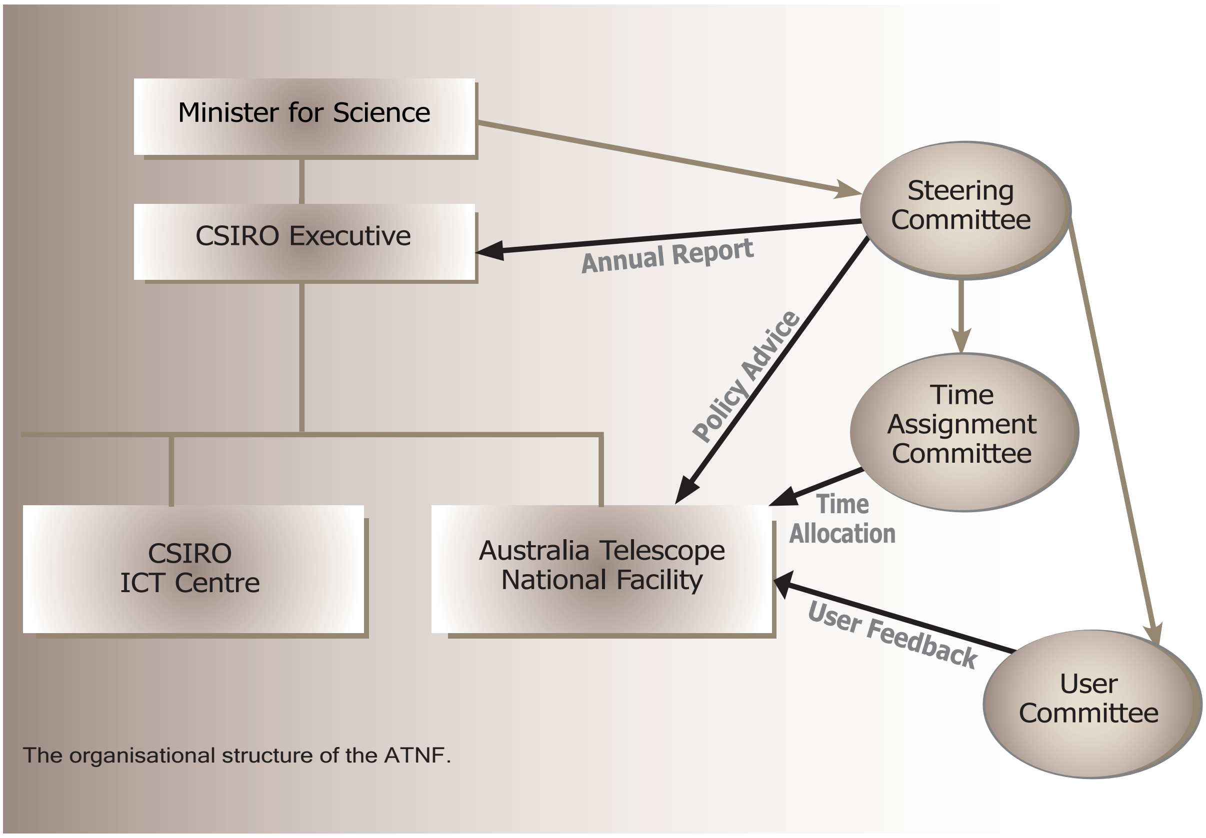
Australian and international observers use the Australia Telescope without access charges. This is in accordance with a general practice of the worldwide astronomical community, in which telescope users from different countries gain reciprocal access to facilities on the basis of scientific merit. This allows Australian scientists to use telescopes in other countries as well as space-based instruments and other international facilities such as particle accelerators. Such access provides Australian scientists with a diversity of instruments and leads to a rich network of international collaborations.

The ATNF's observatories

The Australia Telescope consists of eight radio-receiving antennas, located at three sites in New South Wales. Six of them make up the Australia Telescope Compact Array, located at the Paul Wild Observatory near the town of Narrabri. Five of these antennas sit on a 3-km stretch of rail track running east–west, or on a 200-m spur running north of the main track; they can be moved to different points along the track to build up detailed images of the sky. A sixth antenna lies 3 km to the west of the main group. Each of these antennas has a reflecting surface 22 metres in diameter. After the radio signals from space are "collected" by the antennas' surfaces they are transformed into electrical signals, brought together at a central location, and then processed. The end result is usually a picture or a spectrum of the object being studied—a picture equivalent to a photograph, but made from radio waves instead of visible light.

A further 22-m antenna, known as the Mopra telescope, is located near Mopra Rock in the Warrumbungle Mountains near Coonabarabran, New South Wales.

The other key component of the Australia Telescope is the Parkes 64-m radio telescope, located near the town of Parkes. This telescope has been successfully operated since 1961 and is famous as a national symbol for Australian scientific achievement. Instrumental upgrades, including a 13-beam focal-plane array, have maintained the telescope as a state-of-the-art instrument.



The organisational structure of the ATNF.

The eight ATNF telescopes can be used together as the Long Baseline Array (LBA) for a technique known as very long baseline interferometry (VLBI) which is used to obtain high resolution images of small areas of sky.

The LBA is used as part of a larger Australian network of radio telescopes which includes the NASA satellite tracking antennas at Tidbinbilla, near Canberra, and radio antennas in Tasmania, South Australia and Western Australia. The LBA is also regularly used as part of the Asia-Pacific Telescope which links radio telescopes in Australia, Japan, China, Hawaii and India.

Engineering and technology development

The advance of radio astronomy depends crucially on exploiting the latest technological developments in a range of areas which include electronics, receiver technology, signal detection and processing, control systems, data processing and information technology. The ATNF provides a platform for the development of cutting-edge technology in Australia.

ATNF Steering Committee

ATNF policy is determined by the ATNF Steering Committee, an independent committee appointed by the Minister for Science. The Committee helps the ATNF develop long-term strategies. The inaugural meeting of the ATNF Steering Committee was held in May 1989. Since then it has met at least once a year, to define the broad directions of the ATNF's scientific activities and the development of the Australia Telescope. It is also responsible for promoting the use of the Facility and, indirectly, for allocating observing time.

The Steering Committee appoints the Australia Telescope Users Committee (ATUC) to provide feedback and advice from the user community, and the Time Assignment Committee (TAC) to review proposals and allocate observing time. The committee members for the year 2004 are listed in Appendix C.

Australia Telescope Users Committee

ATUC represents the interests of the Australia Telescope's users. The committee provides feedback to the ATNF Director, discussing problems with, and suggesting changes to, ATNF operations; it also discusses and ranks by scientific merit various future development projects. ATUC meetings are also a forum for informing telescope users of the current status and planned development of ATNF facilities, and recent scientific results. ATUC reports can be found on the web at www.atnf.csiro.au/management/atuc.

Time Assignment Committee

The ATNF receives more applications for observing time than it can accommodate: proposals for time on both the Parkes and Narrabri telescopes exceed the time available by a factor of approximately two. The proposals are assessed, and time allocated to them, by the TAC. The TAC reviews typically one hundred telescope applications at each meeting.

Strategic objectives

The ATNF is one of the world's leading radio astronomy organisations. The strategic objectives for the ATNF are:

- **To continue to operate the Australia Telescope in such a way as to maintain a leading international position**

  The ATNF will provide access to its facilities to satisfy the needs of Australian and overseas users. At least 70% of time on the Parkes and Narrabri telescopes will be used for astronomy. Time lost during scheduled observing periods will be kept to below 5%.

♦ To develop and extend the performance of the Australia Telescope to maintain its competitiveness in the medium term (3 - 8 years)

During the last seven years the Narrabri and Mopra telescopes have been extensively upgraded, under the Major National Research Facilities (MNRF) program, funded in 1997, to work at shorter (millimetre) wavelengths The upgraded telescopes use innovative devices for the detection of extremely faint millimetre-wave signals from space. These system upgrades have been jointly designed by the ATNF and CSIRO Industrial Physics (CIP), a project funded by the CSIRO Executive Special Project. The MNRF upgrade also extends the Australian network of telescopes used for VLBI, which has both astronomical and geodetic applications. The MNRF-1997 upgrades were completed in 2004.

♦ To position the ATNF to participate in major international radio astronomy projects

In the next decade radio astronomy will be dominated by two major international developments: the Atacama Large Millimeter Array (ALMA) and the Square Kilometre Array (SKA). These instruments will allow astronomers to pursue key questions about the early evolution of the Universe. For Australia to maintain its position in radio astronomy, it needs to have a significant role in at least one of these projects. The SKA is a billion-dollar project, the "next-generation" radio telescope with a collecting area of approximately one square kilometre. Its construction is expected to start around 2012. Australia is well-positioned to play a key role in the development of the SKA. Australia offers an ideal location for the SKA as it has a number of regions of low population density which are relatively free from radio interference. The technology development required for the SKA will have wide industrial applications and the construction will involve significant industrial contracts.

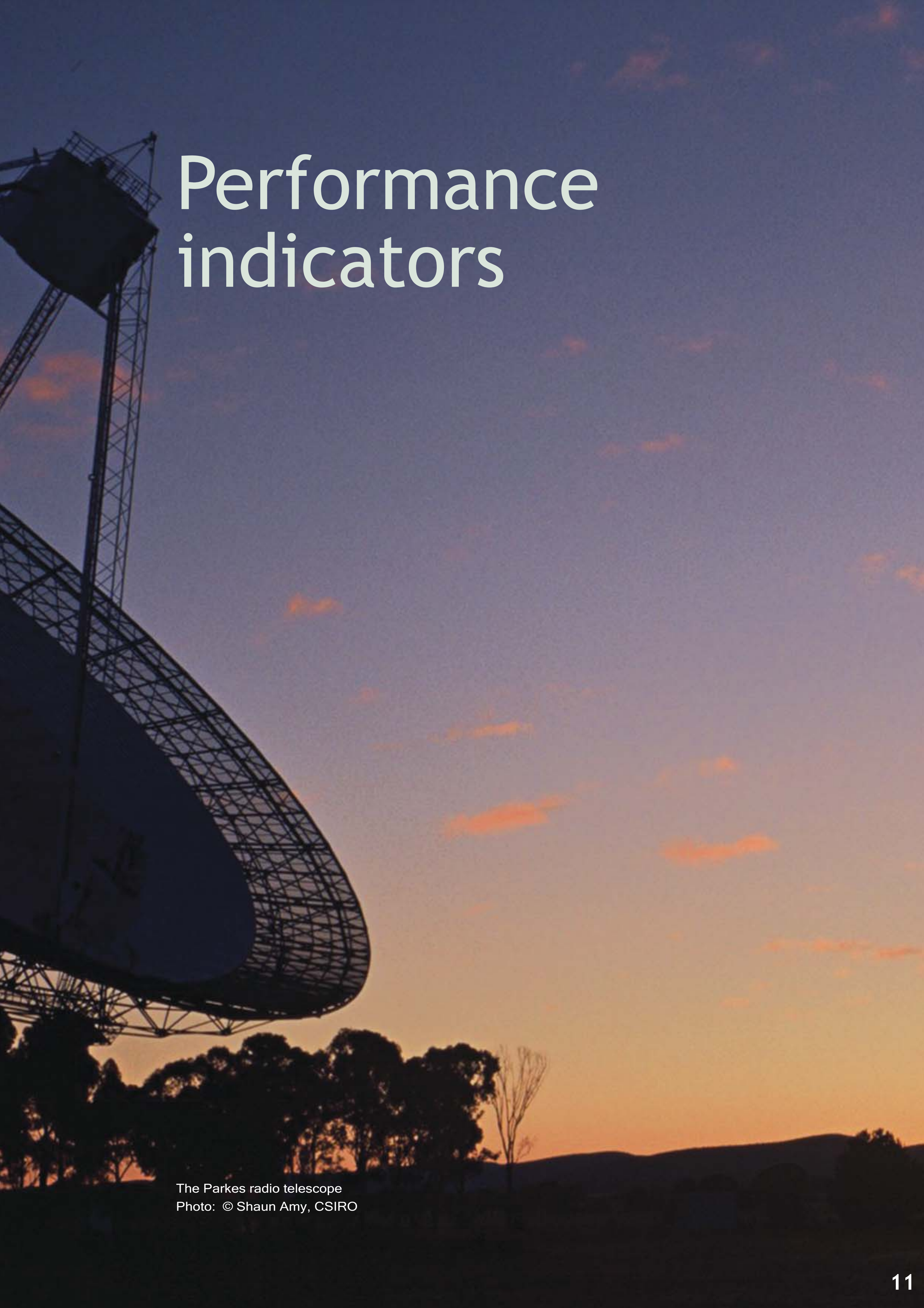
In August 2001 the Australian Government announced the allocation of A$155M under the MNRF-2001 program to 15 successful programs. Of these, the ATNF-led proposal, on behalf of Australian astronomy, received the largest single allocation of A$23.5M. This funding is being used to develop SKA technology and to improve access to the optical/IR Gemini telescopes. This SKA technology development will also result in a significant upgrade of the AT Compact Array.

♦ To conduct an effective outreach program

The ATNF operates Visitors Centres at the sites of the Parkes and Narrabri Observatories and has an active public outreach program which has several goals: to raise the national profile of astronomy and related technology in Australia; to encourage the next generation of scientists by providing educational resources targeted at high school students and their teachers; and to maintain good community relationships.

An aerial view of the Compact Array in a hybrid configuration.
Photo: © CSIRO

Performance indicators



The Parkes radio telescope
Photo: © Shaun Amy, CSIRO

This chapter describes indicators that are used to assess the performance of the ATNF.

1 Scheduled and successfully completed observing time

For the Parkes radio telescope and the Compact Array the ATNF sets a target that at least 70% of the time available should be allocated for astronomical observations while the time lost during scheduled observations from equipment failure should be below 5%.

The following values show the time allocation for scheduled observations in 2004:

	Compact Array	Parkes	Mopra
Time allocated for scheduled observations	73.7%	74.8%	39.4%
Time allocated for NASA tracking observations	–	3.7%	-
Downtime due to equipment failure (during scheduled observations)	2.5%	1.2%	11.5%
Downtime due to weather	0.6%	3.1%	6.9%

For most observing programs, observers are required to be present at Parkes, Mopra or the Compact Array for their observations. For the Compact Array, remote observing is also possible from other sites. In 2004, 12.9% of scheduled observations with the Compact Array were taken remotely.

2 Response of the ATNF to recommendations by the Users Committee

The ATNF Users Committee (ATUC) is an advisory group that meets twice a year, to represent the user community in the ATNF decision-making process. After each meeting, the committee presents a list of recommendations to the Director. ATUC considers matters raised by the user community, current operations and priorities for future developments.

In most cases the ATNF implements ATUC recommendations. In 2003 ATUC made 42 recommendations to the ATNF. Of these, 34 were completed by December 2004, with responses to four requests still in progress and four requests not adopted by ATNF.

The ATUC members are listed in Appendix C. In 2004 it was agreed, that in addition to Australian members, ATUC may have up to one member from the international community present at each meeting.

3 Time allocation on ATNF facilities

The allocation of time on the ATNF facilities is done on the basis of scientific merit. In 2004 the ATNF changed from having three four-month observing terms per year to two six-month observing semesters. The first six-month semester began on 01 October 2004. From January – September 2004 a total of 189 proposals were allocated time on ATNF facilities (each proposal is counted once only per calendar year although some proposals are submitted two or three times). Of these, 122 were for the Australia Telescope Compact Array, 44 were for the Parkes telescope, 14 were for the Mopra telescope and nine were for the Long Baseline Array. A summary of the observing programs is given in Appendix D.

Since January 2003 the ATNF has accepted applications for service observations with the Tidbinbilla DSS43 70-m antenna. The radio telescopes at Tidbinbilla are operated by the Canberra Deep Space Communication Complex, part of NASA's Deep Space Network. From January – September service observations were taken using the DSS43 70-m antenna for six observing programs.

Figures 1 and 2 show the time allocated to observing teams on the Compact Array and Parkes radio telescope as a percentage of the total allocated time, by affiliation of the team leader.

In 2004 the proposals allocated time by the ATNF included at least 400 authors. Of these, approximately 40 authors were from the ATNF, 80 were from 14 other institutions in Australia, and 280 authors were from around 120 overseas institutions in 20 countries.

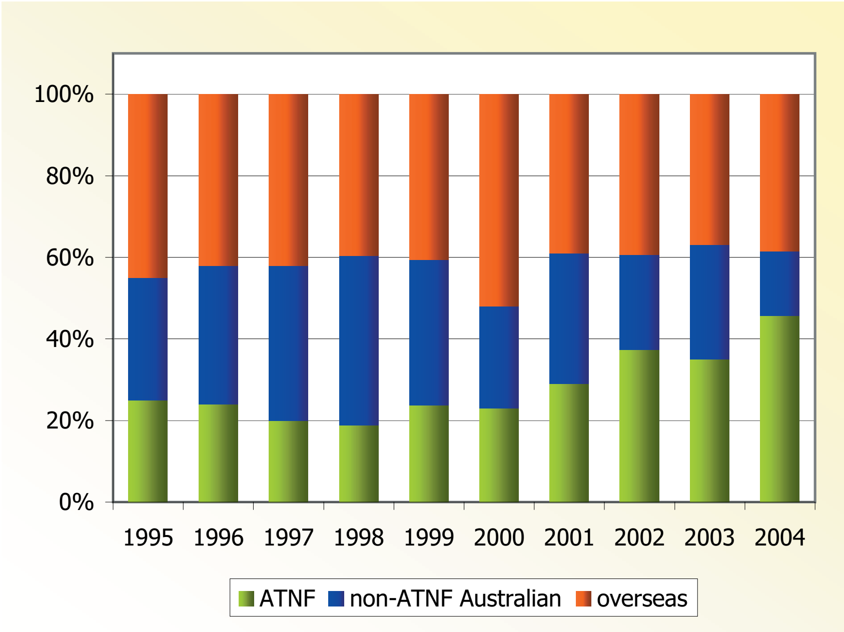


Figure 1 Compact Array time allocation, 1995-2004.

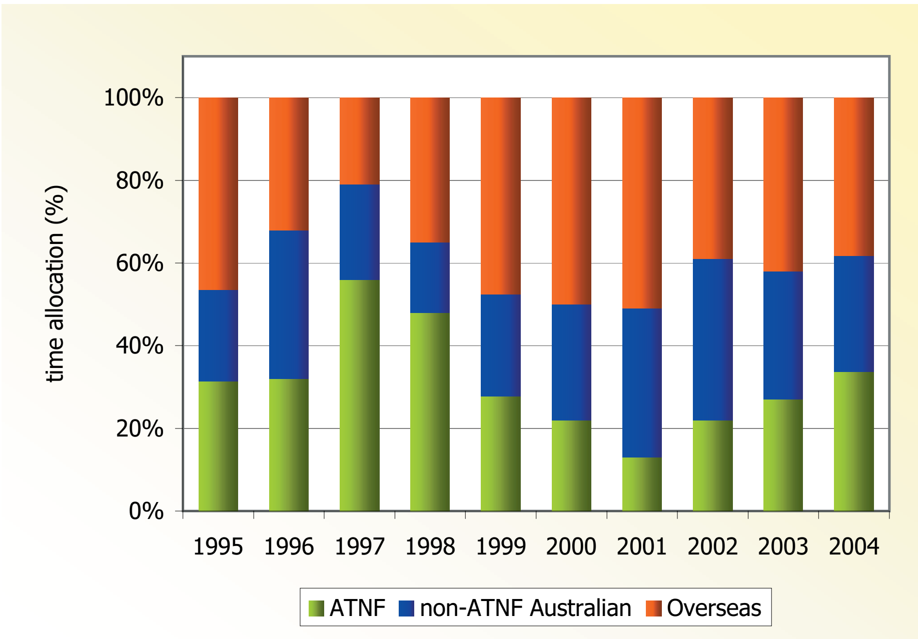


Figure 2 Parkes time allocation, 1995-2004.

4 Teaching, measured by the number of postgraduate students supervised by ATNF staff

In December 2004 there were 28 PhD students affiliated with the ATNF as well as an Australian or overseas university. Their affiliations and project titles are given in Appendix H. Seven students were awarded PhDs during the year. Their theses are listed in Appendix G.

5 Publications

Figure 3 shows the number of publications in refereed journals which include data obtained with the Australia Telescope. The publication counts include papers dealing with operations or data reduction but do not include IAU telegrams, abstracts, reports, historical papers, articles for popular magazines, or other papers by ATNF authors. In 2004, 111 papers with ATNF data were published in refereed journals. These are listed in Appendix G, which also lists 65 conference papers with ATNF data and 79 other papers by ATNF staff.

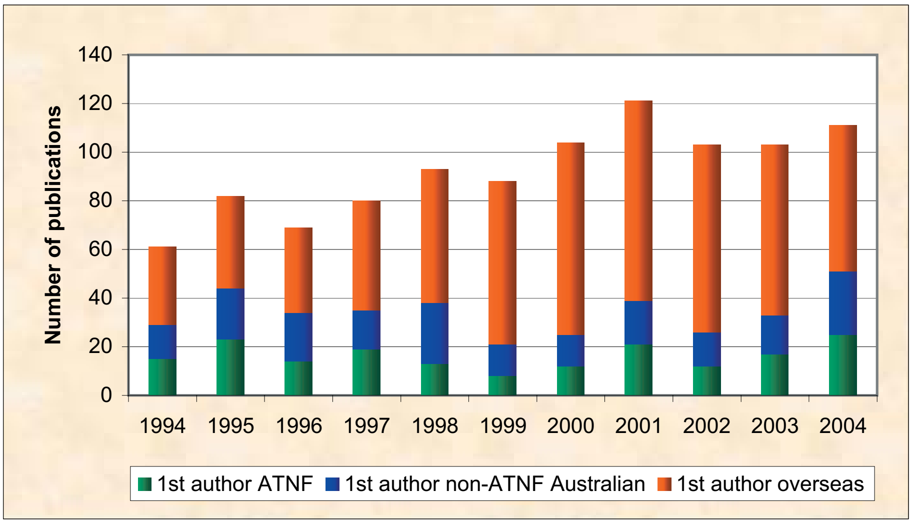


Figure 3 Publications from data obtained with the Australia Telescope, published in refereed journals.

Figure 4 shows ATNF publication numbers for papers that include Compact Array, Parkes, VLBI and Mopra data. A small number of papers with data from more than one facility are counted more than once. For the Compact Array, the number of publications is still rising, after 15 years of operations.

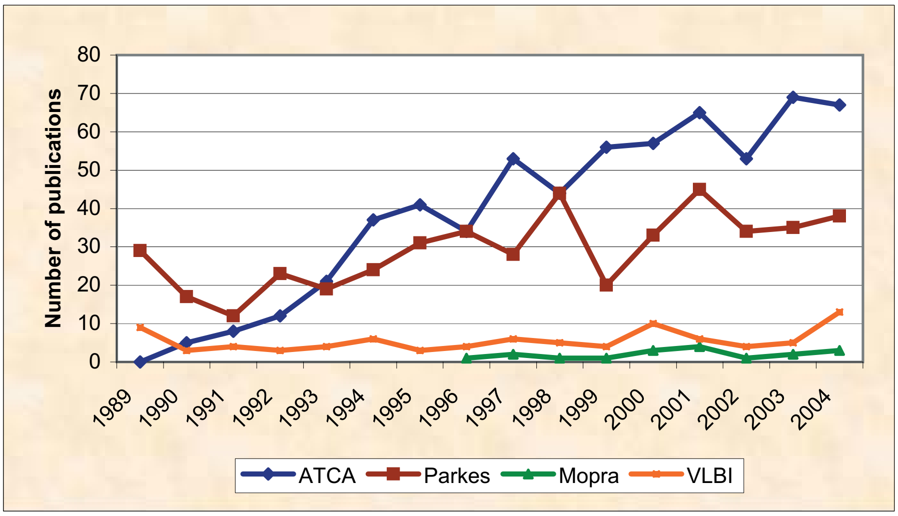


Figure 4 Publications from data obtained with the ATCA, Parkes, VLBI and Mopra, 1989 - 2004.

6 Public relations

Figure 5 shows counts for media activities for the years 1999 – 2004. During the year the ATNF issued five media releases (Appendix F) and featured in at least 140 press items. ATNF staff gave approximately 105 TV and radio talks and 60 public talks.

A major tool for communication is the web. The number of web hits to the central ATNF web site increases each year, with approximately two million hits received each month. In May 2004 a new website for outreach and education was released (see page 57). This received approximately one million hits in the first six months.

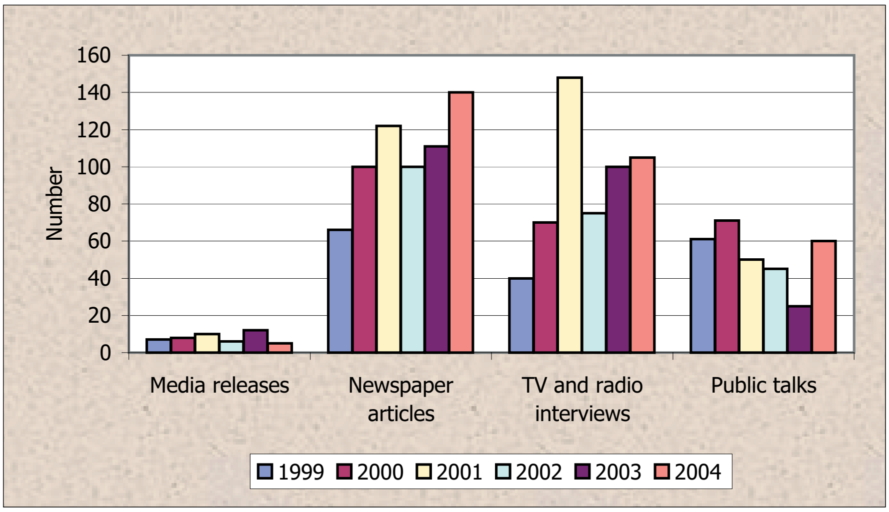


Figure 5 ATNF media activities.

Figure 6 shows the number of visitors to the Parkes Visitors Centre. The strong increase in visitor numbers in 2001 followed the release of the movie *The Dish*. The number of visitors has remained high since then, with approximately 118,000 visitors in 2004.

The number of visitors to the Narrabri Visitors Centre has been fairly constant for some years, with approximately 10,000 visitors per year.

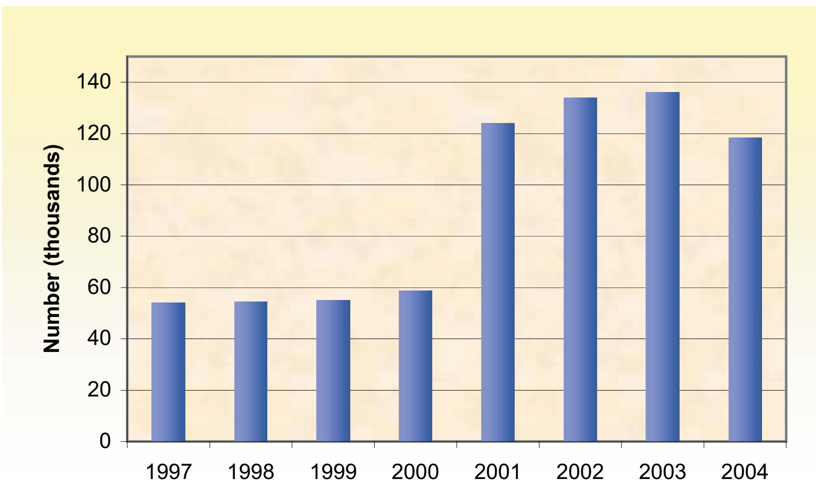


Figure 6 Number of visitors to the Parkes Visitors Centre.

7 User feedback at Narrabri and Parkes

Observers at the Parkes, Narrabri and Mopra observatories are asked to complete a user feedback questionnaire. Figure 7 shows the user responses in 2003 and 2004 for the Parkes Observatory. The user feedback was similar in 2004 to 2003, other than a higher response for support provided before observers arrive at Parkes, and for the library. The averaged response, over all items, was 85%.

Figures 8 and 9 show the user feedback in 2003 and 2004 for Compact Array observations taken with the centimetre and millimetre systems. For standard centimetre observing, the user feedback was also very similar for the two years. For millimetre observing, the 2004 feedback shows an improved response for documentation, and a poorer response for weather.

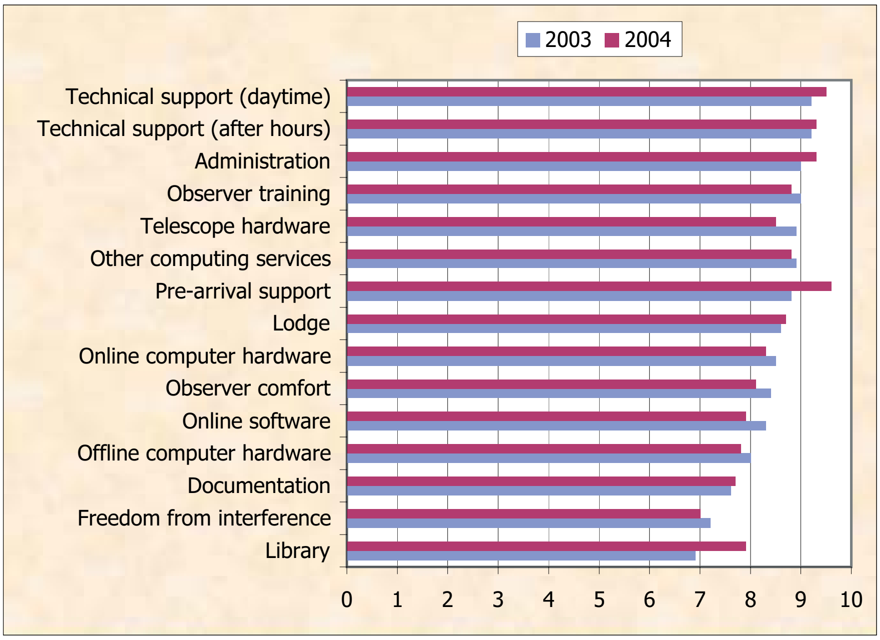


Figure 7 Parkes user feedback on a scale of 1 (poor) to 10 (excellent).

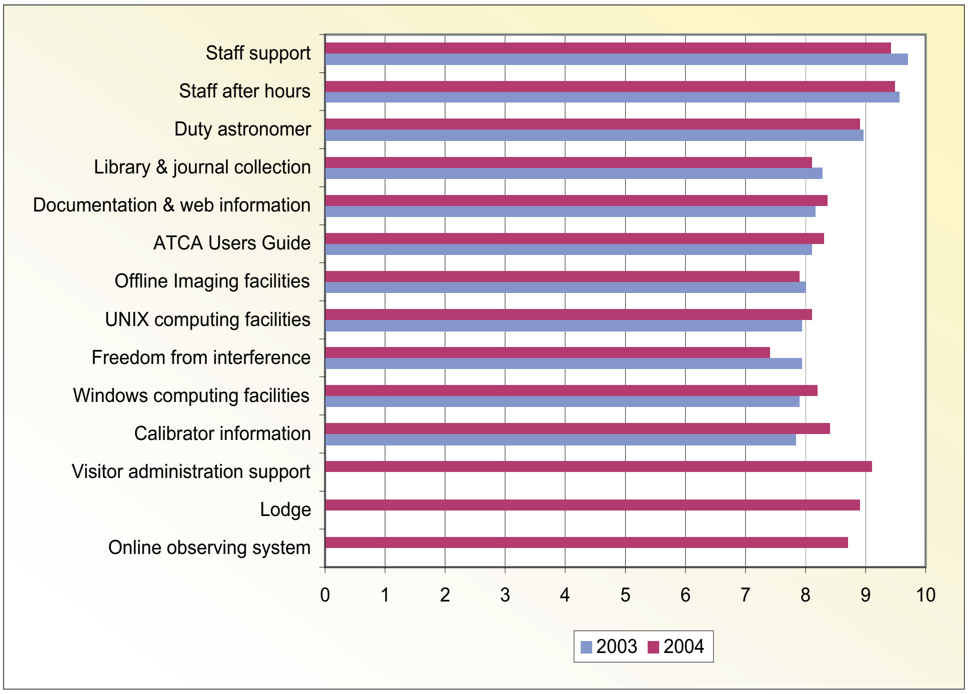


Figure 8 Narrabri user feedback for centimetre observations, on a scale of 1 (poor) to 10 (excellent).

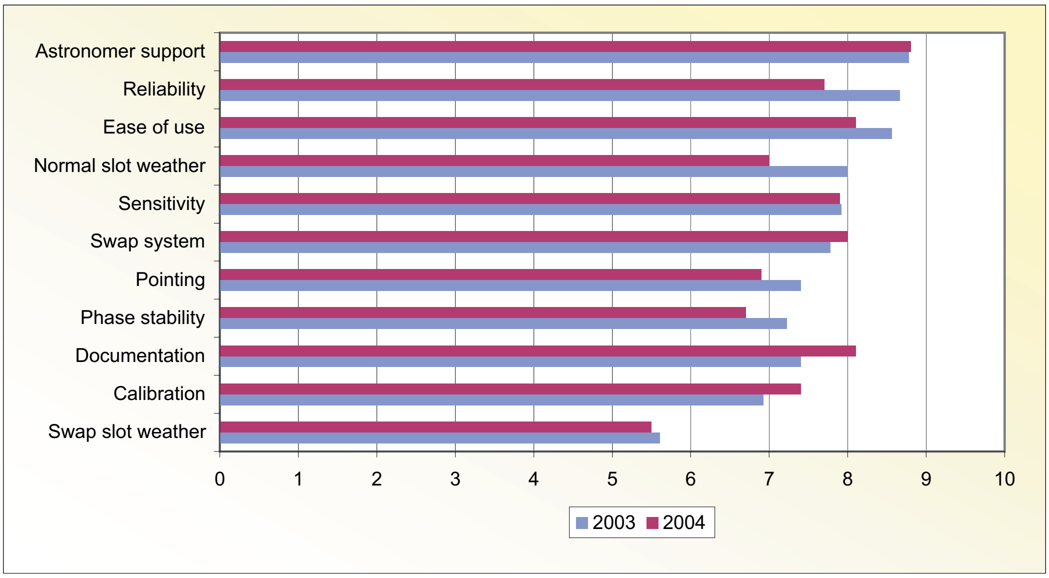


Figure 9 Narrabri user feedback for millimetre observations, on a scale of 1 (poor) to 10 (excellent).

Figure 10 shows the user feedback in 2004 for the Mopra telescope. This was the first year that Mopra feedback was collected. Three areas show relatively poor responses: the online observing system, documentation and web information and offline data processing software. Efforts were initiated to improve these.

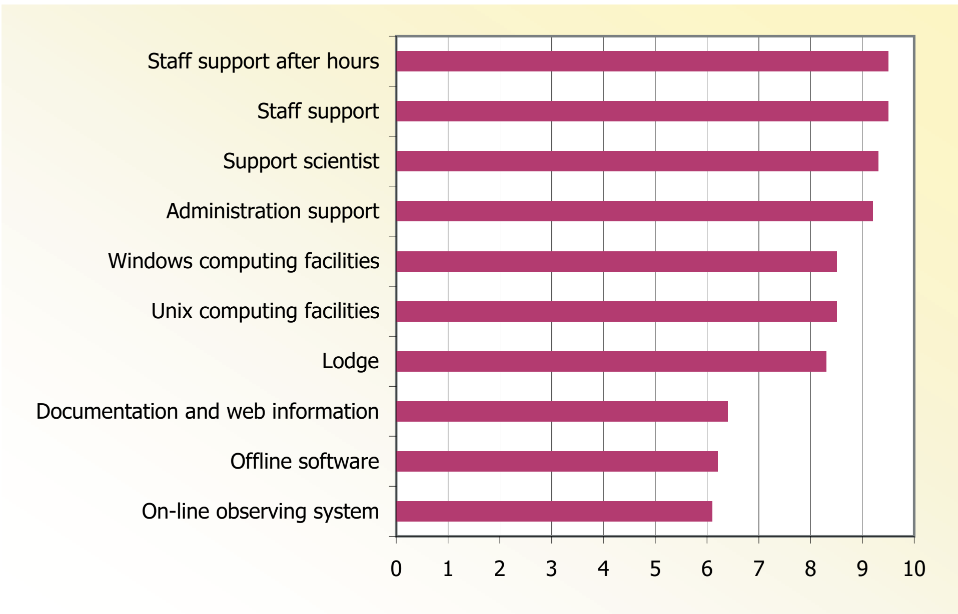


Figure 10 Mopra user feedback on a scale of 1 (poor) to 10 (excellent).

Astronomy reports

The Mopra radio telescope
Photo: © Shaun Amy, CSIRO

A wind bubble around a magnetar

B. M. Gaensler (Harvard-Smithsonian Center for Astrophysics, USA); N. M. McClure-Griffiths (ATNF); S. Oey (University of Michigan, USA); M. Haverkorn (Harvard-Smithsonian Center for Astrophysics, USA); J. Dickey (University of Tasmania); A. Green (University of Sydney)

The last decade has revealed remarkable diversity in the young neutron star population. Particularly notable is the small population of "magnetars", sources whose persistent X-ray emission and occasional X- and gamma-ray bursts are powered by the energy associated with extreme surface magnetic fields, in excess of 10^{15} Gauss. Underpinning studies of this new class of objects is the mystery of why some neutron stars are "normal" radio pulsars, while others are exotic magnetars.

The Southern Galactic Plane Survey (SGPS; see the 2002 Annual Report), which combines 21-cm HI observations from Parkes and the Compact Array, is now complete. The SGPS provides a wonderful resource for understanding populations such as magnetars in the context of their environment. Examination of SGPS data around the position of the well-known magnetar 1E 1048.1–5937 reveals a striking cavity in HI, designated as GSH 288.3–0.5–28, that is almost centred on the position of the neutron star. The SGPS data imply that GSH 288.3–0.5–28 is at a distance of approximately 2.7 kpc, and is expanding at a velocity of approximately 7.5 kilometres per second into gas of density ~17 atoms cm^{-3}.

Shells like GSH 288.3-0.5–28 are common, and represent wind-blown bubbles powered by massive stars expanding into the interstellar medium. The size and expansion speed of GSH 288.3–0.5–28 then imply that the bubble is several million years old, and has been blown by a wind of mechanical luminosity ~ $4x10^{34}$ ergs per second, corresponding to a single star of initial mass 30 to 40 solar masses.

Usually in such cases, the central star is obvious, in the form of a bright O star, supergiant or WR star at the shell's centre. However, even though this field lies in the rich Carina OB1 region, there are no known stars of the appropriate position, distance or luminosity to argue for an association with GSH 288.3–0.5–28. This raises the intriguing possibility that GSH 288.3–0.5–28 was blown by the massive star whose collapse formed 1E 1048.1–5937. The central location of the magnetar within the HI shell suggests that the supernova occurred quite recently. The corresponding blast waves would impact the walls of the HI shell approximately 3000 years after core collapse, producing significant X-ray and radio emission. The lack of such emission requires the neutron star to be very young, consistent with the small ages expected for active magnetars. A common distance of around three kpc is suggested by the properties of both objects.

Most neutron star progenitors will have masses near the minimum mass for core collapse, i.e., eight to nine solar masses. However, it is likely that the progenitor of the magnetar 1E 1048.1–5937 was considerably more massive than this. For some other magnetars, possible associations with massive star clusters similarly argue for high-mass progenitors. It thus appears likely that the difference between normal pulsars and magnetars is the progenitor mass.

Why should massive stars form magnetars? Recent work has shown that magnetars likely result from rapidly rotating (spin periods approximately one millisecond) proto-neutron stars, in which an efficient large-scale dynamo generates a super-strong magnetic field. Recent calculations on supernova progenitors indicate that stars of initial mass 10 to 15 solar masses produce neutron stars with initial periods 10 to 15 milliseconds, too slow to generate magnetar-like fields. However, more massive stars produce much more rapidly spinning neutron stars. For example, a 35 solar mass progenitor results in a neutron star of initial period three milliseconds, in the range needed to give birth to a magnetar.

Within this scenario, a prediction as to the relative birth rates of radio pulsars versus magnetars can be made. If the mass cut between normal pulsars and magnetars is at an initial mass of approximately 25 solar masses, then for a standard initial mass function the magnetar birth rate is expected to be only about 10 per cent of that of radio pulsars. The birth rate estimated from observations of the existing populations of magnetars is already comparable to this. If magnetars indeed form from massive progenitors, then it appears likely that there is no substantial population of such sources yet to be identified.

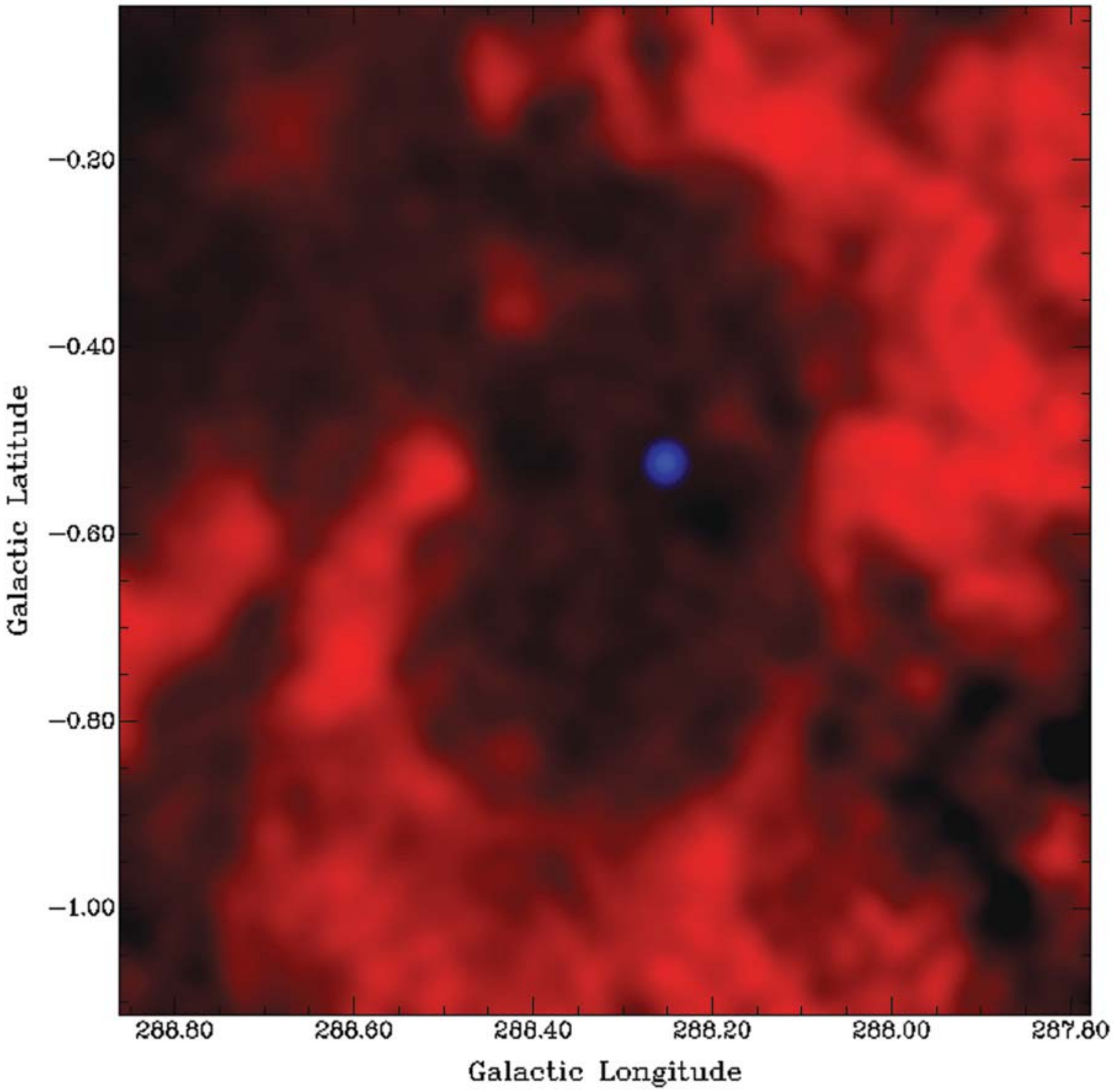


Figure 1: A 35-pc by 23-pc HI shell surrounding the magnetar 1E 1048.1-5937. The red indicates HI emission, mapped with the Compact Array and the Parkes radio telescope as part of the Southern Galactic Plane Survey. The blue represents unresolved X-ray emission from the magnetar, as imaged with the Chandra X-ray Observatory.

Discovery of pulsed OH maser emission stimulated by a pulsar

J. Weisberg (ATNF / University of Sydney / Carleton College, USA); S. Johnston (ATNF), B. Koribalski (ATNF), & S. Stanimirovic (University of California, Berkeley, USA)

Pulsars have proved to be outstanding probes of the interstellar medium. A team of astronomers led by Joel Weisberg has recently embarked on a new type of pulsar-ISM study that uses binned pulsar spectrometry of the OH line. In this approach, spectra are accumulated toward pulsars, with the spectra recorded separately during the pulsar pulse and in the interval between pulses. This makes it possible to isolate the effects of the ISM on the pulsar signal and to study the medium along the line of sight.

This technique was used with the Parkes radio telescope to observe "on" and "off' spectra towards 18 pulsars in the inner Galaxy. For one source, PSR B1641–45 , interstellar OH lines were detected in the pulsar spectrum. This was only the second detection of interstellar OH towards a pulsar and the first time where the OH towards the pulsar is seen in emission as well as in absorption.

The OH emission line seen towards PSR B1641–45 is caused by maser processes. Although there is extensive indirect evidence for maser activity in the ISM, stimulated emission of radiation has never been directly observed in astrophysical situations. For PSR 1641–45, the broadband pulsar spectrum exhibits excess line emission at 1720 MHz as the pulsar's photons stimulate the creation of additional photons in an intervening OH cloud. This excess emission switches on and off with the pulsar, clearly demonstrating its stimulated nature.

Figure 1 displays the 1720-MHz spectra toward PSR B1641–45. The pulsar-off spectrum, acquired in the interval between pulses, shows both emission and absorption against other background sources lying within the Parkes beam. The pulsar-*on* spectrum appears at first glance to be similar. However, when these two spectra are differenced, it is clear that there is excess signal at the line frequency during the pulse – the broadband pulse signal has been amplified by stimulated emission at this frequency. Although maser emission from OH clouds in the ISM has long been studied, these are the first measurements that directly demonstrate the stimulated amplification of a signal propagating through the interstellar medium: the maser amplification is clearly modified as the pulsar cycles on and off. Since this stimulated emission is driven by the pulsar pulse, it varies on a timescale of a few milliseconds, orders of magnitude shorter than the quickest maser variations previously detected. From the strength of the maser line it can be calculated that approximately five excess line photons are stimulated in the cloud for every 100 passing through it.

Pulsar B1641-45 lies in the inner Galaxy near the galactic plane, at (l,b) = (339.2, –0.2). Other available measurements of this region have been combined with the Parkes observations to create a schematic model of the ISM in the direction of the pulsar (see Figure 2). The model has been constructed using distances derived from kinematic analyses of radial velocity measurements. In this region of sky, the ionised hydrogen (HII) region G339.1–0.4 lies between the Earth and the pulsar, while the more distant HII region, G339.1 –0.2, lies beyond the pulsar.

Figure 3 displays spectra toward PSR B1641–45 at the four 18-cm OH lines. Pulsar-off spectra are shown in the left column while pulsar-on spectra are displayed in the right column. A strong OH line at a velocity of –45 km s^{-1} is evident in all eight spectra. The line is seen in absorption at 1612, 1667, and 1665 MHz and in emission at 1720 MHz. This line is likely to occur in OH gas associated with or near the HII region G339.1–0.4, since the velocity of the line is similar to the velocity of the HII region. Another OH line at a velocity of –30 km s^{-1} is also present in most of the spectra including the 1665 and 1667 pulsar spectra. This line may also be associated with G339.1–0.4, or a nearby region.

Another interesting phenomenon can be seen in Figure 3. Each 1720-MHz spectrum (top row) is an inverted copy of the 1612-MHz spectrum (second row). This mirroring, known as "conjugate" line behaviour, results from the initial states of both transitions being overpopulated by an identical physical process, so that the degree of overpopulation is the same at both 1612 and 1720 MHz.

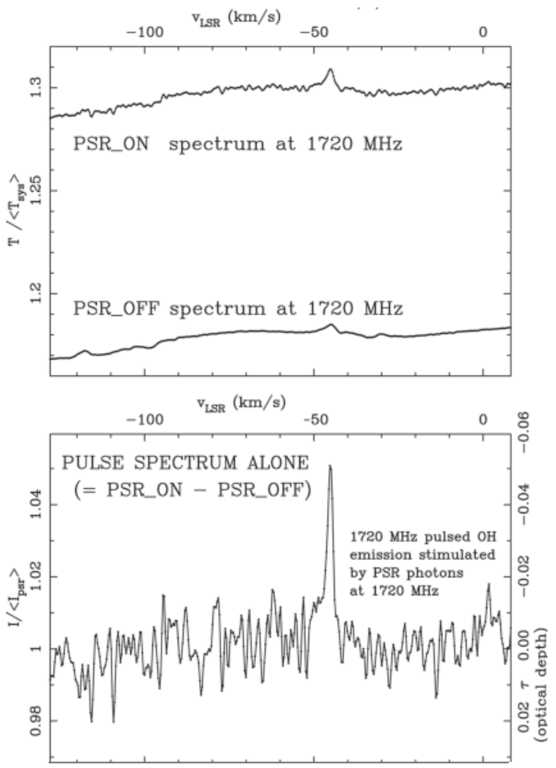


Figure 1: Discovery of pulsed interstellar OH maser emission stimulated by pulsar B1641-45.

Top: The “pulsar-*on*” spectrum, acquired during the pulsar pulse, and the “pulsar-*off*” spectrum, measured in the interval between pulses. The two spectra exhibit both emission and absorption against other (non-pulsar) background source(s) lying within the Parkes beam, while the pulsar-*on* spectrum additionally contains the pulsar signal.

Bottom: The pulsar spectrum, the difference of pulsar-*on* and pulsar-*off*, showing the pulsar signal amplified by intervening OH. The spike in this spectrum at a velocity of -45 km s^{-1} results from excess emission in an OH cloud, stimulated by pulsar photons.

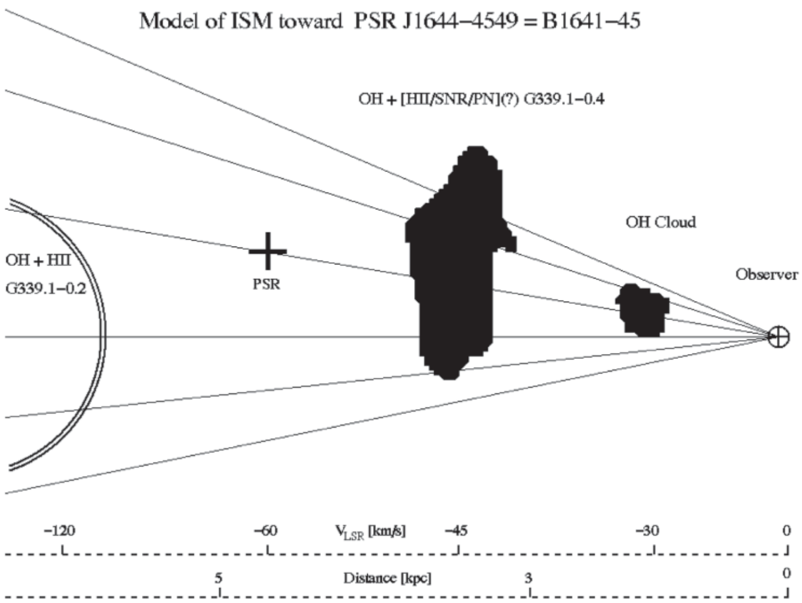


Figure 2: A schematic model of the ISM toward PSR B1641-45. The lines represent various lines of sight within the Parkes beam.

Figure 3 also shows that the pulsar-on spectra (right column) exhibit much stronger absorption and stimulated emission than do the corresponding pulsar-*off* spectra (left column) at the same velocities. This can be explained as a solid-angle effect if the very narrow interstellar column sampled by the pulsar signal possesses significantly different properties from the much more extended medium sampled in the pulsar-*off* spectrum. The pulsar pulse may interact with a small, dense OH cloudlet whose properties are diluted in the beam-averaged pulsar-*off* spectrum. This behaviour differs markedly from HI, where absorbing columns of very different angular solid angles exhibit *similar* statistics. In retrospect, this result is not too surprising, as molecular gas is known to be more clumped than neutral gas.

The Parkes search for OH absorption and stimulated emission in the spectrum of pulsars yielded many interesting results in the direction of the pulsar B1641–45. In future work, the authors plan also to study recombination lines toward this pulsar in an effort to further understand the interstellar medium in this direction.

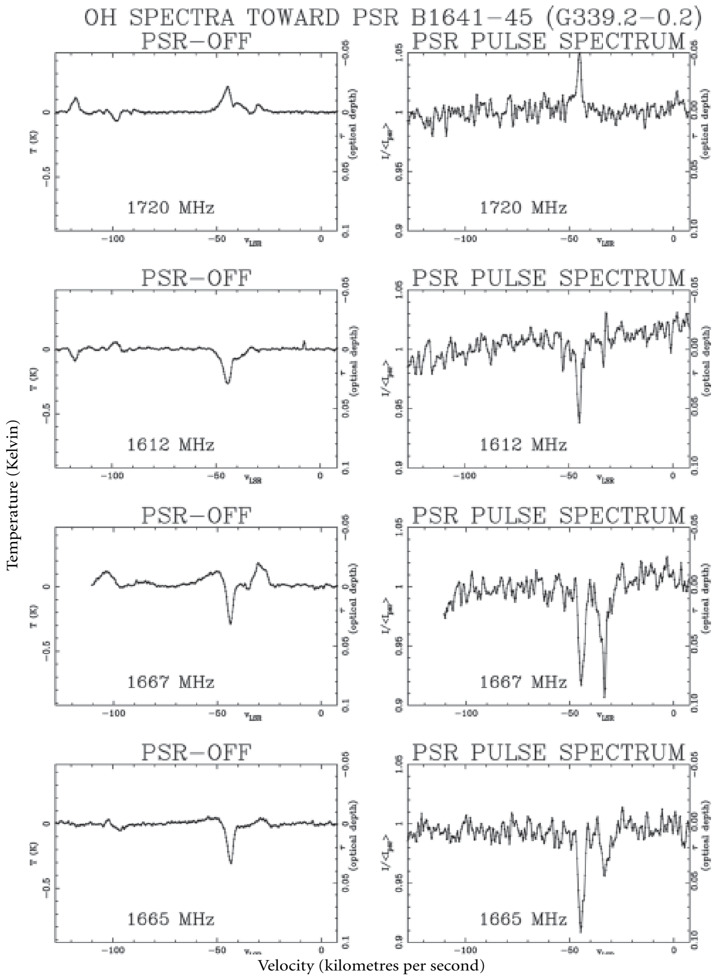


Figure 3: Spectra of the four 18-cm transitions of OH toward pulsar B1641-45. The left column displays the pulsar-*off* spectra at frequencies of 1720, 1612, 1665 and 1667 MHz. The right column shows the four pulsar-*on* spectra.

A “new” spiral arm for the Milky Way?

N. M. McClure-Griffiths (ATNF); J. M. Dickey (University of Tasmania); B. M. Gaensler (Harvard University, USA) & A. J. Green (University of Sydney)

The Southern Galactic Plane Survey (SGPS; McClure-Griffiths et al. 2001) is a survey for neutral hydrogen (HI) and 1.4 GHz radio continuum emission in the fourth quadrant of our Galaxy, using data taken with the Parkes radio telescope and the Compact Array.

As part of the SGPS, a remarkable structure was identified in the far outer disk of the Southern Milky Way. The structure of the outer disk of the Milky Way has long been a mystery to Galactic astronomers. Though it is known that the HI disk extends far beyond the stellar disk, very little is known about its structure in this Galactic "outback". In particular, it is not known how far the HI spiral structure of the Galaxy extends.

The new structure, shown near the top of Figure 1, is seen as a ridge of emission lying at the far positive velocity edge of the SGPS longitude-velocity (l-v) diagram. The l-v diagram shows HI emission in the mid-plane of our Galaxy (b = 0°). In this diagram, HI emission at negative velocities originates from gas that is interior to the solar circle and corresponds to gas at two distances, whereas HI emission at positive velocities occurs from gas that is exterior to the solar circle and generally corresponds to only one distance, with larger velocities at larger distances. The new ridge of emission arcs from l = 253°, v = 102 km s^{-1} through l = 299°, v = 110 km s^{-1} to l = 321°, v = 88 km s^{-1}. It is relatively cohesive across more than 70 degrees on the sky and is notably the last feature before the edge of the Galactic disk. Overlaid on Figure 1 are lines of constant Galactocentric radius (R_g, the radial distance from the centre of the Galaxy), at 16 and 24 kiloparsecs (kpc). These two lines show that the feature extends from a radius of approximately 17 kpc at the low-longitude end to approximately 25 kpc at the high longitude end, with an estimated radial width of about two kpc. The feature extends to a significant distance out of the Galactic plane with a "scale height" that varies between 1.2 and 1.7 kpc. Within the feature, the average surface density is estimated to be 3 x 10^{-3} solar masses pc^{-2}.

The observed ridge in the longitude-velocity diagram could be caused by two different physical effects: a gas density enhancement or a significant velocity perturbation that causes gas at different distances to appear at the same velocity. A spiral arm produces a combination of these effects. Spiral arms typically produce only small HI density enhancements in the HI disk, but they also induce strong non-circular velocities, or streaming motions, where gas interior to an arm is pulled radially by the arm's gravity. Because the observed feature is not at a constant radius and appears to be radially confined, it might be a very distant spiral arm.

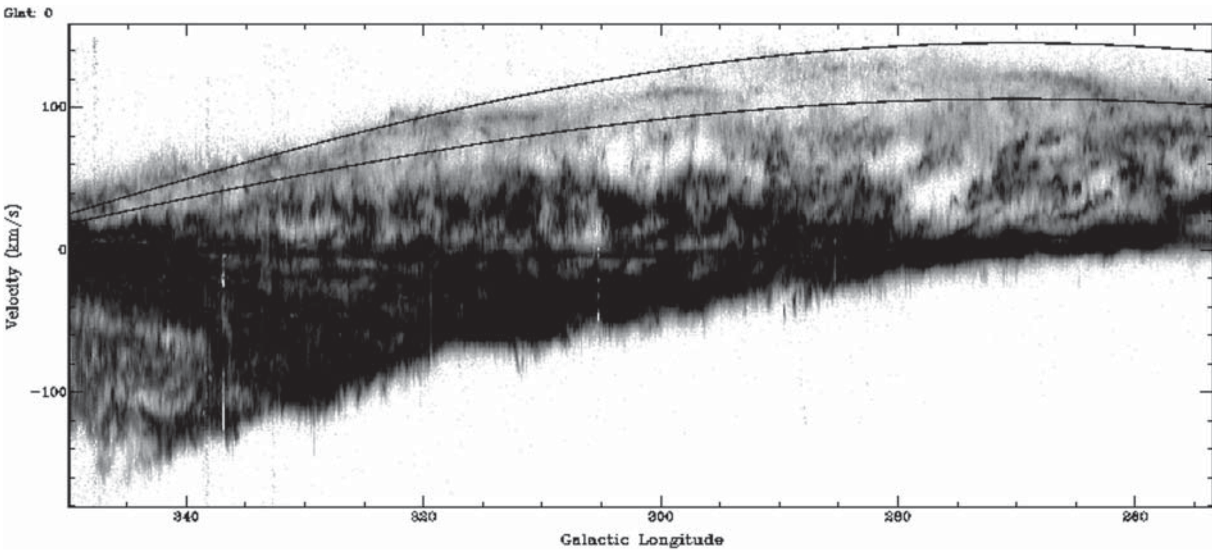


Figure 1: HI longitude-velocity (l-v) diagram of the Southern Galactic Plane showing the outer arm. These data were obtained with the Parkes radio telescope and the Compact Array. The arm is observed as a ridge of emission at the most extreme positive velocities. The image has an angular resolution of 2 arcminutes and a velocity spectral resolution of 0.8 km s^{-1}. The two solid lines show distances from the centre of the Galaxy of 16 and 24 kpc. (From McClure-Griffiths et al. 2004.)

To test this theory it is necessary to understand the shape of a spiral arm in l-v space. Figure 2 (left panel) shows a simple four-arm spiral model for the Milky Way with a "pitch angle", i, that varies linearly from 16° at R_g = 4.25 kpc to 10° at R_g = 18 kpc. Using this spiral model and allowing for streaming motions around the spiral arms, synthetic HI spectra can be created and used to construct a synthetic l-v diagram as shown in the right panel of Figure 2. This model is by no means definitive, but it recreates many of the dominant features of the observed l-v diagram. In particular, the model l-v diagram also shows a narrow ridge of emission at the most positive velocities.

Although the observed feature can be easily explained by a spiral arm, a number of other explanations were also considered such as whether the observed ridge might be due to elliptical gas orbits in the outer Galaxy, or to a very extended and smooth HI disk. However, none of these explanations were well-matched to the data and, on the basis of agreement with the spiral model, it was concluded that the new feature in the outer Galaxy is best described as a spiral arm with a pitch angle of i ~ 9°.

Another notable characteristic of this feature is that it shifts in velocity by about 10 km s^{-1} between longitudes of 275° and 295°, as seen in Figure 1. It is interesting that these longitudes agree well with the Galactic longitudes of the Large and Small Magellanic Clouds and the Leading Arm of the Magellanic Stream. In models of the orbits of the Magellanic Clouds, the Clouds cross the Galactic plane at a longitude of about 280°. It might be expected that the relative proximity of the Clouds would produce a significant dynamical effect on the outer Milky Way disk. Some models, such as Weinberg (1995), estimate that the orbit of the Large Magellanic Cloud should produce a radial shift in the HI at 18 kpc of about 10 km s^{-1}. This may explain the observed velocity shift in the outer arm.

There is still a great deal to understand about this most distant spiral arm in the Milky Way. For example, it remains to be seen whether there are any stars or star formation associated with the arm. Observations from the NANTEN telescope in Chile and follow-up observations with Mopra have revealed some ^{12}CO emission at coincident positions in the low longitude end of the arm (Nakagawa et al., 2004). It is too early to say whether this gas might have formed stars.

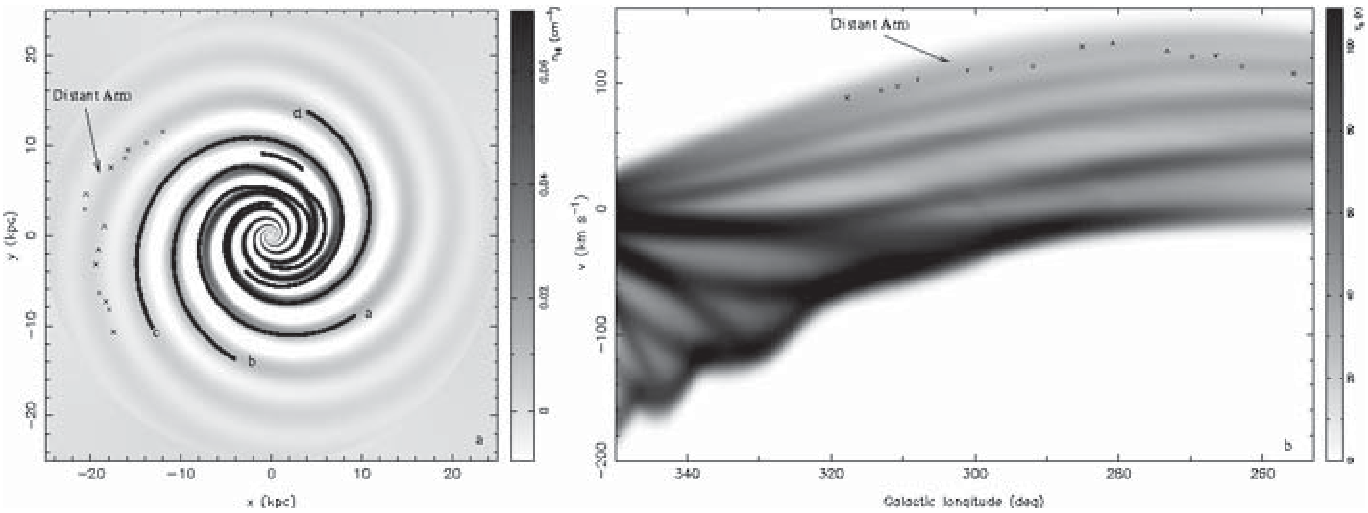


Figure 2: *Left*: A simple four-arm spiral model for the hydrogen gas density in the Milky Way. The Sun is at (x,y) = (0 kpc, 8.5 kpc). Overlaid in solid lines is the spiral model of Cordes & Lazio (2002).

Right: Synthetic *l-v* diagram created from the spiral pattern in the left panel. The proposed distant arm in the right panel corresponds to a ridge of emission at far positive velocities, as marked. (From McClure-Griffiths et al. 2004.)

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The Galactic All-Sky Survey (GASS)

N. McClure-Griffiths (ATNF); A. Ford (Swinburne University); D. J. Pisano (NRL, USA); L. Staveley-Smith (ATNF); P. Kalberla (University of Bonn, Germany); B. Gibson (Swinburne University) & F. J. Lockman (NRAO Greenbank, USA)

Galactic neutral hydrogen (HI) emission is observed in all directions on the sky. Our knowledge of the structure of the HI distribution, however, has been limited to angular scales of typically one degree, provided by the Leiden-Dwingeloo Survey and the complementary Argentinian IAR survey of the Southern sky. While high resolution Galactic Plane surveys like the Canadian and Southern Galactic Plane Surveys (Taylor et al. 2003; McClure-Griffiths et al. 2005) have allowed us to carefully explore the bulk of the Galactic HI emission in the disk, these surveys are not very sensitive and are restricted to a few degrees around the Galactic Plane, leaving most of the volume of the Galaxy unexplored on scales less than a degree. Recently, high resolution observations of targeted areas away from the plane have shown that there is an enormous amount of HI structure on small angular scales, which is not detected with the angular resolution of the current all-sky surveys. In order to understand the small-scale structure of HI in the halo, we have recently begun the Galactic All-Sky Survey (GASS) with the Parkes multibeam receiver. GASS is a fully sampled survey of Galactic HI south of declination = 0º with 15 arcminute resolution, a velocity resolution of one km s^{-1} and a sensitivity limit of 70 milliKelvin.

GASS will be used to answer questions about the kinematics of gas in the halo, the connection of the disk to the halo and the nature of HI structure in the halo. The evolution of the Milky Way is significantly impacted by the two-way flow of gas and energy between the Galactic disk and the halo. It has long been known that the HI halo extends far beyond the disk. However, because of the poor resolution of existing surveys, little is know about the origin and spatial structure of HI in the Galactic halo. In recent years high resolution studies with the Green Bank Telescope (GBT) have shown that the Galactic HI halo contains a plethora of cold, small structures on scales less than 30 arcminutes that appear to be in Galactic rotation (Lockman 2002). An example of such clouds from the GASS data is shown in Figure 1. These clouds may account for as much as half of the mass of the halo, but their origin and their dynamics are not known. Are they part of "Galactic fountain" gas that has been expelled from the disk and is now falling back towards it? GASS will provide a complete inventory of these halo clouds. Using this inventory the GASS team aims to determine the fraction of the halo mass in small clouds and the scale height of clouds, and to investigate the origin and physical state of the clouds.

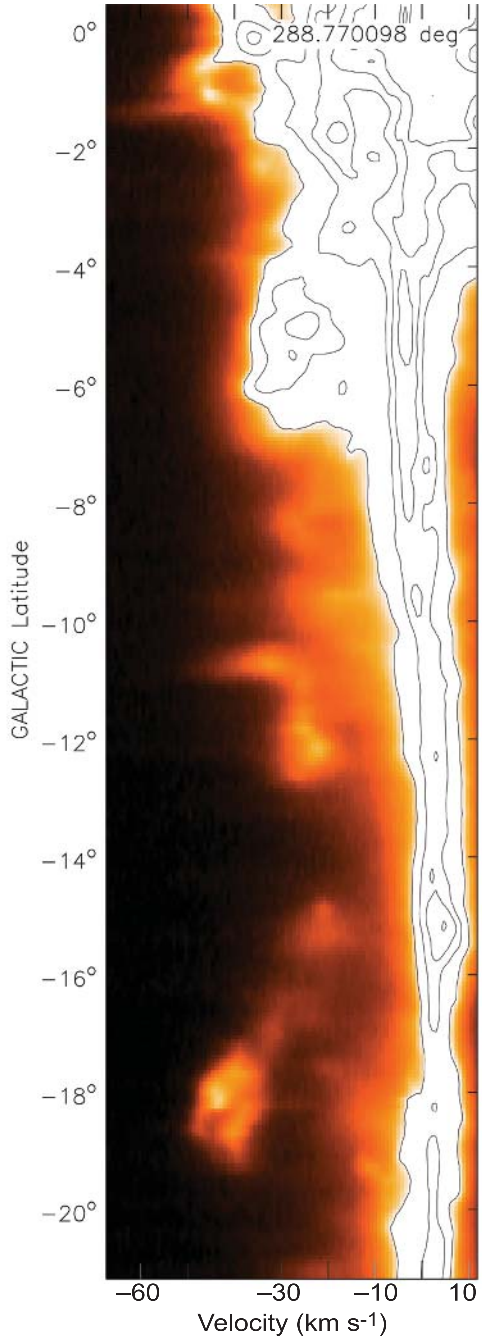

Figure 1: HI clouds in the lower Galactic halo. This HI image is of latitude versus velocity at a Galactic longitude of 288.7°. The colour scale has been intentionally saturated at 15 K to emphasise the low-level emission. The contours show the bright HI emission from 25 K to 125 K in intervals of 25 K. The Galactic midplane is at b = 0°. The image shows several small clumps of gas at high latitudes and velocities, such as the ones at v = -40 km/s, b = -18.5°, v = -31 km s^{-1}, b = -10.8° and v = -23 km s^{-1}, b = -12.3°.

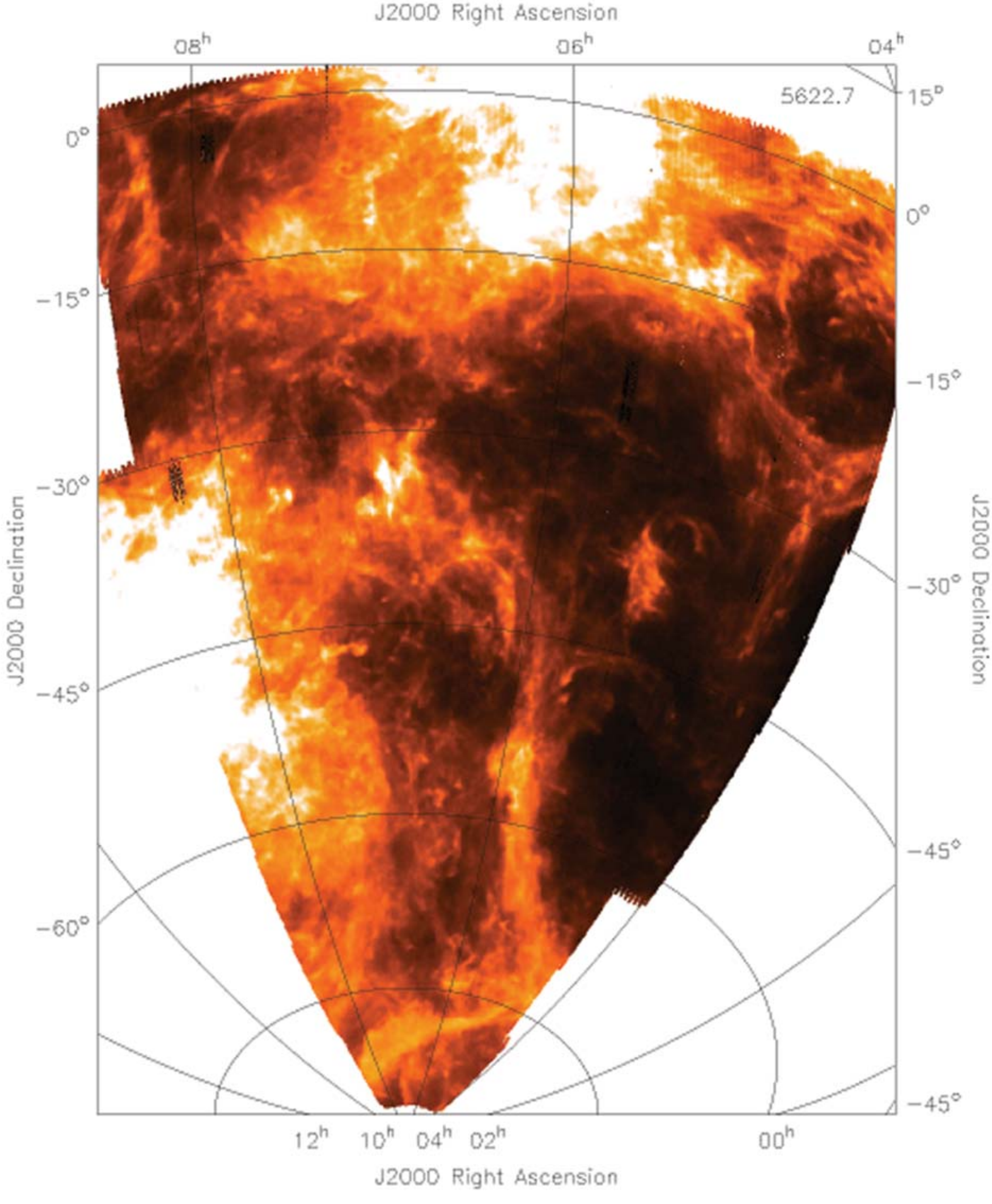

Figure 2: GASS "first light" image of Galactic HI at v = 5.6 kilometres per second, showing gas that is very local to the Sun. This image covers 90° of declination and 4 hours of right ascension with a resolution of ~ 15 arcminutes. A wide variety of structures on all size scales are apparent.

GASS will also provide an unsurpassed resource for studying the distribution, origin and evolution of intermediate and high velocity clouds. In and near our Galaxy, HI with velocities deviating from Galactic rotation is very common. Historically, gas clouds with large non-rotational velocities (above about 100 kilometres per second relative to the local standard of rest) have been called "High-Velocity Clouds" (HVCs). It is now known that these represent a variety of phenomena: some HVCs are probably related to a galactic fountain; some are tidal debris connected to the Magellanic Stream or other satellites; some may be infalling intergalactic gas (e.g. Complex C); and some may be associated with dark matter halos and be the remnants of the formation of the Local Group. The structure and distribution of high velocity gas probes tidal streams and the building blocks of galaxies providing critical information on the evolution in the Milky Way system. Though a great deal is known about the classification of HVCs, their nature and origin is still very unclear. Recent high angular and spectral resolution surveys, such as the Magellanic Stream survey of Brüns et al. (2005) or the CHVC survey of Braun, Burton, & Chengular (2001), have resolved physical and spectral structure in high and intermediate velocity clouds, demonstrating that there is much to be learned about the nature of these clouds on small scales.

As a sensitive, unbiased, high-resolution survey of a large fraction of the sky, GASS will contribute much to understanding the origin of HI structure in the halo and the nature of HVCs. GASS will use more than 1500 hours with the multibeam on the Parkes radio telescope over the course of the next two years. The need for high spectral resolution on all 13 beams of the multibeam has led to a new hybrid correlator mode, in which the multibeam correlator is used for the inner seven beams and the wideband correlator is used for the outer six beams. GASS pilot observations started in September 2004 and the full survey with the new hybrid correlator, in January 2005. The preliminary maps from GASS are spectacular. Figure 2 is an example of one velocity channel at 5 km s^{-1}, taken from the first observing run covering right ascensions from 4 – 8 h and all declinations south of 0º. We look forward to many beautiful images over the next two years.

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The Delta Quadrant Survey

I. Bains (University of New South Wales); T. Wong (ATNF / University of New South Wales) and the Delta Quadrant Survey Team

A comprehensive model that explains how stars form remains elusive to astronomers. It is generally accepted that the gas and dust in molecular clouds collapse to form a gravitationally-bound nascent stellar system, but what causes and regulates this collapse? In recent years, a potentially comprehensive model of star formation has arisen that focuses on the role played by turbulence in driving and regulating stellar birth. The precise origin of the turbulence is unknown but may arise due to large-scale gas flows or expanding supernova bubbles. The models detail how the turbulence cascades across a wide range of spatial scales and can both encourage the formation of clumps in molecular clouds and disrupt any already-forming clumps. Hence it can both drive and regulate the rate of star birth.

In order to provide observational constraints for this promising theory, the Delta Quadrant Survey Team has developed a program of molecular spectral line observations, with the Mopra telescope, of an approximately one degree square region of a giant molecular cloud complex situated in the fourth quadrant (hence "Delta Quadrant") of our Galaxy, near the HII region RCW 106. The purpose of this program is to characterise the turbulence in the molecular cloud and compare it to the star forming efficiency in order to elucidate the link between the two. The program began in 2004, with 10 weeks spent mapping the molecular cloud in the ^{13}CO (J = 1–0) transition at 110 GHz.

This project was made possible by the recent development of "On-the-Fly" (OTF) mapping at Mopra. In this mode, the telescope takes data continuously while scanning across the sky, and accurate coordinate information is written into the datafile with each spectrum. Not only does OTF mapping help to smooth out systematic errors such as in pointing, but it also provides a net gain in efficiency because a single reference

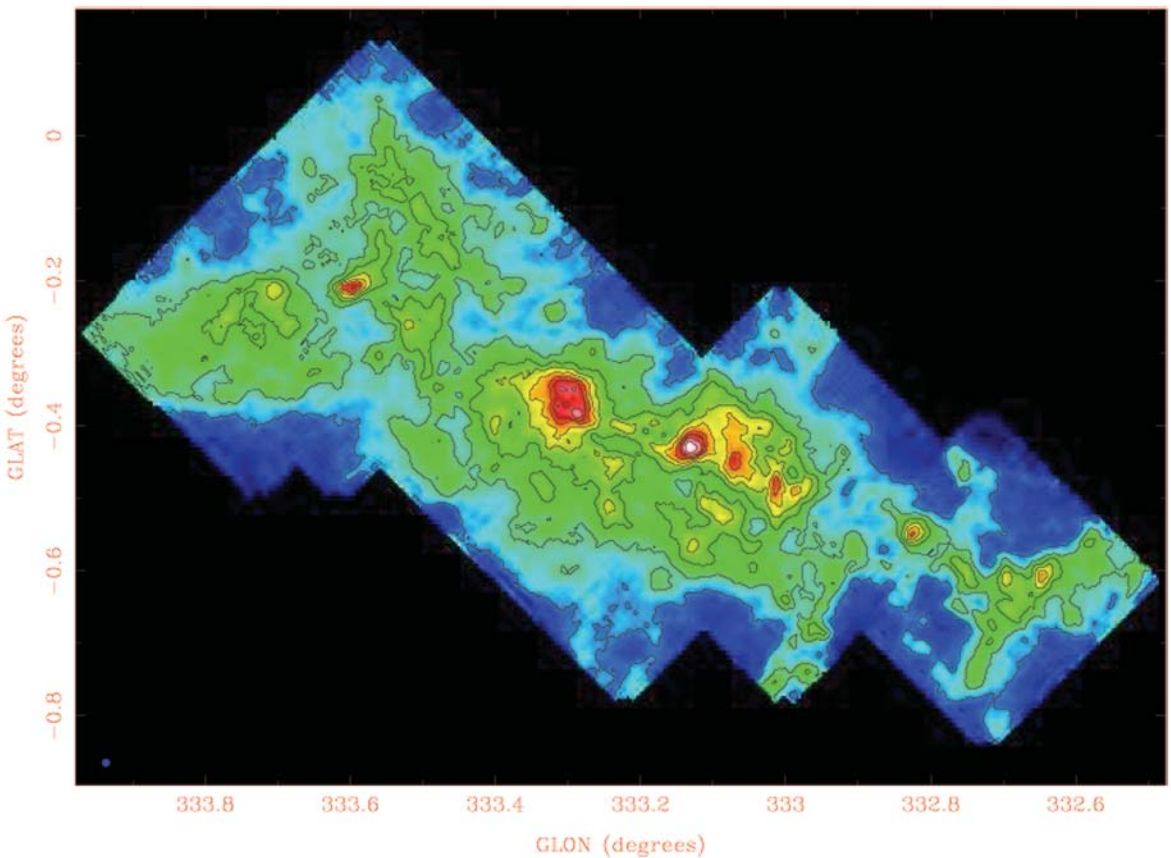

Figure 1: A total intensity map showing ^{13}CO emission from the "Delta Quadrant Survey Region" obtained from data taken with the Mopra radio telescope during 2004.

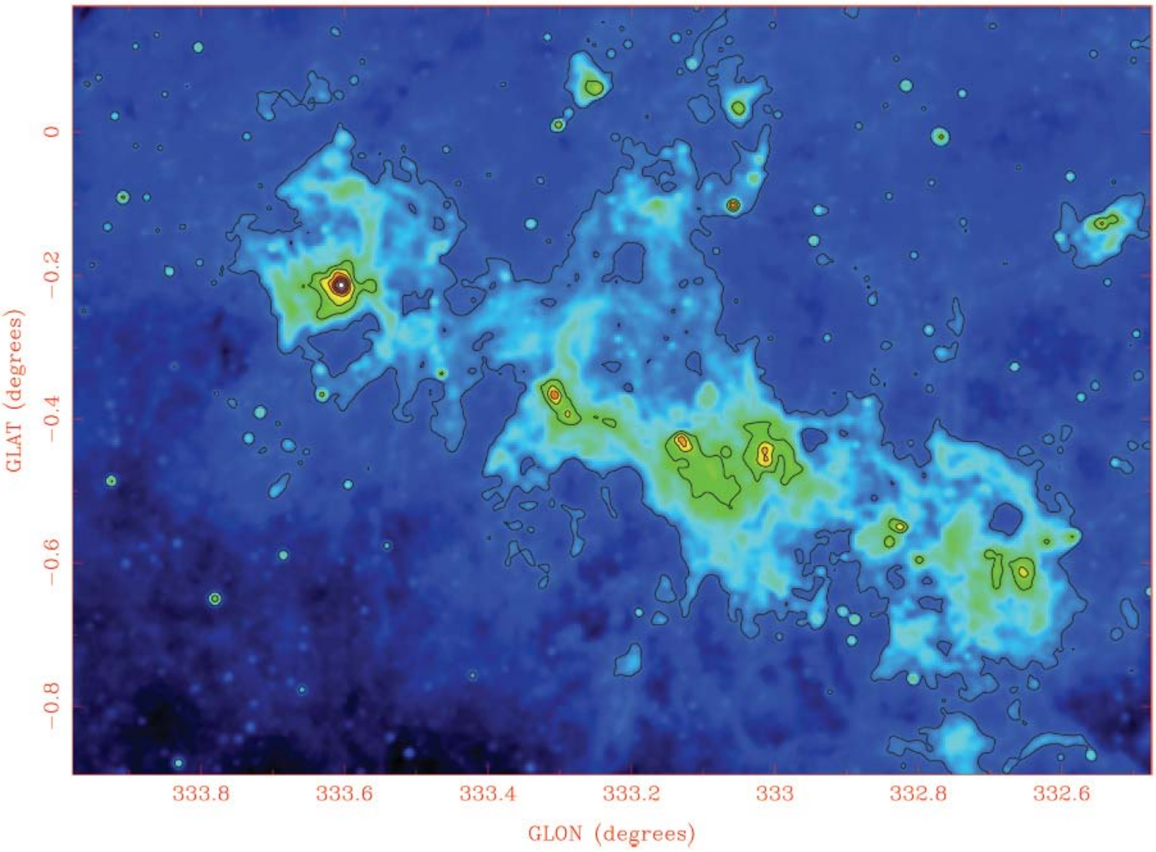

Figure 2: An image showing the 8-micron dust emission for the same region, obtained by the Midcourse Space experiment (MSX) satellite.

spectrum can be applied to multiple source spectra, as the effective on-source integration time is very short. Processing OTF data with the Parkes multibeam software is straightforward and allows data cubes to be efficiently generated.

Figure 1 shows the total intensity map of the ^{13}CO emission, while Figure 2 shows the 8-micron dust emission imaged by the Midcourse Space Experiment (MSX) satellite over the same region. The 8-micron emission is probably due largely to complex organic molecules (known as PAH's) which are excited by the radiation from newly formed stars, and thus should serve as a rough proxy for recent star formation. Note that although there is a clear correspondence between the gas peaks and the regions of recent star formation, the ^{13}CO emission tends to be more extended and to show a more clumpy structure.

The Mopra data are being used to analyse the structure of the ^{13}CO emission using several techniques, including power spectrum, wavelet, and clump-finding methods. This analysis will then be extended to velocity correlations in order to fully characterise the properties of the turbulence. In 2005, the team will begin mapping parts of the region in $C^{18}O$, a more optically thin isotopomer of CO, in order to obtain better column density information. The Spitzer GLIMPSE survey of the region will be used to obtain the stellar census and this can be compared with the molecular gas content to obtain the local star forming efficiency. In this way it will be possible to investigate the relationship between turbulence and star forming efficiency across a region roughly 100 pc in size.

How to feed a starburst

J. Ott (ATNF); C. Henkel (Max Planck Institut für Radioastronomie, Germany); A. Weiss (Institut de Radioastronomie Millimétrique; Spain); F. Walter (Max Planck Institut für Astronomie, Germany)

A major challenge in observational and theoretical astrophysics is to understand the processes which lead to the formation of stars. In the cosmic cycle, interstellar gas condenses and cools down. If the gas is sufficiently cold and dense, the material cannot withstand the gravitational forces imposed by its own mass and eventually collapses. The gravitational collapse condenses the gas to the point where nuclear fusion sets in and a star is born. Once the fusion processes have used all the available fuel, the most massive stars will explode as supernovae, ejecting large amounts of debris, dust and gas, and the cycle starts all over again.

The Milky Way forms about three stars equivalent in mass to our Sun every year, a value which is typical for "normal" spiral galaxies. A few galaxies can be found, however, where a similar or larger number of stars form within an area about five thousand times smaller than the body of the Milky Way. These galaxies are called "starburst galaxies" and the starburst region is usually located at their very centres, from which spectacular outflows of hot gas are observed. The outflows are driven by the combined effect of stellar winds and multiple supernova explosions within this very small area.

The Australia Telescope Compact Array is being used to study in detail how the gas is fed into the starburst region and, in turn, what influence the starburst has on its own supply. During the initial cooling process the gaseous fuel forms molecules. Their formation and destruction rate, as well as their excitation state, depend on the conditions which prevail in the vicinity of the starburst. Many molecules are accessible in the millimetre regime of the electromagnetic spectrum—a window which was recently opened at the Compact Array with the 12- and 3-mm upgrades. One of the most prominent and nearby starburst galaxies is NGC 253, at a distance of 2.6 million parsecs. An image of NGC 253 is shown in Figure 1. First results of the temperature distribution (obtained from multiple transitions of the ammonia molecule in the 12-mm band) within the molecular gas in the nucleus of NGC 253 were shown in the ATNF Annual Report 2003. This report shows more recent 3-mm observations of the (1–0) transitions of the HCN and HNC molecules.

In NGC 253, the interstellar gas is transported toward the galaxy's nucleus along a prominent bar (see Figures 1 and 2). In the process, the gas density increases and eventually forms molecules. The star formation sites are within the very dense molecular gas component (density $>10^4\,cm^{-3}$, e.g., Gao & Solomon 2004), which is compacted by the streaming motion. This peculiar gas phase is traced by rotational transitions of molecules with a large electric dipole moment, such as ammonia, HCN, and HNC. The details of the chemical network are rather complex, but since HCN and HNC consist of the same atoms and have a very similar structure, they should be catalysed in similar quantities (see Schilke et al. 1992; Aalto et al. 2002). At high densities and temperatures, however, HNC is converted into HCN via the reaction: HNC + H → HCN + H, and high HCN/HNC ratios of order 10 are observed in "normal" non-starbursting galaxies.

In contrast, the Compact Array observations of NGC 253 show that the HCN/HNC ratio decreases close to the starburst centre (Figure 2). Indeed, the ammonia observations have shown that the dense gas is cooler at the very centre of the starburst as compared to molecular gas further away. At first glance, this is counter-intuitive as it is the centre where most of the violent star formation takes place. However, this may be explained by the fact that only very cold gas can turn into stars and therefore sustain the purgatory-like conditions in these fascinating galaxies. In addition, close to the starburst centre, within the diffuse molecular gas, the atomic hydrogen is likely to be ionised (see the Hα image in Figure 2). In the very dense gas, which is self-shielded against the ionising radiation of the starburst, most of the hydrogen is transformed into molecular hydrogen H_2. In summary, the lower abundance of atomic hydrogen plus the cooler temperatures within the molecular clumps at the very starburst centre decrease the HNC + H → HCN + H reaction rate. This may be one of the reasons why we observe a lower HCN/HNC ratio at the very centre of NGC 253. A second factor for low HCN/HNC ratios at the centre of the starburst is likely to be the reactions $HCNH^+$ + e^- → HCN + H, and $HCNH^+$ + e^- → HNC + H , which produce HCN and HNC in equal quantities (see above; see also Schilke et al. 1992; Aalto et al. 2002; Meier & Turner 2005). This reaction is enhanced by the high fraction of ions close to the starburst core.

Over the coming months HCN and HNC observations of a larger sample of starburst galaxies will be obtained. The galaxies are selected to have different current star formation rates and some of them also harbour active galactic nuclei, massive black holes that produce extremely collimated and extended jets of relativistic plasma. Together with the Compact Array observations of the ammonia molecule, the HCN and HNC observations will help to determine the physical and chemical state of the dense molecular material in great detail, being able to trace the effects a starburst and an active galactic nucleus have on its own fuel.

Virtually all galaxies that are currently detected at high redshift, i.e., in the early Universe, show evidence of tremendous nuclear or circumnuclear starbursts. The understanding of nearby examples will therefore help us to unravel the star formation processes at any cosmic epoch.

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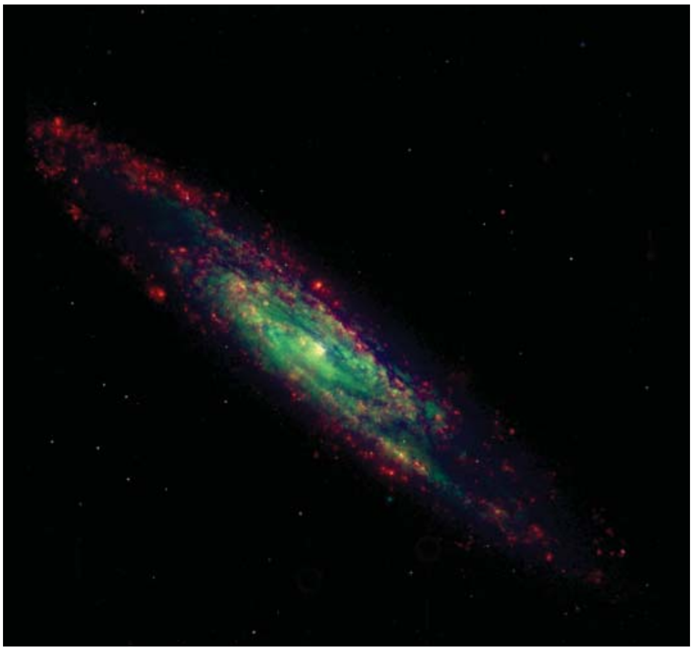


Figure 1: A three-colour composite image of NGC 253. Green shows near-infrared light from evolved stars (H-band image, taken from the 2MASS survey), blue shows optical emission (R-band), and red shows active star forming regions as traced by Hα emission (R-band and Hα images courtesy of M. Dahlem). The white, central spot marks the nuclear starburst in NGC 253 (blow-up shown in Figure 2).

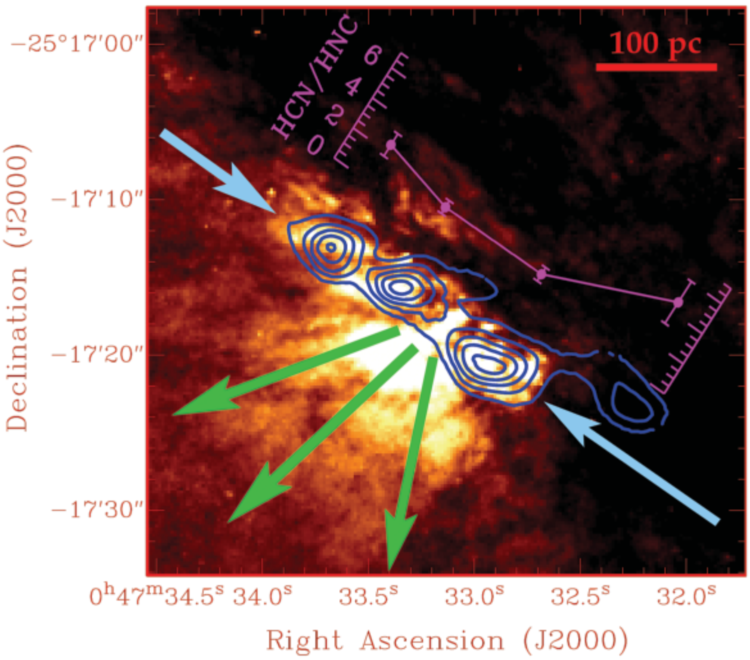


Figure 2: The nucleus of NGC 253 as seen in the light of ionised hydrogen (Hα image, observed by the Hubble Space Telescope WFPC2 instrument). The blue contours overlaid on the image represent the densest regions of molecular gas which are traced by our Compact Array observations of the molecule HCN. The starburst is fed by gas streaming into the starburst nucleus along a massive stellar bar, the direction of which is indicated by the blue arrows. The gas is then transformed into stars which eventually heat the ambient medium, thereby producing the spectacular outflows visible in the Hα line and marked by the green arrows. The ratio of HCN to HNC derived from the peaks along the molecular gas is plotted in the upper right.

Compact Array discovers molecular gas in the very early Universe

I. Klamer (University of Sydney); R. Ekers (ATNF); R. Hunstead (University of Sydney) & E. Sadler (University of Sydney)

The completion of the 12- and 3-mm receiver systems on the Compact Array has secured two new astronomical windows into the southern skies. A slew of new scientific observations are now possible. These include investigating the molecular gas reservoirs in and around galaxies in the very distant (high redshift) Universe. The quantity and distribution of molecular gas in galaxies highlight their recent star formation as well as pinpointing the production sites for future stellar populations. After molecular hydrogen (H_2) which is very difficult to observe at radio wavelengths, carbon monoxide (CO) is the most abundant molecule in the Universe, and on large scales is a very good tracer of H_2. The available Compact Array observing windows for different characteristic transitions of the CO molecule from galaxies over a wide range of redshifts are illustrated in Figure 1.

Powerful radio emission from objects which existed during the first few billion years following the Big Bang pinpoints the sites where the most massive galaxies we see around us today are forming. The highest redshift radio galaxies therefore provide the best clues to the formation epoch of massive galaxies. Observations of molecular gas and stardust in such systems are of crucial importance, as both trace star formation on large scales. Northern hemisphere millimetre interferometers have already observed molecular gas and dust in a handful of high redshift radio galaxies, confirming that these objects are still forming the bulk of their stars.

The most distant radio galaxy known to date is TN J0924–2201, located more than 12.5 billion light years away at a redshift of 5.2. When first discovered in 1999 it was hypothesised that TN J0924–2201 is a young, primeval galaxy in its formative stages. The detection of molecular gas was needed to confirm prodigious amounts of past and present star formation. Until the millimetre upgrade of the Compact Array, this observation

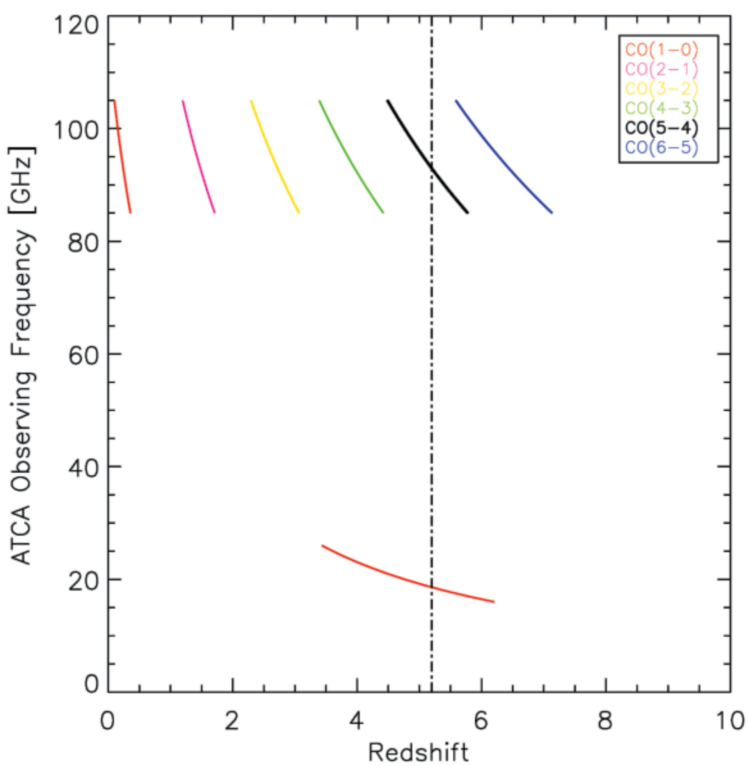


Figure 1: The available observing windows for Compact Array observations of red-shifted carbon monoxide. The dashed line indicates the redshift of TN J0924-2201.

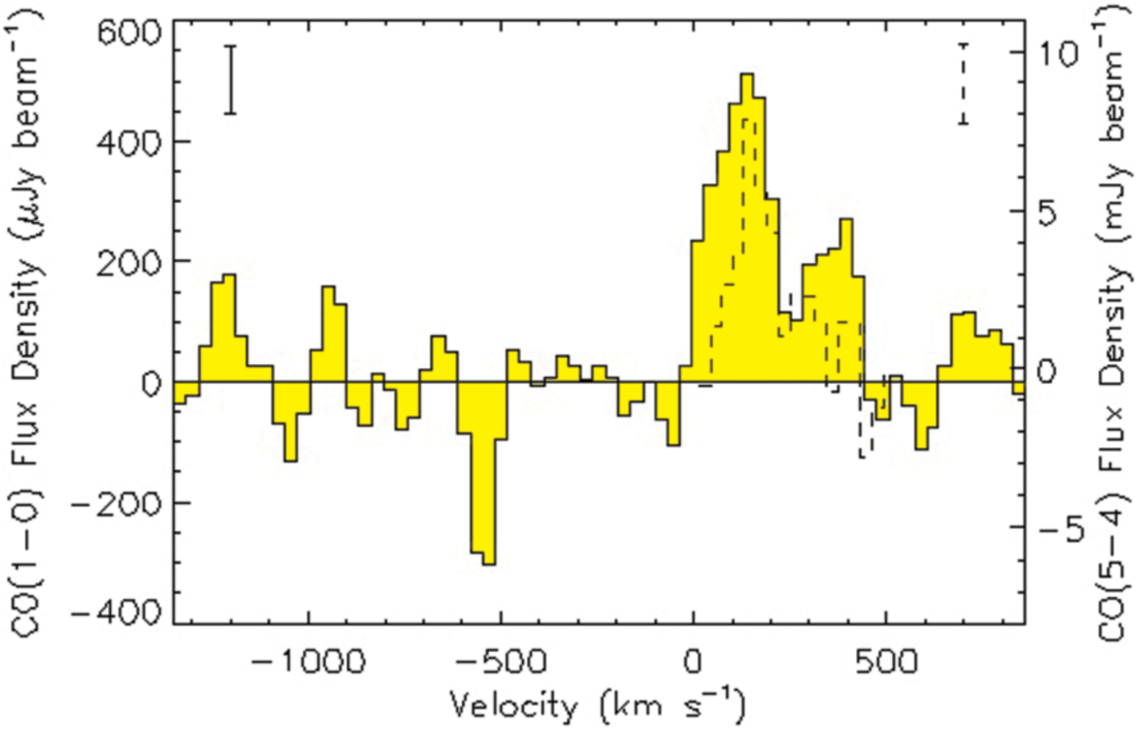


Figure 2: Carbon monoxide emission spectra from the galaxy TN J0924-2201. The J = 1-0 transition is shown in filled yellow, with the J = 5-4 transition overlaid with a dash line. One-sigma thermal noise bars are shown in the top left and right corners respectively.

was not possible—the source is either too far south for northern hemisphere millimetre interferometers, or its redshift moves the characteristic CO frequencies out of available observing bands.

In August and September 2004 the Compact Array discovered about 100 billion solar masses of molecular gas from TN J0924–2201. The CO (J = 1–0) and the CO (J = 5–4) emission spectra from TN J0924–2201 are shown in Figure 2. These observations place a stringent upper limit of 1.1 billion years (the time since the Big Bang) on the timescale for the star formation in the galaxy, since we see the by-product in the form of CO. This timescale also limits the formation of the central super-massive (10^9 solar masses) black hole, which we believe to be responsible for the powerful radio emission.

The discovery of molecular gas in this galaxy surprised many members of the high redshift CO community because the quantity of its CO content implied an equally enormous amount of dust but this has not so far been observed using sub-millimetre telescopes. The inherent difficulty involved in high redshift CO observations, coupled to a limited amount of time allocated to observe such targets, has caused astronomers to fine-tune their samples of galaxies in order to maximise the chances of success. Since molecular gas and dust are both by-products of star formation, and generally trace each other well, the traditional selection technique has been to observe only the immensely dusty objects on the premise that they will be the only ones with equivalently enormous amounts of CO. In fact, the massive content of molecular gas in TN J0924–2201 was discovered *in spite* of its lack of dust. This is the third such object where molecular gas has been detected without pre-selection on dust, hinting that many more such galaxies remain to be discovered.


5

Observatory reports

The Australia Telescope Compact Array
Photo: © Michael Gal,
School of Physics, UNSW

Australia Telescope Compact Array

Upgrades and developments

The Compact Array is a six-element interferometer array, operating at wavelengths from 3 mm to 20 cm. The primary development focus at the Observatory for a number of years has been to upgrade the array to operate at high frequencies with two new observing bands at wavelengths of 12 and 3 mm. In 2004 the millimetre upgrade was essentially completed with the installation of the 3-mm wavelength receiver packages and the 3-mm systems are now in operation (see page 66).

First 3-mm light through antenna 1, operating as a single dish, was achieved on 9 September 2004, while full interferometry using all antennas was first achieved on 20 September 2004. Although there were some commissioning issues to resolve with the new systems, overall the millimetre receivers worked very well. Above-atmosphere system temperatures of 250K and an antenna sensitivity of 25 Jy/K are achieved and the instrumental phase stability was excellent. The initial pointing accuracy was adequate. More complete characterisation and some corrective work were completed after the end of the millimetre season.

Other millimetre developments

To support the new millimetre systems, a broad range of subsidiary electronics and software were replaced or enhanced during the year. In addition, several ancillary projects were carried out to help optimise the Compact Array for millimetre observing.

One of these is the atmospheric seeing monitor. This is a 230-m baseline interferometer that continuously monitors a geostationary satellite at 30 GHz. From its output, three parameters provide information on the atmospheric phase stability: an rms phase noise, a baseline-length dependence and a time dependence. The monitor was completed in May 2004, and has since provided an excellent diagnostic of atmospheric phase conditions. Its output reaffirms the old adage that you cannot tell the phase stability by simply looking out the window.

A newly-installed 3-mm system on one of the Compact Array antennas. The feed horn for observations at 3 mm is seen in front of the much larger feed horn used for observations at 20 cm.
Photo: © David Smyth

One of the two stations use for the atmospheric seeing monitor. Three of the Compact Array antennas can be seen in the background.
Photo: © David Smyth

Another development was a project to provide dynamic correction of the antenna optics. Gravitational distortion of the main surface of the antennas causes an appreciable change in sensitivity with elevation. The antennas are currently optimised for an elevation of 60 degrees (this is the elevation of the geostationary satellite used for holography). At both low and high elevations, there is a reduction in sensitivity that can be as much as a factor of two. In principle, a two-axis movement of the subreflector could recover most of the lost sensitivity, and improve the antenna beamshape. To test this theory, an actuator was installed on antenna 1. This was found to significantly degrade the gain of antenna 1 at 3-mm wavelength. Further testing led to an understanding that the subreflectors and their supports are under-engineered so that the surface accuracy of the subreflectors on the antennas does not conform to the original design specifications. The main antenna surfaces were previously adjusted to maximise the antenna gains without realising that the adjustments also corrected for the subreflector surface flaws. The actuator work on subreflector actuation of antenna 1 modified the subreflector errors to a state where the subreflector and main surface were no longer "matched pairs". This insight into the engineering of the antennas has provided a better basis to plan the dynamic corrections for elevation effects.

Computing developments

For several years, the Observatory has pursued a program to modernise the computing infrastructure used to operate the array. This includes the hardware, software and networks. In 2003 new infrastructure to control the antennas was commissioned, and "first fringes" were achieved using a ported LINUX-based observing system. In 2004, the new observing system was able to support some special astronomy observations. The full switch to the LINUX-based system will be completed in 2005. This will then allow the removal of the now out-dated VAX/VMS systems that have been in use since Narrabri operations began.

Operations

The upgrade of the 3-mm systems required a three-week shutdown in June 2004 and a shorter shutdown in September 2004. The completion of the 3-mm systems for the Compact Array in September 2004 was a couple of months later than expected and this meant that some observing programs had to be rescheduled or cancelled, with a shorter millimetre season scheduled between mid-September and mid-October. From mid-September to mid-October the array was used for a mix of installation, commissioning tests and regular observing (mainly at 3-mm wavelength). The initial 3-mm observations were taken with less than the full complement of five antennas, and sometimes in less than ideal array configurations. Commissioning issues with the new 3-mm systems had a mildly adverse effect on the Observatory lost-time statistics. There were no significant change in the scores give by observers in the user feedback which remained very positive (see page 18). In 2004 the number of feedback responses from users was 40% higher than in 2003.

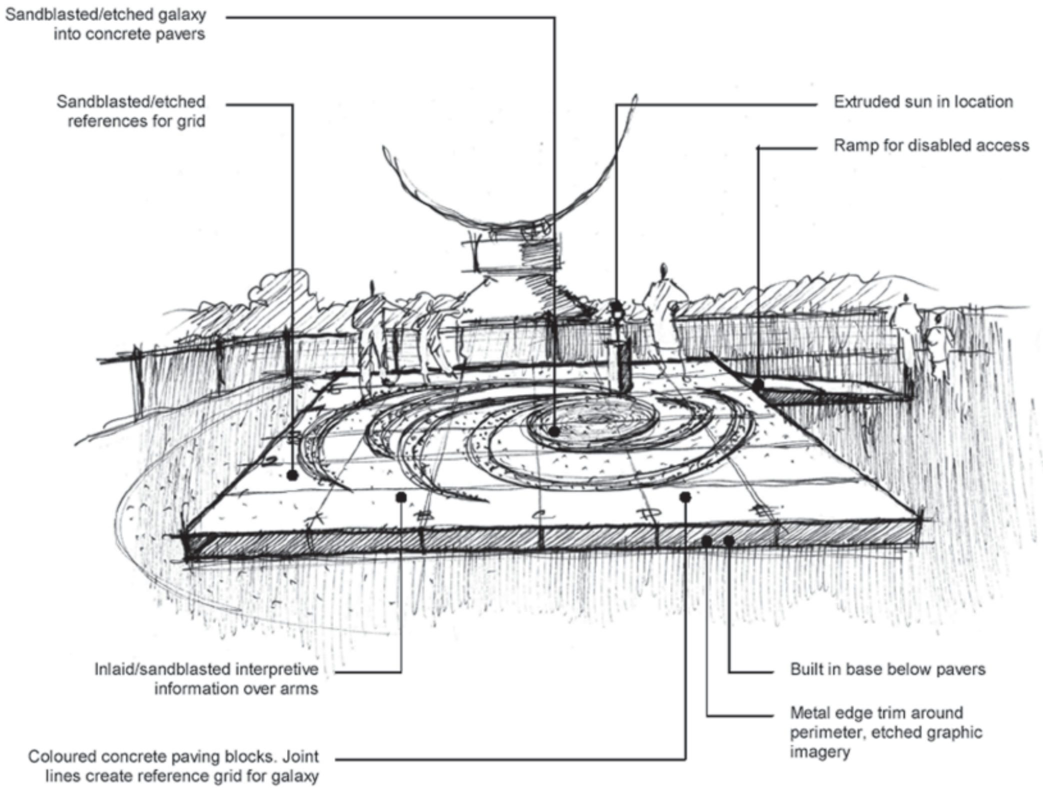
Averaged over the entire year, the fraction of observing time use at the different observing bands was 50.0%, 22.7%, 17.2% and 10.1% for observations at 20/13 cm, 6/3 cm, 12 mm and 3 mm respectively. Compared with 2003, the fraction of time used for 12-mm observing was slightly reduced while the time used for 3-mm observing was slightly increased. During the year, the availability of both these bands was reduced by the upgrade work on the new millimetre systems.

Visitors Centre redevelopment

Each year the Narrabri Visitors Centre receives about 10,000 visitors. In 2004 plans were initiated for a major restructure of the Visitors Centre and the services provided to visitors. These changes are aimed at providing a high-quality experience for visitors to the Observatory, catering for visiting groups, maintaining the Observatory as a major tourist attraction in the Narrabri district and making use of the advantages available on the Narrabri site. These include a natural bush setting and impressive views of the Compact Array.

As part of the restructure, the focus for the visitors will change from displays provided within the Visitors Centre building to new exhibits and information provided in the garden area that surrounds the building. Since July 2004 casual visitors to the Observatory have been largely self guided while pre-booked groups of visitors are provided with special guided tours. In November 2004, a contract was signed with a design company who have been commissioned to develop the outdoor exhibits, in consultation with the ATNF. In addition, ATNF staff provided landscaping work on the garden area and constructed a "Viewing Deck" for viewing the Compact Array antennas.

The new outdoor exhibits will focus on the facilities available on the site, engineering excellence and the natural wonders of astronomy. The redevelopment will also include shading, seating and diversions to keep young children occupied.



A sketch showing the plans for a representation of the Milky Way that may be constructed as part of the Visitors Centre development.
Image credit: Convergence

Site infrastructure

During the year the phone and data infrastructure within and between buildings in the central area of the Observatory was upgraded. This included new copper lines for phones, fire systems and emergency alarms, new network gear in many buildings, and a fibre optic network connecting buildings.

Late in 2004, funding was granted for a major refurbishment and extension to the Control Building. This work is expected to begin by 2006. The Control Building, built in 1964, is now starting to show its age after 40 years of service. In addition the prefabricated structure that currently houses the Electronics Group is substandard on a number of measures. As part of the extension to the Control Building, this prefabricated structure will be demolished.

Visitors to the Narrabri Observatory enjoy seeing the many species of native birds on the site. Two common species in the region are the Apostle Birds (top) and Galahs (bottom). The Apostle Birds are sociable birds that live in family groups. They are often seen playing on the ground and squabbling with each other. Galahs, also known as Rose-breasted Cockatoos, are easily recognised by their striking rose-pink colour. Large, noisy flocks of Galahs gather at twilight to roost for the night in the gum trees.

Photo: © Barnaby Norris

Mopra

Developments

The Mopra radio telescope is used as an antenna in the Australian VLBI array and as a single-dish telescope for spectroscopy at 3-mm wavelengths.

A number of technical developments in 2004 significantly added to the overall productivity of Mopra. The first, and probably most important of these, was the full integration of the new antenna control system into the observing software. This allowed the observing cycle time to be decreased by a factor of five. This substantially reduced a number of overheads in the system and provided substantially improved support for observations that require fast scanning of regions of the sky. Complementing this was a second development: a new software package was developed to support "on-the-fly mapping" with Mopra. This involved work in both the scheduling and off-line software. Mopra's mapping ability was also enhanced by adjustments to the subreflector. Following previous work in 2003, these provided further improvements to the antenna beamshape and efficiency, and reduced the coma lobe. The beam efficiency of the antenna improved from 62% to 65% as a result of the adjustments.

The Mopra radio telescope
Photo: © Shaun Amy, CSIRO

The combination of these changes was to make Mopra a significantly more attractive mapping instrument. Several projects during the millimetre season exploited this ability.

The groundwork was laid at the Observatory for the installation of a wideband digital filterbank. The equipment room was reorganised and a shielded rack was installed. In July 2004 a prototype wideband digital filterbank was installed as a "proof-of-concept" system. The larger velocity range of this system, while maintaining reasonable spectral resolution, was used by some projects for extragalactic observations.

The full implementation of the wideband digital filterbank and the replacement of the Mopra SIS millimetre receiver with a MMIC-based system had been expected during 2004. Unfortunately the technical challenges of these projects have caused their delivery dates to slip into 2005.

At the end of the year, work started to overhaul the primary monitor system at Mopra. This is intended to bring the telescope protection systems to a state where it is safe to operate Mopra remotely from the Narrabri Control Building.

Operations

The Mopra millimetre observing season was scheduled from 23 May – 22 October 2004. Shortly before the season started, the annual "Mopra Introduction Weekend" was again held. This workshop aims at developing better understanding, within the Australian community, of millimetre astronomy and the practicalities of observing with Mopra. It included formal talks, practical sessions and a telescope tour. In total 26 people participated.

An effort was put into bringing Mopra more in line with the operational practices of the other ATNF Observatories. Usage statistics are now systematically recorded, observational data are archived and observer feedback is gathered. Although effort during the year was used to improve the Mopra documentation, the observer feedback showed that the ATNF needs to improve in these areas. Other areas where additional attention is required include the on-line observing system and the off-line reduction software.

The telescope experienced continuing problems with the 4-Kelvin cryogenic systems on the SIS receiver during the millimetre observing season. Contaminants caused blockages in the SIS system cryogenics, despite the system being purged on several occasions. This resulted in a moderate amount of lost time. On the positive side, most proposals that lost time as a result of cryogenics problems were able to be rescheduled. Despite the cryogenic problems, the new technical developments helped to make 2004 one of the most productive years at Mopra.

In total four VLBI sessions were scheduled at Mopra over the year, with almost all the scheduled time outside the millimetre observing season. One of these was a single-day test session for the Huygens/Titan encounter in 2005.

Mopra observing and operations continued to be supported by an operations scientist based in Narrabri. Typically the operations scientist provided observing assistance at Mopra for the first few days of an observing run. Engineering support for Mopra continued to be provided by Narrabri staff with some additional assistance from technical personnel at the Anglo-Australian Telescope.

Participants at the Mopra induction workshop, May 2004.
Photo: © Bob Sault, CSIRO

Parkes

NASA tracking

The agreement with NASA to use Parkes for tracking of spacecraft over the 2003/04 "Asset Contention Period" ended successfully in March 2004. Several ATNF staff members received NASA Group Achievement Awards in January 2005 for individual contributions to the successful outcomes of the Parkes tracking contracts. (For details of this collaboration see the ATNF Annual Report 2003).

Double Pulsar

In December 2004 the journal Science included the discovery of the first known double pulsar, made at Parkes, among its Top Ten Science Breakthroughs for 2004. (The discovery of the second pulsar in this system was published in Science in January 2004). The timing of Science's announcement just before Christmas created limited press coverage, but received wide attention within CSIRO and the Australian scientific community. The discovery of this exciting system and resultant recognition by the editors of Science underlines the transformation that the 20-cm multibeam receiver has brought in recent years to the scientific capabilities of Parkes.

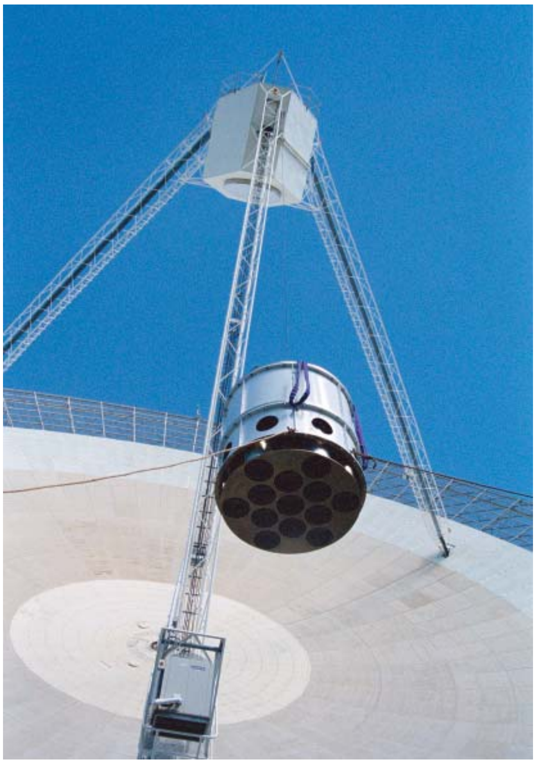


Photo: © John Sarkissian, CSIRO

The Parkes 20-cm multibeam receiver being re-installed on the telescope.

20-cm multibeam receiver

The 20-cm multibeam receiver was re-installed on schedule in September 2004 after the first phase of a major refurbishment cycle. About half of the original Jodrell Bank Low Noise Amplifiers (LNAs) were replaced with new ATNF devices, similar to those used in the Arecibo Multibeam (ALFA). A range of corrosion problems were also addressed. The refurbishment and re-installation of the receiver went very smoothly, however some faults subsequently began to appear in some of the original LNAs with three of these exhibiting low-level instabilities and at least two others showing occasional warning symptoms. It seems unlikely the problems can be cured without replacing all remaining original LNAs. Manufacture of replacements for all remaining original LNAs (plus spares) commenced at Marsfield, and it is planned to remove the receiver early in the 2005 October semester to complete the LNA replacement.

Huygens tracking and e-VLBI

Intensive preparations and rehearsals began early in 2004 in preparation for an ambitious and novel observation to detect ESA's Huygens probe during its descent through the atmosphere of Saturn's moon Titan. The mother craft, Cassini, is due to release the probe on Christmas Day 2004, for a descent and soft-landing onto Titan on 14th January 2005, the first such landing ever attempted on any solar system body beyond Mars.

A global array of radio telescopes, including Parkes, will track the direct signal from the Huygens probe as it descends to the surface of Titan, providing valuable science data to the mission, such as the structure of Titan's atmosphere and winds. The direct observations of the probe will also give the earliest possible indication that Huygens has survived its three-week hibernation in cruise phase and is operating correctly, several hours in advance of the first signals relayed through the Cassini mother craft.

These observations were proposed after the design and launch of the Cassini-Huygens mission, and take advantage of the sensitivity and flexibility of the Global VLBI network, in which Australia takes an active and important role. The project combines the resources of several international space tracking and astronomical organisations including the European Space Agency (ESA), NASA's Jet Propulsion Lab (JPL), the Joint Institute for VLBI in Europe (JIVE), the USA's National Radio Astronomy Observatory (NRAO) and the ATNF.

The contribution made by the Parkes radio telescope will be critical as it is one of probably only two antennae in the world capable of detecting the tiny signal from the probe strongly enough to follow it in real time, offering scientists the tantalising possibility of following the descent of the probe virtually second by second. (The northern hemisphere partner in this role will be the 100-metre Green Bank Telescope at Green Bank).

One of the special demands of the project is the ability to receive a very weak signal at a non-standard frequency, not normally used for either space tracking or astronomy. A very sensitive Parkes system has been assembled very cost effectively by re-using components from earlier projects at Parkes including the NASA Galileo tracking project (receiver and polarizer), and the Project Phoenix SETI mission (wideband S-band feedhorn).

Another feature of the Huygens project will be a demonstration of the effectiveness of the new disk-based VLBI recording systems. These new disk systems, progressively implemented throughout the ATNF in 2004, will be used for the Huygens observations to record data at each Australian station at the rate of 512 Mbits/sec, the highest data rate hitherto attempted on this VLBI network, and 4 times the limit of the current S2 tape recorder systems.

Data archiving

The diversity and volume of data taken at Parkes has, in the past, presented some problems in archiving and cataloguing. A number of steps were taken throughout 2004 to place the retrieval of archival data taken at Parkes on a more secure footing, and bring practices into line with Narrabri. These include:

- A web-based interface to an Observatory observation catalogue. The database includes essentially all spectral-line observations back to at least 1999 and the full HI surveys (HIPASS, ZOA) commenced in 1997. It also includes almost all pulsar observations since 1997, except for those made with the Caltech correlator which will be added later.
- Archival of all pulsar data, in raw form wherever possible, is being implemented progressively. Archival of all filterbank data will be implemented in March 2005. Wideband correlator data have been archived routinely since this instrument was commissioned. It is not practical to archive all raw CPSR2 data owing to data storage constraints, however all folded CPSR2 profiles are being archived on disk at Marsfield and the Centre for Astrophysics and Supercomputing, Swinburne University of Technology.
- The Galactic pulsar survey (P268). The complete dataset is currently held on a disk array at Jodrell Bank. A copy of this database is to be created at either Parkes or Marsfield. All data taken for the associated timing project P276 are currently held on a disk array at Marsfield.

RFI mitigation

The presence of radio frequency interference (RFI) in some bands remains of concern to many Parkes users, as indicated in the observer reports. Of particular concern is the 50-cm band, in which astronomical observations compete with the growing number of television transmitters, particularly new Digital TV services. One technique for mitigating the effects of these TV signals (which are many orders of magnitude stronger than the astronomical signals under study) involves using a small reference antenna to receive a clean copy of the interfering signal, and employing sophisticated signal-processing to recognise and actively cancel that signal from the data recorded with the 64-m antenna. Initial tests of this technique using software emulation have proved very successful, and a hardware system capable of implementing this cancellation in real time is under construction.

Other RFI mitigation work including stand-alone systems to monitor all new equipment for RFI, to detect and identify new sources of RFI both on and off site, and where necessary to shield all new equipment installed on site continues actively.

Performance and time use

The percentage of time scheduled for astronomy in 2004 rose to approximately 75%, returning to normal levels following the conclusion of the NASA tracking project in March 2004. A large fraction of Director's Time, discretionary time set aside in the observing schedule for projects with short lead times, was also used for astronomy. The figures for lost time due to equipment faults and bad weather (high wind) remain at low levels, typical of recent years.

User feedback

The web-based fault reporting and observer feedback system remain important tools in monitoring and maintaining Observatory operations and levels of service. User participation in the feedback system remains healthy and in 2004 confirmed generally high scores in most areas (see page 18). Once again, RFI remains the issue of single greatest concern to users.

Usage statistics for 2004

Successful astronomy observations	70.5%
NASA tracking	3.7%
Unscheduled lost time due to equipment	1.2%
Unscheduled lost time due to weather	3.1%
Maintenance/test time	10.0%
Director's Time	11.5%

Time lost to equipment and wind were typical of those for recent previous years.

"Director's Time" is time reserved in the initial published version of the six-monthly observing schedules, but which is available subsequently on request for approved observing projects. A large fraction (70% or more) of the Director's Time in 2004 was so used. The high value of 11.5% in 2004 reflects to some degree the relatively low subscription factor for Parkes at non-Galactic sidereal times.

Site

Work progressed on a major renovation of the site access road, from the Newell highway to the Observatory, with approximately half of the road completed by the end of the year. The investment in this project was motivated by concerns for safety on the deteriorating old surface and by the needs of the 120,000 members of the public who visit the Observatory each year, many in large coaches. The project is jointly funded by CSIRO Corporate Property and Parkes Shire Council, from its Federal Government "Roads to Recovery" allocation. Completion of the remaining section of the road is planned for 05/06.

The Australian Long Baseline Array

The Australian Long Baseline Array (LBA) operates as a Very Long Baseline Interferometer (VLBI) array utilising most radio telescopes around Australia. It includes all the ATNF antennas (Parkes, Mopra, Compact Array), the Hobart and Ceduna antennas of the University of Tasmania and antennas of NASA's Canberra Deep Space Communications Complex at Tidbinbilla. It also frequently operates in collaboration with overseas antennas, especially the Hartebeesthoek antenna in South Africa, the Kokee Park antenna in Hawaii and the Kashima antenna in Japan.

Technological developments

The LBA uses the S2 VCR-based recorders and the ATNF correlator in Sydney to achieve a maximum data rate of 128 Mbps. Increases in data rate and hence sensitivity are only possible by adopting different recording and correlating systems.

Disk-based recording and software correlation

Disk-based recording systems have been recently developed (e.g. Mk5) and are in use in overseas networks (e.g. EVN). The LBA has adopted the disk interfaces developed by the Metsahovi Radio Observatory and all LBA antennas were equipped in 2004. The LBA system also uses the LBA Data Aquisition System (DAS) and commercial computers to achieve 256 Mbps at all LBA stations. These developments were a collaboration between the Swinburne University of Technology, the University of Tasmania and ATNF.

The disk-recorded data cannot be correlated on the LBA correlator and the Swinburne University of Technology has developed a software correlator on their Beowulf supercomputer. This correlator is very flexible but at this stage much slower than real-time instruments.

In April 2004, two seven-station observations were conducted involving nine different telescopes in Australia, South Africa, Japan and USA. The observations were recorded with mixed Mk5, K5 and LBA disk systems and fringes were obtained to all stations. This clearly demonstrated the power and flexibility of the disk systems and the software correlator.

Real-time fringe checking

The combination of disk recorders and software correlation also enabled the near real-time checking of the LBA systems. During the April 2004 observations a small amount of data on a strong radio source was recorded and transmitted via the internet to the software correlator at Swinburne. Fringes were detected from all antennas within a few minutes, with a record of 40 seconds from recording to detection of fringes.

A system has been implemented to perform such fringe-tests in parallel with routine VLBI tape recordings. Such fringe checking has greatly increased the reliability of the LBA.

VLBI tracking of the Huygens probe

In 2004 the LBA was also asked to participate in a world-wide VLBI tracking of the Huygens probe during the descent onto Titan, after its release from the Cassini spacecraft. This event will occur on 14 January 2005.

Intense preparations for the Huygens experiments took place in 2004. The Huygens probe will transmit at a frequency near 2040 MHz that is not normally available on radio telescopes. To cope with this receivers and IF systems had to be modified at Parkes and Mopra. The Huygens observations require 512 Mbps recording and additional DAS equipment was installed at Parkes and Mopra.

Tests were performed during 2004, culminating with a "dress rehearsal" of VLBI tracking of spacecraft in November 2004. This involved recording on Mk5 and LBA disk-systems and correlation at JIVE and was very successful.

e-VLBI

With the advent of fast networks it has now become feasible to bypass tape or disk recordings and correlate VLBI data directly in real-time. Limited demonstrations of e-VLBI have occurred over the last few years but were hampered by the lack of easy access to fast networks.

In Australia, the AARNET3 Regional Network will provide direct fibre connections to the ATNF telescopes, initially at a data rate of 1 Gbps with a rate of 10 Gbps expected in a few years. Such connectivity was scheduled for late 2004 but has been postponed to 2005.

At the same time, the ATNF is developing a broadband correlator for the Compact Array, capable of handling data rates of 4 x 32 Gbps from each antenna. This correlator will be operational in 2007 and it is designed to be potentially capable of correlating VLBI data. The combination of developments in networks and the correlator will allow real-time e-VLBI observations at multiple 10 Gbps rates. This will increase the sensitivity of the LBA ten-fold and will create one of the most sensitive VLBI networks in the world.

The ATNF setup an e-VLBI project in 2004 and has started working on all aspects of e-VLBI. The first stage of development will involve rates of up to 1 Gbps and will use the same equipment as the disk-based recorders and the software correlator.

Development of Trans-Tasman VLBI capability

During 2004 a collaboration developed between the ATNF, the Swinburne University of Technology, and the Auckland University of Technology (AUT) to develop a significant VLBI facility in New Zealand. This will be used in conjunction with the Australian LBA to conduct Trans-Tasman VLBI. Initially the AUT are building a 1.6 GHz radio frequency system for installation on an existing telecommunications radio telescope. The first fringes across the Tasman Sea are expected to be achieved in 2005. The ATNF aims to assist the AUT to obtain a permanent radio astronomy facility in New Zealand capable of VLBI.

The ATNF-USNO astrometry program

The ATNF and USNO have run a collaborative VLBI astrometric program for the last four years, to increase the accuracy of the International Celestial Reference Frame (ICRF) in the Southern Hemisphere. In 2004, milliarcsecond-accurate astrometric positions for 47 new extragalactic sources south of declination −30 degrees were published, representing the largest group of new sources in this declination range since the initial definition of the ICRF. Images of 116 southern hemisphere extragalactic sources have been determined, the first large and comprehensive VLBI imaging survey in the Southern Hemisphere.

Operations

Proposal demand for the LBA in 2004 continued to be strong, with an effective oversubscription rate of 1.6, similar to previous years. A significant amount of time was again allocated to the ATNF-USNO astrometric program.

Two major LBA observing sessions were held in April and November 2004, each lasting approximately one-week. The weeks were scheduled to avoiding the winter millimetre observing season. In addition, in June and August 2004, two 12 hour VLBI observations were scheduled at 22 GHz. Some test time was also allocated for disk-based systems, especially in preparations for the Huygens spacecraft tracking.

Overall the LBA achieved a success rate of 91.5%, a 2% improvement on the previous year. A summary is given in the table below. Most of the telescopes continued with success rates over 97%, but telescopes are vulnerable to single-point failures with a large impact on a VLBI session.

The Parkes failure rate of 6% during LBA observing was almost entirely due to high winds. The Compact Array lost a significant amount of time due to an error in polarisation identification at 22 GHz. Ceduna suffered a power failure in a single session, with consequent problems for drives and clocks.

Telescope Hours	Parkes	Compact Array	Mopra	Hobart	Ceduna	Tidbinbilla	Hartebeesthoek	Kokee	**All LBA**
observed	302	312	356	362	245	49	103	22	**401**
% success	94	90	98	99	93	100	97	100	**91.5**

Tidbinbilla spectroscopy

Access to the NASA owned and operated antennas at Tidbinbilla is provided under a Host Country agreement and the time is made available to the astronomical community though the ATNF. Host Country time is used for VLBI and, since January 2003, has also been offered through the ATNF as a National Facility for single-dish observations. 2004 saw the second year of service spectroscopy observations with the 70-m antenna.

All 70-m spectroscopy observations in 2004 were conducted in the 1-cm band which remains the most sensitive system in the southern hemisphere for observations in a frequency range of 18 – 26 GHz, with a system temperature of 60 Jy. Tidbinbilla is equipped with an ATNF multibeam correlator block capable of two polarisation products with up to 2048 channels, each with 32 or 64 MHz bandwidth, or up to four polarisation products with a total of 8192 channels and bandwidths of 16 MHz or less.

Time available for spectroscopy in 2004 was generally restricted to periods when Mars was below the horizon due to the continuing high priority given to NASA spacecraft at Mars. For the first half of 2004, Mars was far enough away from the southern Galactic plane to allow good use of available time for service spectroscopy. During the latter half of the year Galactic time became unavailable and fewer proposals could be observed.

In 2004 a total of 180 hours of observing time with the 70-m antenna was used for spectroscopy observations. The oversubscription rate was approximately 2:1.

Caption: View of the hills near the Mopra telescope
Photo: © Martin Mühlegger

General activities

The Parkes Telescope tracking Mars at night
Photo: © John Sarkissian, CSIRO

Astrophysics & Federation Fellowship groups

The major goal of members of the Astrophysics and Federation Fellowship groups is to conduct world-class research in astrophysics using the telescopes operated by the ATNF in order to best exploit scientific opportunities and to best plan for future upgrades. In addition, a significant amount of time is spent by astrophysics staff supporting regular National Facility operations, and hosting visiting observers.

Staff

Simon Johnston joined the astrophysics group as a senior research astronomer in November 2004, from the University of Sydney. Simon's research interests include pulsars and the interstellar medium, and he has heroically taken on the roles of NTD and xNTD project scientist (see page 71).

Other astrophysics appointments include Enno Middelberg (Bolton/CSIRO postdoctoral fellow), Naomi McClure-Griffiths (CSIRO), Russell Edwards (pulsar postdoc, Federation Fellowship program), Roberto Ricci (AT20G postdoc, SISSA/Federation Fellowship program) and Kate Brooks (Bolton Fellow).

Departures during 2004 include D.J. Pisano (to NRL, Washington DC) and Nina Wang (to become Director of the Urumqi Observatory, China).

Events

Compared with the previous year containing the IAU General Assembly, 2004 was quieter. The major meetings were: the joint AAO/ATNF Symposium on 5 April; the MNRF Symposium on June 8; the Federation Fellowship Symposium/9th Charlene Heisler workshop on 22 – 23 November at Mt. Stromlo; and an astrofest on 8 December. Several other meetings were held such as the workshops on science from HYFAR (a concept that has morphed into the International SKA Pathfinder) and CABB. Details of the above events can be obtained by browsing the events archive on the ATNF's www pages.

Visitors program

Under the auspices of the Distinguished Visitors program, the ATNF enjoyed extended visits from many colleagues during the year including: Yi-nan Chin (Tamkang University, Taiwan), Francois Viallefond (Observatoire de Paris, France), Phil Edwards (ISAS, Japan), Trish Henning (University of New Mexico, USA), Rick Jenet (JPL, USA), Tim Cornwell (NRAO, USA), Joel Weisberg (Carleton College, USA), Renee Kraan-Korteweg (University of Guanajuato, Mexico), Eric Wilcots (University of Wisconsin-Madison, USA), Christian Henkel (MPIfR, Germany), Steve Rawlings (University of Oxford, UK) and Ned Ladd (Bucknell University, USA).

Photo: © Ettore Carretti

Marsfield scientific computing group

Software developments

Software developments targetted three main areas during 2004: support for spectroscopy with the Parkes and Mopra telescopes, automated retrieval and reduction of data from the Compact Array, and the remote visualisation of image data in support of Australia's Virtual Observatory program.

Observations with the Parkes 21-cm multibeam receiver are supported by the suite of multibeam software, principally the applications LiveData and GridZilla. New calibration algorithms were added to LiveData to support the new HI Galactic All-Sky Survey (GASS) which uses Parkes observations to study the distribution of HI in the halo and the Milky Way environment. Gridzilla has been extended to provide full support for World Coordinate System (WCS) spectral coordinates. The WCS standard for FITS has been developed with major contributions from ATNF. In a significant piece of collaborative work, support for the seven-beam ALFA instrument built for the Arecibo Observatory (page 69) was added to the multibeam software.

An interactive spectral analysis package (named ASAP) was developed during 2004. This software will be used to analyse single-dish spectral data (from the Parkes and Mopra telescopes) and is being written in response to user demand for a replacement to the ageing SPC program. Public releases of ASAP are planned for 2005 More information about the package is on the web at www.atnf.csiro.au/computing/software/asap.

The Australia Telescope Online Archive (ATOA) project which provides users with access to the full Compact Array data archive online was completed in December 2004. Compact Array data, previously stored on CD-rom at Narrabri and accessible only with manual assistance from ATNF staff at Narrabri, is now directly available though a simple web interface. Users can locate data according to observation date, sky position or project number and download the data in the ATNF native "RPFITS" format. A facility for automatically imaging archived data is being developed. The ATOA service can be accessed at http://atoa.atnf.csiro.au/.

Associated with the automated imaging software, but available as an independent service, is the Remote Visualisation Server (RVS). This system has been developed as part of the ATNF contribution to the Australian Virtual Observatory (Aus-VO). It displays large images across computer networks without the need for a full transfer of the data, and has been applied to providing remote users with visual access to ATNF image archives. More information about the ATNF VO projects is given at www.atnf.csiro.au/vo

Computer support

Computer support in the CSIRO has been centralised. CSIRO IT is now the entity which provides staff with "every-day" computer support. The ATNF headquarters in Sydney was part of the "pilot" implementation that has been in operation since July 2004. CSIRO IT will extend their services to include the rest of CSIRO (including the observatory sites) in 2005. ATNF staff contributed significant effort in the establishment of CSIRO IT to ensure that specialist support for both staff and National Facility users continues to exist. For example, in 2004 several changes to tighten network security were made, but at the same time ATNF was able to introduce new measures to simplify network access for visiting scientists.

Outreach & education

One of the strategic objectives of the ATNF is to conduct an effective outreach program. Astronomy generates a high level of public interest and is ideally suited to promoting science and to encouraging the next generation of students towards a science-based career. The key outreach goals for the ATNF are to attract young people into science, raise the profile of astronomy and science in Australia and maintain and foster good relations with local communities. In 2004 several new and renewed initiatives in education took place.

Lucyna Kedziora-Chudczer and her daughter Joanna looking at the transit of Venus on 8 June 2004. Staff and visitors enjoyed watching the transit on a beautiful afternoon, through telescopes set up on the ATNF site in Marsfield.

Teachers Workshops

A three-day workshop for teachers of junior high school science, *Astronomy from the Ground Up!* was held at Parkes in May. The 25 participants heard talks on current research topics and background theory in astronomy given by ATNF staff and other invited speakers. They took part in a range of practical activities including night time viewing of the stars with small optical telescopes. The highlight for many was a "hayride" and tour of the "Dish" on the last day. The feedback from participants was extremely positive and three-day workshops will now be held as an annual event.

The ATNF Education Officer held other workshop sessions for teachers at events around Australia including CONASTA, the national science teachers' conference in Canberra, the Queensland Astronomy Education Conference and at the Science Teachers Association of NSW Annual Conference and K-6 Science Week teachers' day at the Powerhouse Museum.

Outreach website

In May 2004 the ATNF released a new website for outreach and education. This is available at http://outreach.atnf.csiro.au.

One of the major aims of the new website is to provide educational resources in astronomy for high school students and teachers. The outreach website provides in-depth content for the *Astrophysics* section of the NSW HSC Physics syllabus. This was the first site authorised by the New South Wales Board of Studies to provide online syllabus links. With over 70 pages of content it provides students and teachers with theory, current examples, activities and questions on the entire section of the syllabus. The site also provides information about the ATNF and its history, special feature articles, visitor information and links to public astronomical facilities in Australia.

Work experience program and public talks

The ATNF work experience program had 20 high school students in 2004 with 10 each at Parkes and Narrabri. Participants spent five days at the observatories working alongside staff. Five teachers also took advantage of the Teacher Experience scheme to spend a week at Parkes and gain a greater awareness of current research, and the work of astronomers and engineers.

Many ATNF staff gave public talks or presentations at schools and community groups during the year. Such talks are a valuable way for students and the public to meet professional scientists and engineers and learn about the range of work done by the ATNF. Narrabri staff also supported a Coonabarabran Astrocamp in August with a presentation and tour of Mopra for the students.

Three ATNF staff members mentored seven school students as part of CSIRO's Student Research Scheme. The students spent a week of their holidays working on short projects under the guidance of the scientists.

Competition

A *Sport in Space* competition, held to coincide with National Science Week in August, saw two of the first-prize winners and a second-prize winner visit the Parkes radio telescope. The secondary school winners were; Hsu-Lynn Lee for *Martian Dry Ice Skiing* and Nichola Farnan and Aliki George for *Moon Diving*, both from Telopea Park School, ACT. The winner of the Primary section was Jesse Webb-Smith from Geraldton Grammar School, WA with his illustrated story *Rollo's Big Year Out*.

Jesse Webb-Smith, Chi Kit So and Hsu-Lynn Lee, winners in *Sport in Space* competition, enjoying a hayride on the Parkes telescope.

Photo: © Robert Hollow, CSIRO

One of Jesse's illustrations for his story *Rollo's Big Year Out*.

Image credit: Jesse Webb-Smith

Summer vacation program

For the 2004/2005 summer vacation program the ATNF received almost 200 applications and accepted six students. This was the first time that the ATNF program did not involve other CSIRO Divisions or other Australian institutions. A consequence of the smaller group was that the students quickly got to know each other and formed a strong group. Four of the students were based in Sydney, and two at the Parkes Observatory. The students arrived in early December and spent 10 weeks working on a broad range of research projects. They also spent several days at the Compact Array where 36 hours of observing time was allocated for three group projects. The progam ended with a half-day symposium where the students presented excellent talks on their research and the observatory trip.

Overall the student feedback on the summer vacation program was very positive with an average score, for the program as a whole, of 4.6 out of 5.

ATNF 2004/2005 summer vacation students. Back row: Peter Hansen, Nadia Davidson, Jamil Zaman, Joris Verbiest. Front row: Michael Klinkert, Ruchir Gupta.
Photo: © Shaun Amy, CSIRO

ATNF photoarchive

The ATNF historic photographic archive dates from 1939 to the mid-1990s and comprises over 100,000 individual negatives or slides, and associated prints. The collection includes images of many of the key figures in Australian radio astronomy, photographic records of key events in the history of Australian radio astronomy and images of the radio telescopes and field stations used by the Division of Radiophysics and the ATNF.

The photographic archive is being systematically scanned to create a digital archive of historic images. In 2004, approximately 2,000 images, covering the years 1971 – 1979 were scanned, bringing the digital collection to around 6,700 images in total. The scanned images are catalogued and organised using an asset-management database program, with detailed information on the images entered into the database. Additionally, approximately 600 images covering ATNF activities in 2004 were added into a separate archive of more recent images.

The digital archive is being developed as a resource for research on the history of Australian astronomy and for exhibitions, education and public relations. During the year, work progressed on a book, *The Foundations of Radio Astronomy in Australia*. This includes a large number of photographs from the collection.

Parkes outreach

The Visitors Centre at Parkes Observatory continues as CSIRO's most prominent point of personal contact with the public. In 2004, 118,000 people visited the observatory, down from 135,000 the year before. This is the first decline since the jump in numbers following the release of the movie The Dish in late 2001. Fortunately, this is not as large as the decline seen in Western New South Wales tourism generally, which many operators blame on the continuing drought, increasing petrol prices and cheaper airfares. With these challenges in mind the Visitors Centre continues to work with the local tourism industry to improve visitation numbers. In particular, the Observatory provided assistance and funding to a television and strategic marketing campaign. The campaign, featuring the Western Plains Zoo, the telescope and other attractions in the area, included television commercials in Sydney and Canberra. The telescope also appeared in New South Wales Tourism advertising across Australia. On the last weekend of August the Observatory held two Open Days. These proved very popular with over 1,100 visitors touring the telescope and 2,000 visiting the Observatory. Visitors also enjoyed special displays and helicopter rides.

In July 2004 the Central West Astronomy Society, who regularly meet at the Observatory, held an inaugural Astrofest, a festival for Amateur Astronomers. Several ATNF staff presented at seminars held at the visitor centre and at a Science in the Pub evening in Parkes.

The Dish Cafe remains a popular feature of the observatory with staff, observers and visitors. In December the owners, Andrea and Michael Carter, sold the cafe to Craig and Rochelle Smith. Andrea and Michael were involved in the establishment of the Café right from the concept, through construction, opening to its current success.

The range of items in the Visitors Centre shop was greatly expanded during the year to include childrens' books, science kits and toys. This has proved popular with visitors with the visitors spending more in the shop despite the presence of the cafe.

A partnership between the Visitors Centre and the Swinburne Centre for Astrophysics and Supercomputing continues to be productive with two new 3D shows, The Little Things and After Stars, showing in the centre and planning underway for a 3D virtual tour of the telescope.

As usual the Observatory played a role in broader ATNF outreach, hosting two summer vacation students, winners of the Sport in Space competition, work experience students and a teacher workshop in May. The Observatory also supported several CSIRO Education initiatives by promoting the Double Helix club, running science workshops for club members, and hosting several students as part of the Student Research Scheme.

Photo: © Shaun Amy

John Smith, the manager of the Parkes Visitors Centre, explaining how it all works to visitors on the azimuth track of the Parkes telescope during the Open Day held in August 2004.

Spectrum management

Spectrum management relating to the protection of radio astronomy has been an important activity for CSIRO for more than 30 years. The ATNF has continued to support such activities and at present is involved in the following areas:

- Participation in national spectrum planning and protection activities through the Australian Communications Authority (ACA). This involves not only national spectrum planning issues, but also participation in study groups of the International Telecommunications Union (ITU), and preparations for World Radio Conferences (WRC).
- Participation in regional and international meetings under the auspices of the ITU. The primary activity is the regular meetings of ITU Working Party 7D (RadioAstronomy) in Study Group 7 (Science Services). This group is responsible for all technical studies and ITU Recommendations for the protection of Radio Astronomy.
- Participation in IUCAF[1] (Scientific Committee on the Allocation of Frequencies for Radio Astronomy and Space Sciences), an inter-union committee of the IAU, URSI and COSPAR. IUCAF has been very active in ITU meetings and has had a significant impact on Study Group and WRC deliberations.
- Participation in the Radio Astronomy Frequency Committee in the Asia Pacific region (RAFCAP), which promotes awareness of radio astronomy and protection of the radio spectrum in the Asia Pacific. RAFCAP works closely with the regional spectrum management group, the Asia Pacific Telecommunity (APT).

Activities in 2004

At the ITU, most activity in 2004 was directed at starting the new study cycle that will culminate with the WRC in 2007. Critical items for radio-astronomy in this cycle are: the protection of the 1400-MHz passive band from proposed satellite services; the issue of "out-of-band" unwanted emissions encroaching into radio astronomy bands; the impact of new ubiquitous services such as UltraWideBand internet over power lines and power provision via microwave; and the definition in the ITU of radio astronomy "radio quiet zones".

IUCAF activity in 2004 was focused in the RFI-2004 workshop on RFI mitigation issues held as part of the SKA meeting in Penticton. IUCAF co-sponsored this workshop and ATNF staff contributed to both mitigation and regulation discussions. This also led in involvement on the SKA "Task Force on Regulatory Issues" to define the protection criteria for the SKA.

RAFCAP held a meeting and workshop on radio astronomy and spectrum protection in Malaysia in May 2004. This helped to promote radio astronomy and raise awareness of spectrum issues in the Asia Pacific. In particular, Malaysia does not have any radio astronomy facilities at present but is very active in radiocommunication services and satellites.

In Australia the ATNF continued to work with the ACA in defining "radio sensitive sites" around existing radio telescopes, as recommended by the Productivity Commission review in 2002. However, the focus of national activities has been work towards the definition of a radio quiet zone at the Australian candidate SKA site in Mileura WA. The necessity of such a zone has been broadly discussed with the relevant government departments. Work has been initiated with the ACA to define the regulatory mechanisms needed for the establishment of an radio quite zone for the SKA.

The ATNF has continued work on RFI measurement and characterisation at all radio telescopes. Details can be found via the ATNF spectrum coordination site at www.atnf.csiro.au/spectrum, which also provides a single point of contact for outside organisations interested in spectrum management.

[1] IUCAF was previously known as the Inter-union Commission for the Allocation of Frequencies.

Human resources and awards

The skill and commitment of its staff is amongst the greatest strengths of the ATNF, and this remained undiminished through 2004. The continued excellent operations of the existing world-class facilities for astronomical research, together with the delivery of significant upgrades to those facilities, are by far the best indication of the quality of ATNF's people.

Both the team spirit and individual excellence of ATNF staff were epitomised through ATNF Awards made during 2004 to acknowledge work of particular merit.

Two groups of staff received ATNF Divisional Awards in 2004.

Parkes Observatory staff were recognised for their "cohesive teamwork, commitment and adaptability" that has played a significant role in ensuring that the strategic alliance between the ATNF and NASA will continue. This ATNF award, in the Partner or Perish category, was specifically for ensuring the outstanding success of the Mars tracking contract between the ATNF and NASA, an outcome that clearly has a long term benefit to CSIRO through the development of a strategic alliance with another R&D provider.

The Arecibo multibeam team received an award for the successful completion of the Arecibo multibeam receiver, built by the ATNF receiver group under contract to the National Astronomy and Ionosphere Center, Cornell University. The "Go for Growth Awards" recognise achievements that open national or international markets in which CSIRO previously had a minimal presence. The award to the Arecibo Multibeam Team recognised the success of this project "of international significance ... [which] opens up the world market for ATNF built receivers and other innovative technical equipment ...[and] confirms the ATNF as the major world player in supplying such equipment to the world radio astronomy community".

Two ATNF Divisional Awards were made to individual staff, one for "Leadership" and the other for a "Lifetime Contribution":

Dr John Reynolds received an award for "Outstanding leadership as Parkes Officer-in-Charge since 1998", acknowledging his "success in forging a committed and tremendously effective team [which] routinely ensures that the Parkes Telescope operates as a world-class facility".

Dr Dick Manchester received a Lifetime Contribution Award for his "Outstanding contributions to pulsar research". His award acknowledges an "outstanding career of over 35 years beginning with the discovery of the first pulsar glitch, spanning a series of large-scale surveys which have made the Parkes radio telescope the pre-eminent instrument in the world for the discovery of pulsars, recently crowned by the first ever detection of a double-pulsar system".

Dr John Reynolds, Officer-in-Charge of the Parkes Observatory
Photo: © John Sarkissian, CSIRO

The Pilliga:

The Narrabri Observatory is located in the north-west of NSW near the outskirts of the Pilliga Forests. The Pilliga region has the largest temperate woodland left in Australia and is home to more than 900 known plant species and 200 bird species, including endangered species such as the Barking Owl and Pilliga Mouse. It is also home one to the largest koala populations in NSW.

Photo: © Barnaby Norris

Occupational health, safety and environment

During 2004, all staff and visitors to the ATNF were encouraged to consider risk management and how to integrate simple concepts of identification, assessment and control into everyday research and other activities. All projects at the planning phase now require consultation to review and control health and safety risk factors associated with the project's work activities. The ATNF management is taking a pro-active approach to prevent accidents from occuring.

The risk profile for the ATNF indicates the three most likely or significant injury factors are :

- travel to/from Sydney to rural locations;
- electrical contact; and
- manual handling.

Risk management activity is underway to address these and also to address other risk factors such as working alone, field work, emergency management, machinery and equipment, chemical storage and handling and office ergonomics.

Some interesting challenges are also presented by rural wildlife (including terrorist magpies), structural work on the antennas at considerable heights, and balancing the scientific enthusiasm of observers with fatigue management and driver safety.

Training and awareness initiatives included:

- Visitor induction revised for improved safety at Narrabri, Mopra and Parkes;
- OHS supervisor training for new supervisors ;
- Manual handling – prepare and protect your body for work activity;
- First aid refresher & defibrillator training;
- Safe handling of cryogenic liquids and compressed gases;
- Reducing our *"footprint on the earth"* – environmental awareness; and
- Think *"What if?"….not … "if only"* – proactive safety focus to foresee where an accident could occur and prevent it … rather than thinking "if only" too late!

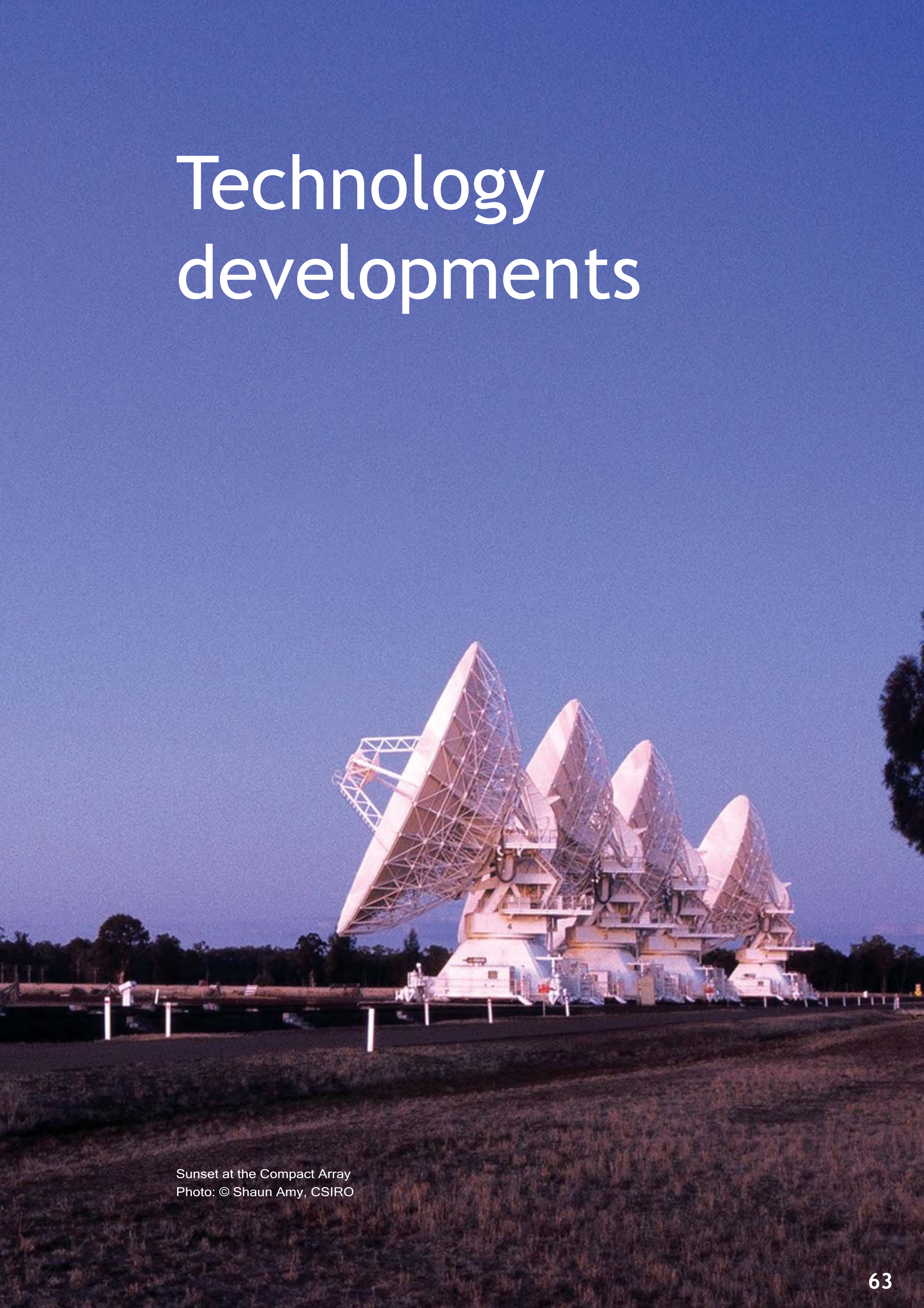
The Parkes Visitors Centre is now home to a first aid defibrillator donated by St John's Ambulance through Project HeartStart Australia with the support of NRMA Insurance. Hosting around 135,000 visitors per annum and located over 20 km from town, this is a welcome addition to the emergency facilities at the site.

During the year the ATNF established an environmental management system at each of our sites to minimise impact on the environment from ATNF activities.

At the Marsfield site, ATNF staff, in conjunction with colleagues from the ICT Centre and Industrial Physics, are working towards a reduction in resource usage and improved recycling and waste disposal methods.

At Narrabri and Parkes, environmental initiatives address more unique issues presented by a rural location. Initiatives include taking action in collaboration with the local community to minimise the bushfire risk at the Narrabri site and planting trees to create an animal corridor and prevent soil erosion at the Parkes site. Staff also maintain a keen focus on resource minimisation and recycling despite having limited country-based outlets.

Technology developments



Sunset at the Compact Array
Photo: © Shaun Amy, CSIRO

MNRF-1997

The ATNF has almost completed a set of substantial projects under the Commonwealth Government's Major National Research Facilities (MNRF) program, governed by a contract signed with the Government in February 1997. The major part of this contract was to upgrade the Australia Telescope Compact Array to work at high (millimetre-wave) frequencies in the 3- and 12-mm observing bands.

12/3-mm receiving systems for the Compact Array and Mopra

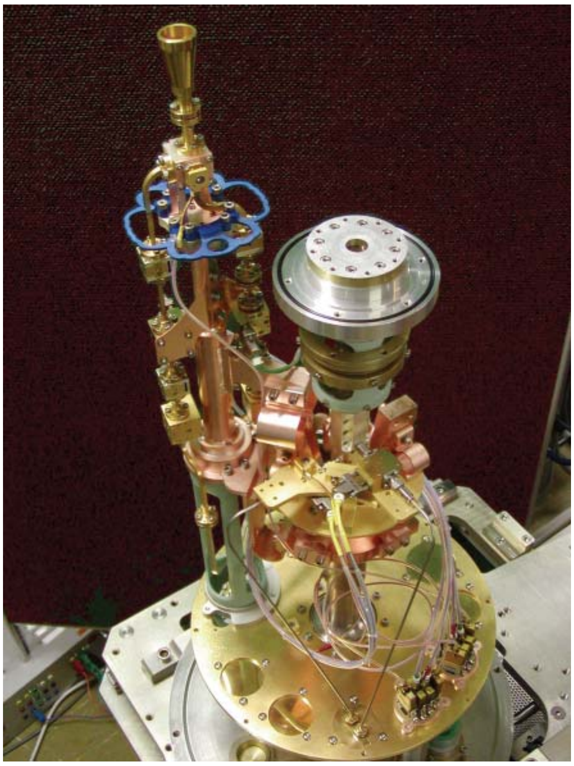
One of the major goals of the MNRF-1997 program was achieved in September 2004 when the first successful observations were obtained in the 3-mm band using five antennas of the Compact Array. The installation of the 3-mm receivers represents the final stage of the millimetre wavelength upgrade of the Compact Array.

During an extended shutdown in June 2004 three new 12/3-mm receiver packages were installed to replace prototype units, and 3-mm components were installed into two existing 12-mm receivers. Although the major installation work was completed in June, delays in the fabrication of some components in the conversion and local oscillator systems meant that the 3-mm receivers did not become operational until mid-September. Subsequent system tests and observations during October showed good performance at frequencies below 100 GHz but some degradation at higher frequencies. In particular, above 100 GHz, high noise levels in the local oscillator chain and low gain in the low noise amplifiers (LNAs), leading to poor sideband rejection, were identified as problem areas.

Since October 2004, the millimetre receiver work has concentrated on the fabrication of spare components for the Compact Array 12/3-mm receivers and on the construction of a millimetre receiver for Mopra. The spare receivers are required to support operations during the first full millimetre observing session at the Compact Array in 2005.

The Mopra 12/3-mm receiver is similar to the Compact Array systems but is modified to operate at frequencies up to 115 GHz, in order to be an effective replacement for the existing Mopra SIS receiver. In 2004 some development work was done on the local oscillator chain for the new Mopra receiver. This work is not yet completed but should provide the means of dealing with some of the high frequency problems at the Compact Array.

The other major development required for 115 GHz observations at Mopra is an improved LNA. This has been developed using an ATNF-designed coplanar waveguide indium phosphide (InP) monolithic microwave integrated circuit (MMIC) design. Following extensive cooled tests of this device, a configuration has been developed that is expected to provide satisfactory performance over the entire 85 – 115 GHz band. The new Mopra 12/3-mm receiver will be installed in 2005.



Part of a 12/3-mm receiver showing the 3-mm feed horn and the radio frequency chain to the left, and the 12-mm radio frequency chain to the right.

The Square Kilometre Array and MNRF-2001

SKA overview

The ATNF is committed to the SKA as its primary strategic development project. The SKA is a next generation radio telescope which will have a collecting area of approximately one square kilometre, making it one hundred times more sensitive than any existing radio telescope. It will operate at centimetre wavelengths. Construction is expected to start about 2012, with full operation in 2020.

The International SKA Consortium is headed by an International SKA Steering Committee (ISSC), and managed by the International SKA Director. SKA activities are coordinated by the Australian SKA Consortium Committee (ASKACC), and the ATNF is one of several institutions which contribute to ASKACC activities. In July 2003, the ATNF Director was elected to the position of ISSC vice-chair.

The Square Kilometre Array continued to enjoy a significant profile with the Commonwealth Government in 2004. Following a presentation by an Australian astronomy working group to the Prime Minister's Science, Engineering and Innovation Council, an inter-departmental Steering Group was established in November 2004 to consider and guide the Government's position on the SKA. This steering group included the ATNF Director as an observer and will receive significant input from the ATNF as part of its final report due in February 2005.

The ATNF is contributing to the international SKA project in a number of ways, including the development of technology and the evaluation of potential locations within Australia. The ATNF is also planning to build a low-frequency SKA demonstrator telescope, known as the New Technology Demonstrator (NTD).

In 2004, research and development continued on several strategic areas of SKA technology development, and on Australian SKA siting studies. Some highlights from the year are presented in this chapter.

MNRF-2001 overview

In early 2001 the government announced, as part of a new innovation statement, a *Major National Research Facilities* (MNRF) program. The Australian astronomical community decided to combine their two highest priorities for future growth into one proposal for MNRF funding. These priorities, as identified by the Australian astronomical community in the report Beyond 2000: The Way Ahead, are additional access to the optical/infrared telescopes of the Gemini project and development of the Square Kilometre Array (SKA) – the next generation radio telescope. On 21 August 2001, the Minister for Industry, Science, and Resources, Senator Nick Minchin announced the allocation of $155M under the MNRF-2001 program to fifteen successful proposals. Of these the ATNF-led proposal was granted the largest single allocation, $23.5M. The major goals of the MNRF-2001 program are to increase Australia's share in the International Gemini Telescopes, and to develop enabling technologies for the SKA.

Compact Array broadband upgrade

The Compact Array broadband (CABB) upgrade is a project that aims to develop new signal processing techniques for the SKA and to apply these techniques as an upgrade for the Compact Array. This will provide a significantly enhanced facility for National Facility users whilst also providing a test bed for SKA developments.

In 2004 work on the CABB project concentrated on the development of prototypes. The core signal processing component for the new backend being developed for the Compact Array is a polyphase digital filterbank (DFB). This device is used to split the intermediate frequency (IF) signals from each antenna into many narrow frequency channels prior to the correlation processes which form the interferometer outputs. The DFBs are implemented in large reconfigurable logic circuits called field programmable gate arrays (FPGAs).

An important milestone was reached in July 2004 when a 1024 channel, 256-MHz bandwidth DFB spectrometer, implemented on commercial FPGA prototyping hardware, was used for the first time in astronomical observations at Mopra. Although the performance of this unit was impressive, it did not meet the CABB specifications, which require a maximum of 2048 frequency channels over a 2-GHz bandwidth. Achieving this performance will only be possible with state-of-the-art custom-built hardware. In 2004, work began on a new printed circuit board (PCB). This is designed to contain seventeen large high-speed FPGA chips, which will be capable of providing the processing power needed to implement two 2-GHz DFBs. Unfortunately the complexity of this very large PCB stretched the capabilities of the PCB design software to the extent that significant delays have resulted. The projected design completion date is now mid-April 2005, with a prototype 2-GHz bandwidth DFB operating in July 2005.

The prototype 2-GHz DFB board will also be used in an 8-GHz spectrometer being constructed for the Mopra antenna. In combination with the new 12/3-mm receiver, this spectrometer will significantly enhance the performance of Mopra at millimeter wavelengths.

Monolithic microwave integrated circuit development

On-wafer testing of circuits from an InP HEMT fabrication run in 2003 was successfully completed early in 2004. Due to the higher priority of work on the Compact Array 12/3-mm receivers, the next stage of the development of these InP MMICs, involving packaging, and, in the case of the LNA designs, testing at cryogenic temperatures, was delayed until late in 2004. A coplanar waveguide 85 – 115 GHz LNA from this run has undergone extensive cooled testing and will be used in the Mopra 12/3-mm receiver. Other LNA designs, which have now been packaged and will be cool tested in 2005, are:

- 1 – 3 GHz and 4 – 12 GHz LNA MMICs, intended for an upgrade of the centimetre receivers on the Compact Array.
- 30 – 50 GHz LNA MMICs for an eventual 7-mm upgrade of the Compact Array.

A design study was carried out to determine the feasibility of producing a MMIC LNA for the New Technology Demonstrator (NTD) project, in the frequency range 800 – 1700 MHz. The study showed that InP HEMT MMICs are not the optimum technology for such a broadband low-frequency LNA. Instead, some large format transistors will be included in the next InP run, scheduled for May 2005, aimed at developing a discrete transistor LNA for the NTD.

A second stream of the MMIC project is concerned with the design of an integrated receiver MMIC. The requirement arises from the fact that future large-array telescopes such as the SKA will need very high levels of integration. The aim is to produce a MMIC which contains all components from the antenna through to digitisation and data transfer, including RF amplifiers, frequency conversion, filtering, A/D conversion and data formatting for communication. As the NTD project is an early customer for such an integrated receiver, the initial specifications have been tailored to meet the NTD requirements. The design uses RF-CMOS technology, which is well suited to the diverse functions to be implemented on the chip. Design of the MMIC was well advanced by the end of 2004.

ASKACC SKA national site selection

In September 2004, the International SKA Project Office (ISPO) issued a Request for Proposals (RFP) for the siting of the SKA. Conditions in the RFP required the ASKACC to proceed immediately to select one candidate Australian site from three candidate sites presented in an initial site analysis document submitted to the ISPO in May 2003. On 5 November 2004, ASKACC determined that the Western Australian candidate SKA site, centred on Mileura Station, best satisfied the requirements and decided that the WA site should be the national candidate SKA site proposed to the ISPO.

The remotely operating radio-frequency monitoring set-up to be deployed at Mileura Station during 2005. Note the antenna mount on the right as well as the solar-powered radio-frequency-screened trailer containing the data collection equipment.
Photo: Ron Beresford, ATNF

ASKACC site submission

Radio-frequency monitoring program

The deadline for responses to the Request for Proposals (RFP) for SKA siting is 31 December 2005. One requirement of the RFP is that site proponents conduct 12 months of radio-frequency monitoring on the candidate site by March 2006. Following ASKACC's selection of Mileura Station, WA, as the preferred Australian core site for the SKA, radio frequency interference (RFI) measuring equipment was put together during the second half of 2004 in order to meet the ISPO's requirements for long-term site monitoring. A fully functional mobile RFI measuring station was prepared for installation at the Mileura site in January 2005.

The station includes a solar powered trailer containing an RFI screened enclosure housing a broadband high frequency resolution spectrum analyser and control and data acquisition computer. This instrumentation is connected to a number of antennas covering the frequency range 50 MHz to 26.5 GHz.

Radio-quiet zone

A further requirement of the RFP is that site proponents indicate the strategy proposed for establishment of a radio-quiet zone for the SKA array-stations, to protect operation of the telescope from increase in man-made radio-frequency emissions. After a Government forum of key stakeholders, held at Parliament House in August 2004, negotiations are continuing between ATNF, the ACA and the Government of Western Australia to develop a procedure for establishment of a radio-quiet zone.

The NTD and the xNTD

In December 2004, the ATNF obtained approval from the Australian Astronomy Board of Management (and subsequently from DEST) for the revised NTD project plan. This will establish a technical radio astronomy demonstrator on the Mileura site (provided that technical risks inherent in any such project can be addressed over the next year). During the year, the ATNF also explored additional funding options to enable a powerful scientific facility, known as the extended NTD, or "xNTD", to be established on the site by 2009. By this means Australia plans to establish a radio astronomy presence on the Australian site in time to influence international site choice, and to establish technical lead and local capability to support a promising SKA technology in time to influence the SKA technology choice scheduled for 2008 – 2009.

Early in 2004, the Luneberg Lens concept was withdrawn as a candidate SKA design. The ATNF has continued to work on alternative SKA technology options as part of the NTD project of the MNRF program. The Australian SKA community decided that the NTD will be a technology demonstrator for wide field-of-view, low-frequency SKA solutions. The NTD project is now focused on the development of focal plane array technology in association with parabolic reflectors for the antenna systems. The project has successfully completed a concept design review and is aiming towards a critical design review in December 2005.

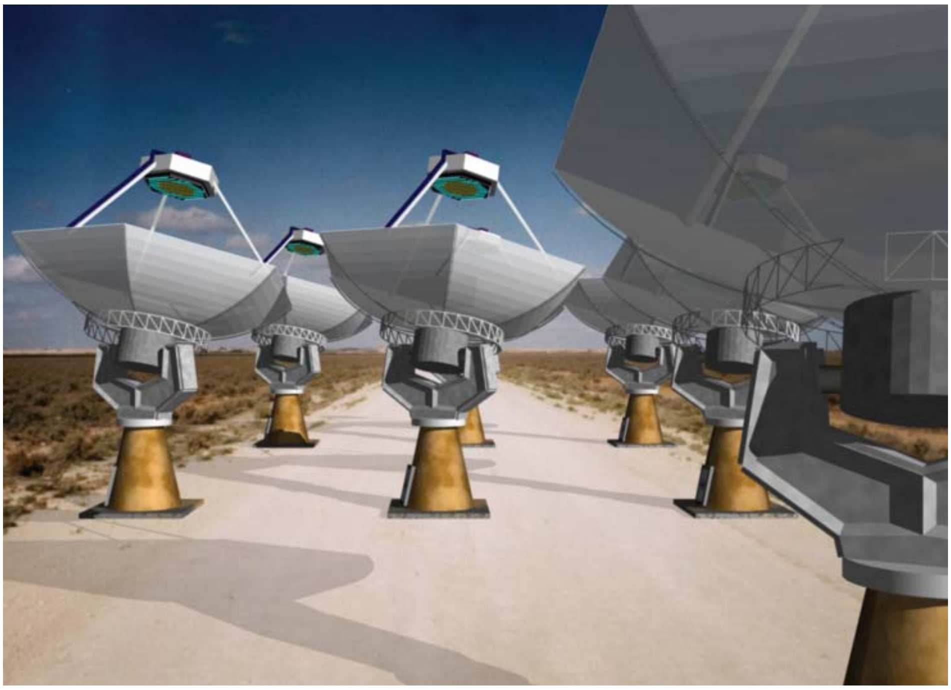
The technology objectives of the NTD are to provide:

- a 10 x 10 focal plane array operating over the frequency range 800 – 1700 MHz, with two parabolic reflector antennas;
- RFI and spectral line ripple cancellation using the focal plane array (commercial applications are possible);
- radio frequency and intermediate frequency beam-forming to give extremely wide fields of view;
- polarisation purity;
- correlation of the signals from a large number (at least 20) of independent beams;
- wideband operation with low RFI levels;
- use of the receiver-on-a-chip technology being developed under the MNRF MMIC project; and
- proof of infrastructure in a remote desert environment (power supply, on-site data transport).

The xNTD project aims are to use and further develop the technology provided by the new technology demonstrator project to build a state-of-the-art radio telescope with sufficient surface area to do carry out new scientific research programs.

The NTD will consist of two small dishes and is largely an experimental platform to develop focal plane arrays and beam-forming technology. The xNTD is planned to have at least twenty parabolic dishes, each with a 48 square degree field of view. The total surface area of this array will be larger than that of the Parkes radio telescope. With full cross correlation of all antennas, the xNTD will be highly competitive with other current and planned instruments and in particular will be ideal for large-scale surveys.

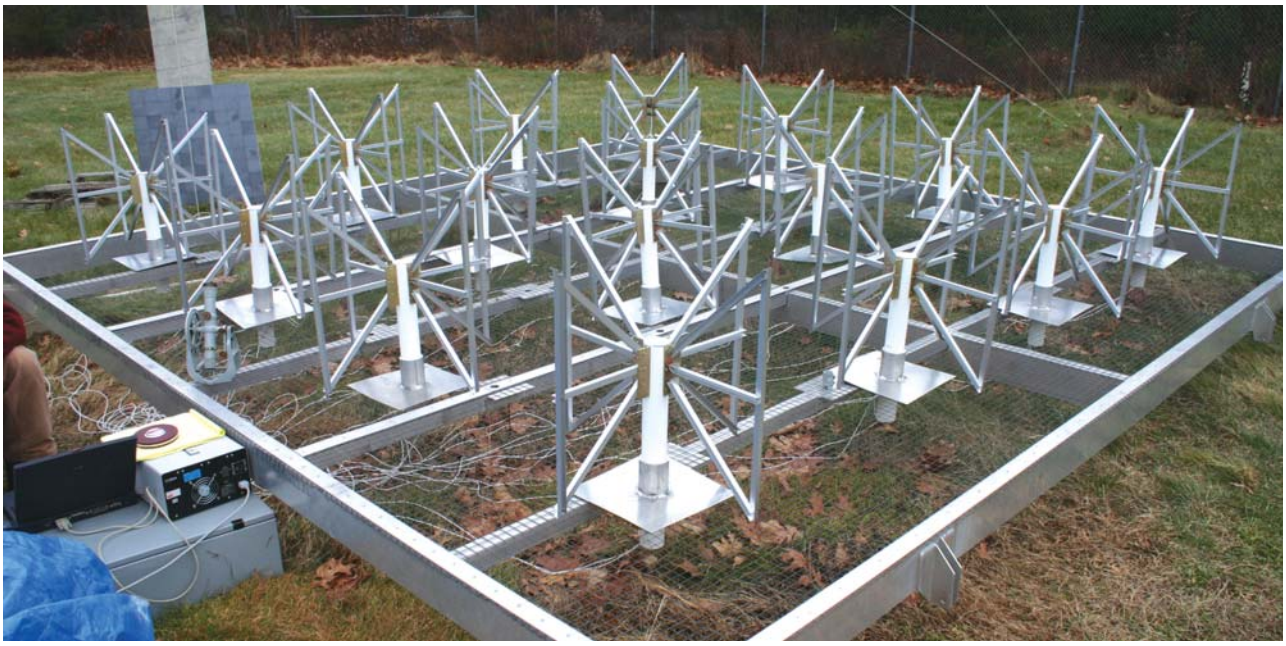
In addition to the technology from the NTD, the xNTD will require state-of-the-art design for the manufacture of cheaper dishes, a high speed correlator, advanced telescope control software, and new data processing (post-correlator) software that can cope with the enormous quantity of data that will be produced.



A computer visualisation of the technology being developed for the New Technology Demonstrator project. Each parabolic dish is 15 m diameter.
Image credit: Chris Fluke, Swinburne University

Other experiments

Other groups in Australia and overseas are also interested in siting radio astronomy experiments on an established Australian radio-quiet site. The international experiment with most advanced links with Australia thus far is the Low Frequency Demonstrator (LFD) project being led by MIT Haystack Observatory from the US. The ATNF and Haystack Observatory are collaborating on aspects of the NTD and LFD development. In addition, a consortium of Australian universities led by the University of Melbourne is being formed to further support the LFD. The LFD is currently dependent on US National Science Foundation funding.



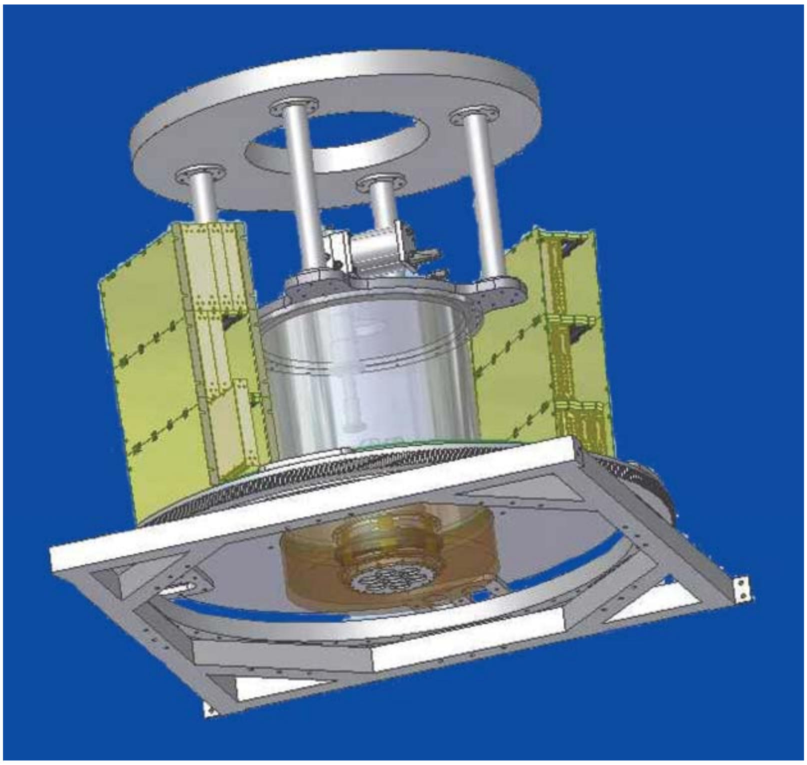
One antenna tile (approximately six square metres) of the Low Frequency Demonstrator array project being let by MIT Haystack Observatory in the US. The project team hope to deploy some prototype antennas for testing at Mileura Station during 2005.
Photo: Colin Lonsdale, MIT

Other developments

The 6-GHz Parkes multibeam receiver

A new multibeam receiver for the Parkes radio telescope is being developed. This project is a collaboration between ATNF and Jodrell Bank, UK. The receiver will be a seven-beam survey instrument in the frequency range 6.7-GHz, used for spectral line (methanol and excited OH) and pulsar observations. A particular design requirement is that the receiver should be capable of installation on both the Parkes and Jodrell Bank (Lovell) telescopes. ATNF will provide the major mechanical components, i.e. the feed, dewar and cryogenics as well as bias electronics and cable assemblies, while Jodrell Bank will provide the LNAs and first down-conversion electronics. At Parkes the receiver will share backend components such as the correlator and pulsar processor with the HI multibeam receiver.

Design of the receiver progressed well in 2004, with major mechanical assemblies now in production. The receiver is due for initial installation at Parkes in October 2005.



A 3-D design drawing of the Parkes/Jodrell Bank seven-beam 6-GHz multibeam receiver. The seven feed horns can be seen in the centre at the bottom. The first conversion electronics assemblies sit to the side of the dewar, with the cable rotator tray above.

External contracts

Arecibo 21cm multibeam receiver

ALFA – the Arecibo L-band Feed Array, is a seven-beam 21-cm multibeam receiver designed and built by the ATNF, under contract to NAIC, for the Arecibo radio telescope. The receiver is an adaptation of the highly successful Parkes 13-beam 21-cm multibeam receiver. ALFA was installed on schedule in April 2004. ATNF engineers Graeme Carrad and Pat Sykes travelled to Arecibo to participate in the installation and acceptance testing, all of which was achieved with commendable outcomes. Since installation, the receiver has met all specifications. It is now in full operation for sensitive large-scale surveys of the sky.

NASA Deep Space Network array design studies

NASA is investigating using antenna arrays as a replacement for their existing deep space network communications antennas. CSIRO was invited to contribute to a design study being led by JPL to investigate possible next-generation deep space network arrays. A contract was established in September 2003 between JPL, ATNF and the CSIRO ICT Centre with CSIRO required to provide:

- A study reviewing the overall systems design for the JPL prototype array electronics implementation and providing alternative solutions. The scope of the study covered antenna feed systems, low noise receiver systems, down-converters, inter-array data transmissions, digital beam-forming systems and control and monitoring systems.

- A study identifying appropriate sites for a DSN array in Australia. This was compiled with input from State and Territory governments.
- An investigation of options for providing a communications uplink to a spacecraft. The major component is a detailed examination of several calibration schemes that ensure that an uplink array would be correctly phased.
- A costing and implementation study for an array at nominated sites in Australia.

This contract was successfully completed in October 2004.

ALFA almost at its final destination, being lifted into the focus cabin of the Arecibo radio telescope. ALFA is the small object hanging above the background saddle.

Photo: © Graeme Carrad, CSIRO

Appendices

The Parkes radio telescope under construction in 1960. The telescope has been used for observations since 1961.
Photo: © CSIRO

A: Financial information

Expenditure (actual) 2003-2004

Expenditure (actual) 2003-2004	A$1,000s
Operation of the Narrabri (Paul Wild) Observatory[1]	3,296
Operation of the Parkes Observatory[2]	2,844
Research support Marsfield (ATNF contribution)[3]	1,862
Engineering, development and asset replacement	2,330
External contracts	1,432
Office of the Director	882
Astrophysics program	1,476
Computing	1,151
National Facility support	617
MNRF-1997	–212
MNRF-2001	4,589
Federation Fellowships	1,152
Corporate writeback	1,751
Depreciation	4,700
TOTAL	27,870

Revenue (actual) 2003-2004

Direct appropriation	17,397
Research and services revenue	9,768
Other external revenue	580
Asset replacement reserve draw down	1,200
Corporate writeback	1,751
TOTAL	30,696

Notes:

1. Includes the operation of the Narrabri Observatory Visitors Centre and the Mopra Observatory.
2. Includes the operation of the Parkes Observatory Visitors Centre.
3. The ATNF shares its Sydney headquarters with CSIRO Industrial Physics.

B: Staff list, January to December 2004.

Marsfield

J Archer (Finance & Administration)
P Axtens (Receivers)
A Barends (Office of Director, PA)
R Beresford (Electronics)
R Bolton (Receivers)
P Bonvino (Machine Shop)
M Bourne (Machine Shop)
M Bowen (Receivers)
B Boyle (ATNF Director)
K Brooks (Bolton Fellow/Astrophysics)
W Brouw (Astrophysics/Computing)
A Brown (Electronics)
M Calabretta (Computing)
G Carrad (Receivers)
J Caswell (Astrophysics)
A Chandra (Computing)
J Chapman (Head, National Facility Support)
R Chekkala (Electronics)
A Chippendale (Electronics)
G Cook (Machine Shop)
E Davis (Electronics)
M Death (Machine Shop)
V Drazenovic (National Facility Support)
A Dunning (Receivers)
D Ede (Finance & Administration)
R Edwards (Postdoctoral Fellow/Astrophysics)
R Ekers (Federation Fellow)
T Elton (Electronics)
R Ferris (Electronics)
D Gain (Receivers)
G Gay (Receivers/overseas)
R Gough (Receivers)
G Graves (Receivers)
E Hakvoort (Receivers)
P Hall (Electronics)
G Hampson (Electronics)
G Hobbs (Bolton Fellow/Astrophysics)
M Hobbs (Astrophysics)
R Hollow (National Facility Support)
P Howson (Finance & Administration)
T Huynh (Machine Shop)
O Iannello (Machine Shop)
C Jackson (Business Development Manager)
S Jackson (Electronics)
S Johnston (Astrophysics)
A Jones (OHS&E)
E Kachwalla (National Facility Support)
H Kanoniuk (Receivers)
M Kesteven (Astrophysics/Engineering Research)
V Kilborn (Swinb/ATNF/ARC CSIRO Fellow)
N Killeen (Head, Computing)
B Koribalski (Astrophysics)
M Leach (Electronics)
J Lie (Receivers)
S Little (Astrophysics/Federation Fellow PA)
M Marquarding (Computing)
S Magri (Electronics)
R Manchester (Federation Fellow)
G Manefield (Engineering PA)
M McAuley (Executive Officer)
N McClure-Griffiths (Bolton/CSIRO Fellow/Astrophysics)
D McConnell (General Manager)
V McIntyre (Computing)
E Middelberg (Bolton/CSIRO Fellow/Astrophysics)
R Moncay (Machine Shop)
G Moorey (Receivers)
T Murphy (Computing)
R Norris (Deputy Director)
R Ojha (Astrophysics)
W Orchiston (National Facility Support)
J Ott (Bolton Fellow/Astrophysics)
S O'Toole (Human Resources)
C Owen (National Facility Support)
B Parsons (Assistant Engineering Manager)
C Phillips (Bolton Fellow/Astrophysics/Engineering)
D Pisano (Bolton Fellow/Astrophysics)
G Powell (Receivers)
R Ricci (AT20G Postdoctoral/Astrophysics)
L Reilly (Receivers)
P Roberts (Electronics)
S Saunders (Electronics)
G Scott (LBA Correlator)
H Sim (National Facility Support)
L Staveley-Smith (Head, Astrophysics)
M Storey (SKA)
P Sykes (Receivers)
P Tokachichu (Computing)
A Tzioumis (Astrophysics/LBA)
T Uppal (Astrophysics)
N Wang (ATNF/USyd Postdoctoral Fellow)
B Wilson (Finance & Administration)
W Wilson (Head, Engineering)
T Wong (UNSW/ATNF ARC/CSIRO Fellow)
M Wright (Receivers)

Marsfield Staff shared with CSIRO Industrial Physics

S Clark (Canteen)
O D'Amico (Store)
C Duffy (Reception)
C Hodges (Reception)
A Joos (Library)
K Lambert (Store)
B Wrbik (Canteen)
P Cooper (Engineering Services)
W Finch (Engineering Services)
M McDonald (Site Services)
P Sharp (Engineering Services)
C van der Leeuw (Library)
B Wilcockson (Assistant Engineering Manager)

Narrabri

D Aboltin (Electronics)
B Adamson (Administration)
R Behrendt (Electronics)
D Brennan (Lodge)
D Brodrick (Computing)
D Brooke (Electronics)
M Dahlem (Operations & Astrophysics)
E Darcey (Antennas & Site Services)
A Fairfull (Administration)
K Forbes (Administration)
C Gay (Administration)
J Giovannis (Computing)
M Hill (Electronics)
B Hiscock (Deputy Officer-in-Charge)
J Houldsworth (Visitor Services)
B Johnson (Antennas & Site Services)
P Kelly (Visitor Services)
T Kennedy (Visitors Centre)
S Koljatic (Electronics)
M Laxen (Electronics)
C Leven (Antennas & Site Services)
J McFee (Electronics)
M McFee (Visitor Services)
P Mirtschin (Electronics)
S Munting (Electronics)
M Rees (Lodge)
S Robertson (Operations & Astrophysics)
D Rowe-McDonald (Visitor Services)
L Saripalli (Operations & Astrophysics)
R Sault (Officer-in-Charge)
R Subrahmanyan (Operations & Astrophysics)
G Sunderland (Antennas & Site Services)
B Tough (Electronics)
E Troup (Computing)
M Voronkov (Computing)
R Wark (Operations & Astrophysics)
N Webster (Antennas & Site Services)
J Wieringa (Library)
M Wieringa (Computing)
C Wilson (Lodge)
T Wilson (Antennas & Site Services)

Parkes

L Ball (Deputy Officer-in-Charge/HR Manager)
G Ballantyne (Visitors Centre)
S Brady (Site Services)
D Catlin (RF systems)
J Cole (Lodge)
L Coleman (Quarters)
J Crocker (Site Services)
B Dawson (RF Systems)
R Eslick (Site Services)
A Evans (Site Services)
G Freeman (Administration)
C Grover (Site Services)
A Hockings (Site Services)
J Hockings (PA/Visitors Centre)
S Hoyle (Computing)
A Hunt (Electronics/Servo)
S Ingram (Lodge/Site Services)
J Lees (Administration Trainee)
R Lees (Site Services)
D Lewis (Operations)
S Mader (Operations)
L Milgate (Visitors Centre)
B Preisig (Electronics/Servo)
L Price (Visitors Centre)
K Reeves (Site Services)
J Reynolds (Officer-in-Charge)
T Ruckley (Research Support)
J Sarkissian (Operations)
J Smith (Visitors Centre Manager)
M Smith (RF systems)
G Spratt (Computing)
T Trim (Visitors Centre)
B Turner (Site Services)
S Turner (Site Services)
K Unger (Visitors Centre)
J Vera (RF Systems)
R Walker (Visitors Centre)
T Wilkie (Visitors Centre)
L Williams (Site Services)

Canberra

F Briggs ANU/ATNF (Astrophysics/SKA)
D Jauncey (Astrophysics)
J Lovell (Astrophysics/Tidbinbilla)

C: Committee membership

ATNF Steering Committee at 31 December 2004

Chairman

Prof Matthew Bailes, Swinburne University of Technology

Secretary

Mrs Anne Barends, ATNF

Members

Ex-Officio

Prof Brian Boyle, Director, ATNF, CSIRO

Dr Matthew Colless, Director, Anglo-Australian Observatory

Dr Gerry Haddad, Chief, CSIRO Industrial Physics

Dr Ron Sandland, Deputy Chief Executive, CSIRO

Astronomers

Prof Frank Briggs, Research School of Astronomy and Astrophysics, Australian National University

Prof Anne Green, School of Physics, University of Sydney

International advisers

Dr Norio Kaifu, Director General, National Astronomical Observatory of Japan, Tokyo, Japan

Prof Phil Diamond, Director Merlin and VLBI National Facility, Jodrell Bank, UK

Dr Ken Kellermann, National Radio Astronomy Observatory, Charlottesville, USA

Industry

Dr Robert Frater, Vice President, Innovation, Res Med, North Ryde

Dr Stephen Rotheram, Executive Vice President, Network, Singapore Telecommunications, Singapore

Australia Telescope Users Committee

January to December 2004

Chair

Dr S Tingay, Swinburne University

Secretary

Dr J Lovell, ATNF, CSIRO

Members

Dr D Barnes, University of Melbourne

Dr J Bland-Hawthorn, Anglo-Australian Observatory

Dr A Burgasser, University of California, Los Angeles, USA

Dr S Ellingsen, University of Tasmania

Dr B Gibson, Swinburne University

Mr A Hotan*, Swinburne University

Dr M Hunt, University of New South Wales

Dr H Jerjen, Research School of Astronomy & Astrophysics, Australian National University

Dr S Johnston, University of Sydney/ATNF, CSIRO

Dr N McClure-Griffiths, ATNF, CSIRO

Dr J Ott, ATNF, CSIRO

Dr E Sadler, University of Sydney

Mr M Wardle, Macquarie University

Mr B Warren*, Research School of Astronomy & Astrophysics, Australian National University

Dr T Wong, ATNF, CSIRO

Dr C Wright, Australian Defence Force Academy

* student member

Australia Telescope Time Assignment Committee

January to December 2004

Chair

Prof B Schmidt, Research School of Astronomy & Astrophysics, Australian National University

Executive secretary

Dr J Chapman, ATNF, CSIRO

Members

Ex-Offico

Prof B Boyle, Director, ATNF, CSIRO

Dr J Reynolds, Officer-in-Charge, Parkes Observatory, ATNF, CSIRO

Dr R Sault, Officer-in-Charge, Narrabri Observatory, ATNF, CSIRO

Voting members

Dr P Francis, Research School of Astronomy & Astrophysics, Australian National University

Dr A Green, University of Sydney

Dr A Melatos, University of Melbourne

Prof J Storey, University of New South Wales

Dr L Staveley-Smith, ATNF, CSIRO

Dr W Walsh, University of New South Wales

D: Observing programs

Observations made with the Australia Telescope Compact Array January to September 2004

Observers	Affiliations	Program	Number	Hours
Sault, Wark, Wieringa	ATNF, ATNF, ATNF	Calibrators at 12 and 3 mm	C007	20.5
Staveley-Smith, Manchester, Gaensler, Tzoiumis, Kesteven	ATNF, ATNF, CfA, ATNF, ATNF	SNR 1987A	C015	92
Duncan, Koribalski, White	ATNF, ATNF, UMar	High-spatial-resolution observations of Eta Carinae	C186	24.5
Voronkov, Ramsdale, Ellingsen	ATNF, UTas, UTas	Methanol masers seen projected against ultra-compact HII regions	C291	35
Johnston, Wang, Manchester	USyd, ATNF/USyd, ATNF	Unpulsed transient emission from the PSR B1259-63 system	C326	63.5
McClure-Griffiths, Dickey, Gaensler, Haverkorn, Green	ATNF, UMinn, CfA, CfA, USyd	The SGPS II: the Galactic center	C596	187
Benaglia, Koribalski	IAR, ATNF	The radio spectrum of HD 93129A	C678	16
Gallo, Fender, Corbel, Tzioumis	UAm, UAm, CEA, ATNF	Simultaneous ATCA and Chandra observations of GX 339-4	C767	36
Dodson, Voronkov, Ellingsen	ISAS, ATNF, UTas	Coincidence of 4765-MHz OH maser emission with other transitions	C798	2.5
Lovell, Jauncey, Godfrey, Bicknell, Marshall, Schwartz, Gelbord, Perlman, Worrall, Birkinshaw, Murphy, Preston	ATNF, ATNF, RSAA, RSAA, MIT, CfA, MIT, UMar, UBr, UBr, JPL, JPL	High angular resolution imaging of AGN with X-ray jets	C890	104
Ryder, Koribalski, Bekki	AAO, ATNF, UNSW	Mapping the diffuse gas around NGC 2442	C933	45.5
Hunstead, Johnston, Cotter, Morganti, Sadler	USyd, USyd, UOx, NFRA, USyd	The radio galaxy B1221-423: forming an AGN in a merger?	C956	24.5
Beasley, Staveley-Smith, Claussen, Marvel	Caltech, ATNF, NRAO, AAS	A water maser survey of Halpha-bright regions in the SMC	C973	16
Brocksopp, Corbel, Fender, Hannikainen, Tzioumis	MSSL, CEA, UAm, UHel, ATNF	Radio jets in recurrent and new black hole X-ray transients	C989	NAPA
Wright, Wilner, Bourke, Jorgensen, van Dishoeck, Wong	ADFA, CfA, CfA, LO, LO, ATNF/UNSW	Further 3-mm studies of pre-planetary disks	C996	37
Bignall, Tzioumis, Landt, Padovani	NFRA, ATNF, STScI, STScI	Observations of a faint sample of BL Lac objects	C1010	32.5
Wayth, Webster	UMelb, UMelb	Snapshots of southern gravitational lens candidates	C1037	55
Ekers, Calabretta, Jackson, Kesteven, Phillips, Ricci, Sadler, Staveley-Smith, Subrahmanyan, Walker, Wall, Wilson, Zotti	ATNF, ATNF, ATNF/RSAA, ATNF, ATNF, OAT, USyd, ATNF, ATNF, ATNF/USyd, UOx, ATNF, OAP	Wideband 20-GHz sky survey	C1049	489.5
Ryder, Sadler, Subrahmanyan, Weiler	AAO, USyd, ATNF, NRL	The radio-luminous supernova 2001ig	C1066	24
Fender, Spencer, Tzioumis, Jonker, van der Klis	UAm, JB, ATNF, IoA, UAm	The secular evolution of the ultrarelativistic jet source Circinus X-1	C1073	12
Hoare, Lumsden, Busfield, Oudmaijer, Burton	ULeeds, ULeeds, ULeeds, ULeeds, UNSW	Massive star formation in the Galaxy: Red MSX sources	C1088	102
Jones	ATNF	Flaring FR I jets in radio galaxies	C1096	11
McConnell, Subrahmanyan, Carretti, Cortiglioni, Poppi, Sault	ATNF, ATNF, IASF-CNR, IASF-CNR, IRA-CNR, ATNF	Sky polarisation at 5 GHz	C1109	55
Bouchard, Jerjen, DaCosta, Staveley-Smith, Freeman	RSAA/ATNF, RSAA, RSAA, ATNF, RSAA	HI survey of dwarf galaxies in the CenA and ScI groups	C1133	49.5
Buxton, Bailyn, Tzioumis	Yale, Yale, ATNF	Jet energetics in low-mass X-ray binaries	C1150	NAPA

Purcell, Minier, Bontemps, Herpin, Caswell, Wong, Jones, Burton, Hunt	UNSW, CEA, CEA, CEA, ATNF, ATNF, ATNF, UNSW, UNSW	A multi-frequency survey of NGC 3576	C1158	24
Voronkov, Sobolev, Ellingsen, Obstrovskii	ATNF, USU, UTas, USU	6.7GHz-methanol maser at OMC-1	C1162	9
White, Duncan, Chapman, Koribalski	UMar, ATNF, ATNF, ATNF	High-resolution millimeter images of the Eta Carinae system	C1167	36
Bernardi, Carretti, Cortiglioni, Sault, Subrahmanyan, Poppi, McConnell, Kesteven, Haverkorn	IASF/CNR, IASF/CNR, IASF/CNR, ATNF, ATNF, IRA/CNR, ATNF, ATNF, CfA	Observations of galactic polarisation in the DASI field at 20 cm	C1168	79
Maddison, Burton, Rathborne	Swinb, UNSW, UBos	3-mm observations of protostellar disks in Chamaeleon 1	C1173	8
Gibb, Hoare, Purcell, Burton	UMar, ULeeds, UNSW, UNSW	Searching for disks around massive young stellar objects	C1176	33
Sadler, Hunstead, Jackson, Couch, Bekki	USyd, USyd, ATNF, UNSW, UNSW	Timescales for triggering radio galaxies	C1183	37
Ott, Wong, Mizuno, Weiss, Johansson	ATNF, ATNF/UNSW, UNag, IRAM, OSO	Ionisation fractions of dense molecular cores in the Magellanic Clouds	C1187	48
Caswell	ATNF	Pilot study for a 22-GHz water maser survey	C1189	7.5
Corbel, Fender, Tzioumis, Kaaret, Orosz, Tomsick	CEA, UAm, ATNF, CfA, UCSD, UCSD	Searching for large scale radio jets in a microquasar	C1199	25
Kaaret, Corbel, Tzioumis, Fender	CfA, CEA, ATNF, UAm	The fossil relativistic jets of 4U 1755-33	C1211	10.5
Gelfand, Gaensler, Slane, Rakowski, Haverkorn, Hughes, Dickey, McClure-Griffiths, Green	CfA, CfA, CfA, CfA, CfA, URutg, UMinn, ATNF, USyd	A search for pulsar nebulae in small supernova remnants	C1213	135
Klamer, Sadler, Ekers, Hunstead	USyd/ATNF, USyd, ATNF, USyd	Cool molecular gas at high redshift (II) - TN 0924-2201	C1214B	88.5
Subrahmanyan, Saripalli, Ekers, Safouris, Bicknell, Boyle	ATNF, ATNF, ATNF, RSAA/ATNF, RSAA, ATNF	Giant radio galaxies and the intergalactic medium	C1217	12.5
Chung, van Gorkom, Bureau, Koribalski	UClmba, UClmba, UClmba, ATNF	A kinematic study of spirals with counter-rotating gas	C1218	12
Ott, Jackson, Norris, Jogee, Wiklind, Huynh, Koekemoer, Mobasher	ATNF, ATNF, ATNF, STScI, STScI, RSAA, STScI, STScI	Molecular gas in the reionisation era	C1223	72.5
Ott, Henkel, Weiss, Walter	ATNF, MPIfR, IRAM, NRAO	Temperature variations of dense molecular gas in starburst cores	C1224	47
Wong, Ott, Koribalski, Sault	ATNF, ATNF, ATNF, ATNF	Millimetre fluxes for calibrators	C1225	8.5
Barnard, Wong, Pierce-Price, Blain, Richer	JAC, ATNF/UNSW, JAC, Caltech, CL	Continued observations of an isolated prestellar fragment	C1226	10
Abada-Simon, Desmurs, Serber, Meintjes, Hoffman, Terada, Hudec,	OPM, IRAM, IAPRAS, UFSSA, UFSSA, IFCTR, IFCTR	Coordinated observations of nonthermal flares from AE Aqr	C1231	14.5
Dubner, Giacani, Reynoso, Decourchelle, Ballet	IAFE, IAFE, IAFE, CEA, CEA	The composite supernova remnant G0.9+0.1	C1233	12
Migliari, Fender, Lommen, Tzioumis, van der Klis	UAm, UAm, UAm, ATNF, UAm	Disc-jet coupling in X-ray binaries at high accretion rates	C1234	12
Migliari, Fender, Tzioumis, van der Klis	UAm, UAm, ATNF, UAm	Disc-jet coupling in (atoll) neutron star X-ray binaries	C1236	NAPA
Brown, Ambruster	CASA, UVil	Radio emission from Pleiades-age K dwarfs vs. rotation	C1237	32.5
Serra, Trager, van der Hulst, Oosterloo, Morganti, Sadler	KI, KI, KI, NFRA, NFRA, USyd	The evolution of gas-rich early-type galaxies	C1238	114
Kilborn, Forbes, Koribalski, Barnes	Swinb, Swinb, ATNF, UMelb	The evolution of gas in galaxy groups	C1239	48
Urquhart, Thompson, White, Morgan	UKC, UKC, UKC, UKC	Bright-rimmed clouds: ammonia search for protostellar cores	C1240	73
Boyle, Norris, Jackson, Koekemoer, Condon, APEX Team, SWIRE Team, XMM Team	ATNF, ATNF, ATNF, STScI, STScI, ROE, IPAC, OABol	Wide-area deep radio observations of SWIRE/APEX fields	C1241	212

Rupen, Miller, Hunstead, Steeghs	NRAO, CfA, USyd, CfA	Radio monitoring during deep XMM observations of GX 339-4	C1242	56
Wilcots, Grcevich	UWis, UWis	HI mapping of Magellanic Spirals: the origin of asymmetry	C1244	24.5
Stanimirovic, van Loon, Oliveira, Heiles, Staveley-Smith	UCB, UKeele, UKeele, UCB, ATNF	Cold, bullet-like clouds in the Small Magellanic Cloud	C1245	49
Pillai, Wyrowski, Menten	MPIfR, MPIfR, MPIfR	Methanol masers toward massive cold cores	C1246	12
Johnston-Hollitt, Vogt, Hunstead	LO, MPIfR, USyd	Detailed study of the double relic cluster A3376	C1247	48
Gomez, Lovell, de Gregorio-Monsalvo, Miranda, Torrelles	LAEFF, ATNF, LAEFF, IAC, IEEC	Spectral index of the planetary nebula IRAS 17347-3139	C1248	5
Bower, Tzioumis, Roberts, Yusef-Zadeh, Falcke	UCB, ATNF, NWU, NWU, NFRA	Coordinated radio through gamma-ray observations of Sgr A*	C1249	52
Phillips, Beuther	ATNF, CfA	Methanol masers: tracers of high mass protostars and discs?	C1250	38
Phillips, van Langevelde, Ellingsen	ATNF, JIVE, UTas	Survey of H_2CO towards massive star forming regions	C1251	42
Slee, Willes, Wilson	ATNF, USyd, ATNF	Coherent radio emission for RS CVn binaries	C1252	9.5
Ott, de Blok, Walter, Brinks	ATNF, UCardiff, NRAO, INAOE	The HI structure of southern local group dIrrs	C1253	111
Soderberg, Kulkarni, Frail, Subrahmanyan, Wieringa	Caltech, Caltech, NRAO, ATNF, ATNF	The supernova/gamma-ray burst connection	C1254	19
Faulkner, Lyne, Kramer, Manchester, D'Amico, Possenti	JB, JB, JB, ATNF, CAO, CAO	Position of a new relativistic double neutron star system	C1255	8
Wu, Hannikainen, Feng, Tennant, Zhang	MSSL, UHel, NSSTC, MSFC, UAl	Plateau to flare transition in the microquasar GRS 1915+105	C1256	NAPA
Kanekar	KI	A search for OH megamasers in ultra-luminous infrared galaxies	C1257	78.5
Corbel, Fender, Tzioumis, Nowak, Markoff, Bailyn + 6 others	CEA, UAM, ATNF, MIT, MIT, Yale	NAPA observations of GX 339-4 and XTE J1550-564 in the low-hard state	C1258	NAPA
Reynoso, Johnston, Dubner, Giacani, Green	IAFE, USyd, IAFE, IAFE, USyd	Imaging of the pulsar wind nebular in Vela Junior	C1259	25.5
Benaglia, Ribo, Combi, Johnston, Mirabel	IAR, CEA, UJaen, USyd, CEA	The nature of the X-ray source AX J1639.0-4642/3EG J1639-4702	C1260	12
Subrahmanyan, Ekers, Saripalli, Sadler	ATNF, ATNF, ATNF, USyd	The low-surface-brightness radio source population	C1261	50.5
Kranz, Freeman, Koribalski, Wong, Bland-Hawthorn, Ryder	RSAA, RSAA, ATNF, ATNF, AAO, AAO	A multi-wavelength study of isolated, asymmetric sprial galaxies	C1262	97
Saripalli, Mack, Subrahmanyan	ATNF, IRA-CNR, ATNF	HI absorption towards cores of radio galaxies	C1263	121
Maccarone, Fender, Tzioumis	UAm, UAm, ATNF	Searching for an intermediate mass Black Hole in Omega Cen	C1265	11.5
Audard, Brown, Gudel, Gizis, Briggs, Telleschi	UClmba, CASA, PSInst, UDel, PSInst, PSInst	Radio & X-ray emissions of the nearest brown dwarf	C1269	26
Gentile, Pizzella, Ott	RAIUB, UPad, ATNF	The sigma - circular velocity relation and the dark matter density profiles	C1272	58.5
Ellingsen, Minier, Burton, Caswell	UTas, CEA, UNSW, ATNF	The relationship between Class I and Class II methanol masers	C1273	29.5
Nielbock, Koribalski, Chini	URuhr, ATNF, URuhr	The multiplicity of protostars	C1274	15
Ferrari, Hunstead, Feretti, Shindler	IAI, USyd, IRA-CNR, IAI	Low-power radio galaxies in the merging cluster A3921	C1276	24
Friesen, Johnstone, Walsh, Myers, Di Francesco	UVictoria, NRC-HIA, CfA, CfA, NRC-HIA	Ammonia observations of the Ophiuchus B core	C1280	34
Zhang, Bourke, Sridharan, Wang, Beuther, Balasubramanyam	CfA, CfA, CfA, CfA, CfA, RRI	Rotating disks toward high mass protostellar objects	C1281	24
Beuther, Thorwith, Hunter, Megeath, Zhang, Walsh, Menten	CfA, CfA, CfA, CfA, CfA, CfA, MPIfR	The onset of massive star formation: the case of the twin-core system NGC 6334 I and I(N)	C1283	19

Safouris, Bicknell, Subrahamanyan, Saripalli	RSAA/ATNF, RSAA, ATNF, ATNF	Recurrent activity in giant radio galaxies	C1284	24
Mueller, Barnes	MPE, USyd	Asteriod surface effects and their use as FIR-to-mm calibrators	C1286	8
Longmore, Barnes, Burton, Minier, Hoare	UNSW, USyd, UNSW, CEA, ULeeds	An ammonia survey of high-mass protostars	C1287	55.5
Gaensler, Haverkorn, Dickey, Stanimirov, Gelfand, McClure-Griffiths, Staveley-Smith	CfA, CfA, UMinn/UTas, UCB, CfA ATNF, ATNF	The magnetic field of the Small Magellanic Cloud	C1288	101.5
Kaempgen, Chini, Menten, Pillai, Wyrowski	URuhr, URuhr, MPIfR, MPIfR, MPIfR	Far infrared "quiet" objects in Bok globules - how radio interferometry probes the earliest stages of star formation	C1293	12
Perez, van der Hulst	KI, KI	Dark matter content of bulge dominated LSB galaxies	C1294	12.5
Matthews, Bourke, Fiege, Pound	UCB, CfA, NRC-HIA, UMar	Origins of the pillars of the Eagle nebulae	C1298	22.5
Morganti, Oosterloo, Saripalli, Subrahmanyan, Tzioumis	NFRA, NFRA, ATNF, ATNF, ATNF	IC 5063: AGN driven outflow of warm and cold gas?	C1300	12
Lundqvist, Bjornsson, Fransson, Ryder, Schmidt, Perez-Torres	StO, StO, StO, AAO, RSAA, IAA-CSIG	Probing the radio emission from a young Type Ia supernova	C1303	NAPA
Buyle, Ferrarese, Gentile, Dejonghe	UGhent, URutg, RAIUB, UGhent	Supermassive black holes and dark matter haloes	C1304	48.5
Bourke, Jorgensen, Launhardt, Noreiga-Crespo, Wright	CfA, LO, MPIA, JPL, ADFA	mm continuum and $N_2H^+(1–0)$ observations of the HH 46 protostar	C1310	8
Kilborn, Forbes, Koribalski, Musgrave	Swinb, Swinb, ATNF, Swinb	The evolution of gas in galaxy groups	C1311	24
Possenti, Burgay, Murgia, Manchester, Wilson, Kramer, McLaughlin, Faulkner, Lyne, D'Amico, Camilo, Stairs	UBol, UBol, UBol, ATNF, ATNF, JB, JB, JB, JB, UBol, UClmba, UBC	Orbital mapping of the continuum flux from the double pulsar PSR J0737-3039A/B	C1312	24
Launhardt, Bourke	MPIA, CfA	Distribution of angular momentum in binary protostars	C1314	48.5
Ott, Henkel, Weiss, Walter	ATNF, MPIfR, IRAM, NRAO (VLA)	Dense molecular gas heated by starbursts and AGNs	C1321	87.5
Wong, Ryder, Kohno, Buta	ATNF/UNSW, AAO, TMU, UAI	Circumnuclear rings: probes of star formation and galaxy dynamics	C1328	61
Caswell, McClure-Griffiths	ATNF, ATNF	Polarisation of W49B; probing the galactic magnetic field	C1329	17.5
Caswell	ATNF	Positions of 22-GHz water masers relative to methanol masers	C1330	38
Slee, Osten, Carter, Budding, Collier-Cameron	ATNF, NRAO, USQld, UCAN, USAND	Magnetic fields and coronal emission from CC Eri	C1333	32.5
Meyer, Zwaan, Webster	STSCI, ESO, UMelb	Intrinsic scatter of the Tully-Fisher relation	C1336	117
McClure-Griffiths, Pisano, Chapman + approx 9 students	ATNF, ATNF, ATNF	Vacation student observing session	C1012	36
Frail, Wieringa	NRAO, ATNF	GRB 040106	CX054	12
Cimo	UTas	IDV quasar PMN J1326-5215	CX055	3
Koribalski	ATNF	The HI content of distant clusters	CX056	10
Dahlem	ATNF	HI observations of elliptical galaxies in different environments	CX057	68
Ott	ATNF	Atomic and molecular gas in low metallicity and starburst galaxies	CX058	4
Ott	ATNF	A search for CO (2-1) in a z=10 galaxy	CX059	15
Wong	ATNF	Ammonia in the Cha I and II molecular clouds	CX060	0.5
Lewis	UTas	Coordinated multi-wavelength observations of PKS 2004-447	CX061	4
Koribalski	ATNF	ATCA HI survey of nearby galaxies	CX062	12

Urqhuart, Muna	UKC, UKC	High resolution observations of high-mass star formation within the bright-rimmed cloud SFO 79	CX063	14
Londish	NASA	A radio quiet BL Lac object	CX064	10
Kondratko	CfA	Extremely high-velocity emission in Circinus	CX065	7
Saripalli	ATNF	A continuum observation of NGC 5018	CX066	5
Sault	ATNF	The outburst of V4641 Sgr	CX067	8
Curran	UNSW	OH in high redshift systems	CX068	20
Kedziora-Chudczer	USyd	Intraday variability of 0405-385	CX070	9

Observations made with the Mopra radio telescope January to September 2004

Observers	Affiliations	Program Title	Number	Hours
Hoare, Busfield, Lumsden, Oudmaijer, Burton	ULeeds, ULeeds, ULeeds, ULeeds, UNSW	Massive star formation in the Galaxy: red MSX sources	M121	317
Kim, Burton, Robertson	UIL, UNSW, ATNF	Massive molecular outflows in the southern hemisphere	M123	209
Ladd, Wong, Robertson, Mizuno	UBuck, ATNF/UNSW, ATNF, UNag	Spectral line mapping of a star-forming core in Chamaeleon: A test of Mopra's mapping capability	M130	81.5
Voronkov, Robertson	ATNF, ATNF	A search for southern 104.3 GHz methanol masers	M131	77
Kisanova, Sobolev, Voronkov, Robertson	USU, USU, ATNF, ATNF	Methanol at 96.7 GHz in the dark cloud L183	M132	156
Mookerjea, Kramer, Burton	UKoeln, UKoeln, UNSW	Multi-transition study of millimetre sources around RCW 106	M133	90
Deacon, Chapman, Green	USyd, ATNF, USyd	The origins of planetary nebulae morphology	M134	85.5
Muller	AO	Mapping CO (1-0) in the Magellanic Bridge	M136	54
Lazendic, Hunt, Slane, Dame, Green	CfA, UNSW, CfA, CfA, CfA	Identifying molecular clouds associated with SNR G347.3-0.5	M137	109.5
Barnes, Bourke, Wong, Ladd	USyd, CfA, ATNF/UNSW, UBuck	OTF mapping of low- and high-mass dense molecular cores	M139	108.5
Nagakawa, McClure-Griffiths, Ladd, Mizuno, Fukui	UNag, ATNF, UBuck, UNag, UNag	Molecular cloud in the furthest arm in the Milky Way	M140	152
Oshima, Kuno, Ota	ISAS, NRO, TMU	Mapping CO emission from the NGC 55 chminey candidate	M142	90.5
Wong, Ladd, Mizuno, Wright	ATNF/UNSW, UBuck, UNag, ADFA	OTF mapping of dense cores in Chamaeleon II	M143	62.5
Pisano, Ott, Bouchard	ATNF, ATNF, RSAA	A CO survey of dwarf galaxies in the Cen A and sculptor groups	M144	120

Observations made with the Parkes radio telescope January to September 2004

Observers	Affiliations	Program	Number	Days
Johnston, Wang, Manchester	USyd, ATNF, ATNF	The 2004 periastron passage of PSR B1259-63	P116	1.84
Kaspi, Manchester	UMcGill, ATNF	Long-term monitoring of PSR J0045-7319	P138	0.72
Bailes, Ord, Hotan, Knight, Manchester, Anderson, Kulkarni, Jacoby	Swinb, Swinb, Swinb, Swinb, ATNF, Caltech, Caltech, Caltech	Precision pulsar timing	P140	17.87
Manchester, Hobbs, Lewis, Sarkissian, Kaspi	ATNF, ATNF, UTas, ATNF, UMcGill,	Timing of young pulsars	P262	3.99
Lyne, Kramer, Manchester, Camilo, Stairs, Hobbs, D'Amico, Possenti, Kaspi, Faulkner	JB, JB, ATNF, UClmba, UBC, ATNF, UBol, UBol, UMcGill, JB	Pulsar multibeam survey: final observations	P268	8.80
Manchester, Hobbs, Camilo, Lyne, Kramer, Faulkner, Stairs, Kaspi, D'Amico, Possenti	ATNF, ATNF, UClmba, JB, JB, JB, UBC, UMcGill, UBol, UBol	Timing of multibeam pulsar discoveries	P276	13.60
Freire, Lyne, Kramer, Manchester, Lorimer, Camilo, D'Amico	AO, JB, JB, ATNF, JB, UClmba, UBol	Timing and searching for pulsars in 47 Tucanae	P282	7.28
Bailes, Ord, Hotan, van Straton, Jacoby	Swinb, Swinb, Swinb, NFRA, Caltech	Studies of relativistic binary pulsars	P361	13.06
Camilo, Manchester, Sarkissian	UClmba, ATNF, ATNF	Timing two young and energetic pulsars	P395	2.43
Kramer, Lyne, Stairs, Kaspi, Manchester, Camilo	JB, JB, NRAO (GB), UMcGill, ATNF, UClmba	Geodetic precession in PSR J1141-6545	P400	2.17
Roberts, Ransom, Kaspi, Hessels, Tam, Livingstone, Crawford	UMcGill, MIT, UMcGill, UMcGill, UMcGill, UMcGill, Haverford	A search for pulsars in mid-latitude EGRET error boxes	P406	1.06
Deacon, Chapman, Green	USyd/ATNF, ATNF, USyd	Linear polarisation of planetary nebulae precursors	P414	0.94
Kramer, Lyne, Esamdin, McLaughlin, Hobbs, Manchester, Stairs, Camilo, Faulkner, Lorimer	JB, JB, JB, JB, ATNF, ATNF, UBC, UClmba, JB, JB	Investigating a new class of transient radio pulsars	P417	3.98
D'Amico, Lyne, Manchester, Sarkissian, Possenti, Corongiu, Camilo	CAO, JB, ATNF, ATNF, CAO, CAO, UClmba	Timing and searching millisecond pulsars in Globular Clusters	P427	6.57
Little, Briggs, Ord, Kanekar, Staveley-Smith	RSAA, RSAA/ATNF, Swinb, KI, ATNF	Hydrogen 21-cm line absorption at z » 1 against high redshift radio sources	P440	11.01
Wang, Manchester, Johnston, Lyne, Kramer	ATNF/USyd, ATNF, USyd, JB, JB	Nulling of Parkes mulitbeam pulsars	P445	3.62
Jacoby, Kulkarni, Bailes, Ord, Hotan	Caltech, Caltech, Swinb, Swinb, Swinb	Timing the Swinburne intermediate latitude pulsars	P447	6.44
Karastergiou, Johnston, Manchester	USyd, USyd, ATNF	High frequency polarimetry of radio pulsars	P452	2.18
Wang, Johnston, Manchester, Johnston	ATNF/USyd, USyd, ATNF, USyd	Monitoring the interstellar medium with Parkes	P453	3.88
Burgay, Kramer, D'Amico, Possenti, Manchester, Stairs, Faulkner, McLaughlin, Lyne, Camilo	UBol, JB, CAO, CAO, ATNF, UBC, JB, JB, JB, UClmba	Timing & geodetic precession in the double pulsar & the DNS PSR J1756-2251	P455	4.08
Manchester, Bailes, Hotan, Ord, Hobbs, Edwards, Sarkissian, Kesteven, Kulkarni, Jacoby	ATNF, Swinb, Swinb, Swinb, ATNF, ATNF, ATNF, ATNF, Caltech, Caltech	A millisecond pulsar timing array	P456	28.93
Dodson, Reynolds, Sarkissian, Blandford, Coppi	ISAS, ATNF, ATNF, UStan, UStan	NAPA: Vela - the morning after	P457	NAPA
Curran, Whiting, Francis, Webb, Murphy	UNSW, UNSW, ANU, UNSW, IoA	Redshifted OH absorption in red quasars	P458	1.02

Voronkov, Slysh, Alakoz	ATNF, ASC, ASC	A search for 2.9 GHz methanol maser emission	P459	1.45
Knight, Bailes, Ord, Kulkarni	Swinb, Swinb, Swinb, Caltech	Searching for giant pulses from millisecond pulsars	P460	2.36
Knight, Bailes, Ord, Kulkarni, Jacoby	Swinb/ATNF, Swinb, Swinb, Caltech, Caltech	A pilot 50-cm pulsar survey	P461	12.72
Stootman, Filipovic	UWS (Nepean), UWS (Nepean)	Rapid time variations of astrophysical masers	P462	3.40
Burgay, Kramer, D'Amico, Possenti, Manchester, Stairs, Faulkner, McLaughlin, Lyne, Camilo	UBol, JB, CAO, CAO, ATNF, UBC, JB, JB, JB, UClmba	Geodetic precession in two new double neutron star systems	P463	1.08
Burgay, McLaughlin, Kramer, Lyne, D'Amico, Possenti, Manchester, Camilo	UBol, JB, JB, JB, CAO, CAO, ATNF, UClmba	Timing and confirmation of high-latitude survey discoveries	P465	3.14
Curran, Webb, Murphy	UNSW, UNSW, IoA	6-cm OH absorption in PKS 1830-211	P466	2.25
McClure-Griffiths, Pisano, Staveley-Smith, Bruens, Kalbera, Gibson, Lockman	ATNF, ATNF, ATNF, UBonn, UBonn, Swinb, NRAO	GASS: The Galactic All Sky Survey project	P467	3.21
Macquart, van Straten, Johnston, Ord	KI, NFRA, USyd, Swinb	Interstellar turbulence: strongly scattered pulsar radiation	P468	1.50
Chin, Lemme, Kaiser	UTamk, Taipei, UHawaii	A search for interstellar Benzonitrile, a key tracer of Benzene	P469	1.27
Weisberg, Johnston, Koribalski, Stanimirovic	Carleton, USyd, ATNF, UCB	OH emission and absorption measurements towards low-latitude pulsars	P470	3.04
Camilo, Lorimer, McLaughlin	UClmba, UMan, Uman	Deep multibeam pulsar survey at 50° < l < 60°	P471	1.94
Carretti, McConnell, Subrahmanyan, Bernadi, Cortiglioni	IASF-CNR, ATNF, ATNF, CNR, CNR	Polarised diffuse emission observations at 2.4 GHz	P472	3.20
Lorimer, Faulkner, Lyne, Kramer, McLaughlin, Stairs, Camilo, Manchester, Burgay, Possenti, D'Amico	JB, JB, JB, JB, JB, UBC, UClmba, ATNF, CAO, CAO, CAO	A search for double-pulsar binaries	P473	1.53
Possenti, Bailes, Hotan, Corongiu, Manchester, D'Amico, Ord	CAO, Swinb, Swinb, CAO, ATNF, CAO, Swinb	Is there a planet orbiting PSR J1807-2459A in NGC 6544?	P476	0.38
Lyne, D'Amico, Burgay, McLaughlin, Possenti, Lorimer, Kramer, Manchester, Hobbs, Camilo, Stairs	JB, CAO, CAO, JB, CAO, JB, JB, ATNF, ATNF, UClmba, UBC	The Perseus Arm pulsar multibeam survey	P477	3.17
Lyne, McLaughlin, Kramer, Lorimer, Johnston, Stairs, Camilo, Manchester	JB, JB, JB, JB, USyd, UBC, UClmba, ATNF	Monitoring of an eclipsing pulsar with a massive companion	P478	2.27
McLaughlin, Lyne, Kramer, Lorimer, Hobbs, Manchester, Stairs, Camilo, Faulkner	JB, JB, JB, JB, ATNF, ATNF, UBC, UClmba, JB	Investigating a new population of repeating radio transients	P479	4.84
Kranz, Freeman, Koribalski, Wong, Bland-Hawthorn, Ryder	RSAA, RSAA, ATNF, ATNF/UNSW, AAO, AAO	A multi-wavelength study of isolated, asymmetric spiral galaxies	P482	0.75
Titov, Govind and others	GeosAus, GeosAus	Improving the terrestrial and celestial reference frames	P483	1.00
McClure-Griffiths, Chapman + approx 9 students	ATNF, ATNF, ATNF	Vacation student observing session	PSPP006	1.46

VLBI observations - January to September 2004

Observers	Affiliations	Program	Number	Hours
Ojha, Reynolds, Fey, Johnston, Tzioumis, Jauncey, Ellingsen, Cimo Nicolson, Quick	ATNF, ATNF, USNO, USNO, ATNF, ATNF, UTas, UTas HartRAO, HartRAO	Astrometry/imaging of southern hemisphere ICRF sources	V131	52
Dodson, Johnston, Reynolds, Karastergiou	ISAS, USyd, ATNF, USyd	Distance and proper motion of PSR B1259-63	V156	24
Dodson, Johnston, Ord, Reynolds	ISAS, USyd, Swinb, ATNF	Pulsars: where are they from, where are they going	V162	3
Dodson, van Straten, Reynolds, Bailes	ISAS, Swinb, ATNF, Swinb	The LBA millisecond pulsar timing array	V166	6
Tingay, Forbes	Swinb, Swinb	LBA imaging of extragalactic supernova remnants and jet interaction regions	V168	12
Cimo, Jauncey, Ellingsen, McCulloch, Carter, Lovell, Ojha, Tzioumis, Reynolds, Fey	UTas, ATNF, UTas, UTas, UTas, ATNF, ATNF, ATNF, ATNF, USNO	Milliarcsec structure of micro-arcsecond sources	V172	24
Kondratko, Greenhill, Moran, Lovell, Jauncey, Kuiper	CfA, CfA, CfA, ATNF, ATNF, JPL	Follow-up imaging of the water megamaser in NGC 5643	V173	12
McCallum, Ellingsen, Lovell, Jauncey	UTas, UTas, ATNF, ATNF	Scintillation in Circinus	V176	24
Phillips, Caswell, van Langevelde	ATNF, ATNF, JIVE	High resolution imaging of water masers	V178	12

Tidbinbilla observations - January to September 2004

Observers	Affiliations	Program	Number	Hours
Valdettaro, Chapman, Palla	OAAI, ATNF, OAAI	Star formation in bright rimmed clouds: any water masers?	T001	2
Phillips, Lovell, Beuther	ATNF, ATNF, MPIfR	Methanol Masers: tracers of high mass protostars and discs?	T002	32
McCallum, Ellingsen, Lovell, Jauncey	UTas/ATNF, UTas, ATNF, ATNF	The Circinus Galaxy - simply scintilating?	T004	37
Deacon, Chapman, Green	USyd/ATNF, ATNF, USyd	The origin of planetary nebulae morphology	T005	37
Kondratko, Greenhill, Moran, Lovell, Jauncey, Kuiper	CfA, CfA, CfA, ATNF, ATNF, JPL	Monitoring of water megamasers newly discovered at DSS43: an update	T010	18
Curran, Whiting, Wiklind, Webb, Murphy	UNSW, UNSW, STScI, UNSW, IoA	High redshift molecular absorption in optically faintquasars	T011	3

E: Affiliations

AAO	Anglo-Australian Observatory, Australia
AAS	American Astronomical Society, USA
ADFA	Australian Defence Force Academy, Australia
ANU	Australia National University, Australia
AO	Arecibo Observatory, USA
ASC	Astrospace Centre, Russia
ASIAA	Academia Sinica, IAA, Taiwan
ATNF	Australia Telescope National Facility, Australia
AUT	Auckland University of Technology, New Zealand
BAO	Beijing Astronomical Observatory, China
BIMA	Berkeley-Illinois-Maryland Association, USA
Caltech	California Institute of Technology, USA
CAO	Cagliari Astronomical Observatory, Italy
Carleton	Carleton College, USA
CASA	CASA, University of Colorado, USA
CDSSC	Canberra Deep Space Communications Complex, Australia
CEA	Centre d'Etudes d'Astrophysique, Saclay, France
CfA	Center for Astrophysics, Harvard University, USA
CITNZ	Central Institute of Technology, New Zealand
CL	Cavendish Laboratories, UK
CO	Carter Observatory, New Zealand
Cornell	Cornell University, USA
CSR	Center for Space Research, USA
CIP	CSIRO Industrial Physics, Australia
DRAO	Dominion Radio Astrophysical Observatory, Canada
ESO	European Southern Observatory, Germany
ESTEC	ESTEC Astrophysics Division, The Netherlands
GBT	Green Bank Telescope, USA
GeosAus	Geoscience Australia, Australia
GSFC	Goddard Space Flight Center, USA
HartRAO	Hartebeesthoek Radio Astronomical Observatory, South Africa
Harvard	Harvard University, USA
Haverford	Haverford College, USA
IAA-CSIG	Intituto de Astrofisica de Andalucia, Spain
IAC	Instituto de Astrofisica de Canarias, Spain
IAFE	Instituto d'Astronomia y Fisica del Espacio, Argentina
IAI	Institute of Astrophyics Innsbruck, Austria
IAP	Institute d'Astrophysique Paris, France
IAPRAS	Insitute Applied Physics, Russian Academy of Science, Russia
IAR	Instituto Argentino de Radioastronomica, Argentina
IASp	Institut d'Astrophysique Spatiale, France
IEEC	IEEC, Spain
IFCTR	Instituto de Fisica Cosmica - CNR, Italy
ImCol	Imperial College London, UK
INAOE	Instituto nacional de astrofisica, Optica y Electronica, Mexico
IoA	Institute of Astronomy, UK
IPAC	IPAC, Caltech, USA
IRA-CNR	Institute of Radio Astronomy, CNR, Bologna, Italy
IRAM	Institut de Radioastronomie Millimétrique, Spain
ISAS	Institute of Space and Astronautical Science, Japan
ISU	Iowa State University, USA
JAC	Joint Astronomy Centre, Hilo, USA
JB	Jodrell Bank Observatory, UK
JHU	John Hopkins University, USA
JILA	JILA, University of Colorado, USA
JIVE	Joint Institute for VLBI in Europe, The Netherlands
JPL	Jet Propulsion Laboratory, USA
KI	Kapteyn Institute, Netherlands
LAEFF	LAEFF-INTA, Spain
LivJMU	Liverpool John Moores University, UK
LLNL	Lawrence Livermore National Laboratory, USA
LO	Leiden Observatory, The Netherlands
MSFC	Marshall Space Flight Center, USA
MERLIN	Multi-element Radio Linked Interferometry Network, UK
MIT	Massachusetts Institute of Technology, USA
Monash	Monash University, Australia
MPE	Max Planck Inst. für Extraterrestrische Physik, Germany
MPIA	Max Planck Insitut. für Astronomie, Germany
MPIfA	Max Planck Inst. für Astrophysik, Germany
MPIfR	Max Planck Inst. für Radioastronomie, Germany
MRAO	Mullard Radio Astronomical Observatory, UK
MRO	Mesahovi Radio Observatory, Finland
MSFC	Marshall Space Flight Centre, USA
MSSL	Mullard Space Science Laboratory, UCL, UK
NAIC	National Astronomy and Ionosphere Centre, USA
NAOJ	National Astronomical Observatory, Japan
NASA-RC	NASA Ames Research Center, USA
NFRA	Netherlands Foundation for Research in Astronomy, The Netherlands
NOAO	National Optical Astronomical Observatory, USA
NRAO	National Radio Astronomy Observatory, USA
NRC-HIA	Hiesberg Institute of Astrophysics - NRC, Canada
NRL	Naval Research Laboratories, USA
NRO	Nobeyama Radio Observatory, Japan
NSSTC	National Space Science and Technology Center, USA
NWU	Northwestern University, USA
OAAI	Osservatorio Astrofisico di Arcetri, Italy
OABol	Osservatorio Astronomico di Bologna, Italy
OAP	Osservatorio Astonomico di Padova, Italy
OARome	Osservatorio Astronomico di Roma, Italy
OAT	Osservatorio Astronomico di Trieste, Italy
OCat	Osservatorio Astronomico di Catania, Italy
OHP	Observatoire de Haute Provence, France
OMs	Observatorire de Marseille, France

OPM	Observatoire de Paris, Meudon, France
OSO	Onsala Space Observatory, Sweden
PMO	Purple Mountain Observatory, China
PSInst	Paul Scherrer Institut, Switzerland
Queens	Queens University, Canada
RAIUB	Radio Astronomy Institute, University of Bonn, Germany
ROB	Royal Observatory of Belgium, Belgium
ROE	Royal Observatory Edinburgh, Scotland
RRI	Raman Research Institute, India
RSAA	Research School of Astronomy & Astrophysics, Australia
SETI	SETI Institute, USA
ShO	Shangai Observatory, China
StO	Stockholm Observatory, Sweden
STScI	Space Telescope Science Institute, USA
Swinb	Swinburne University of Technology, Australia
TGU	Tokyo Gakugei University, Japan
TMU	Tokyo Metropolitan University, Japan
TIFR	Tata Institute for Radio Astronomy, India
UAd	University of Adelaide, Australia
UAl	University of Alabama, USA
UAm	University of Amsterdam, The Netherlands
UBC	University of British Columbia, Canada
UBir	University of Birmingham, UK
UBol	University of Bologna, Italy
UBonn	University of Bonn, Germany
UBos	Boston University, USA
UBr	University of Bristol, UK
UBuck	Bucknell University, USA
UC	University of Colorado, USA
UCal	University of Calgary, Canada
UCan	Canakkale University, Turkey
UCB	University of California, Berkeley, USA
UCardiff	Universiy of Cardiff, UK
UCha	University of Champagne-Urbana, USA
UChi	University of Chile, Chile
UChig	University of Chicago, USA
UCL	University College London, UK
UClmba	Columbia University, USA
UCLO	University of California Lick Observatory, USA
UCSB	University of California, Santa Barbara, USA
UCSC	University of California, Santa Cruz, USA
UCSD	University of California, San Diego, USA
UDel	University of Delaware, USA
UDur	University of Durham, England
UEdin	University of Edinburgh, UK
UFSSA	University of the Free State, South Africa
UGhent	Universiteit Ghent, Belgium
UHawaii	University of Hawaii, USA
UHel	University of Helsinki, Finland
UHerts	University of Hertfordshire, UK
UHilo	University of Hilo, USA
UHK	University of Hong Kong, PR China
UIL	University of Illinois, USA
UIow	Iowa State University, USA
UJaen	Universidad de Jaen, Spain
UKC	University of Kent, UK
UKeele	University of Keele, UK
UKoeln	University of Koeln, Germany
UKST	United Kingdom Schmidt Telescope, Australia
UKyoto	University of Kyoto, Japan
ULeeds	University of Leeds, UK
ULeic	University of Leicester, UK
UMac	Macquarie University, Australia
UMan	University of Manchester, UK
UMar	University of Maryland, USA
UMaur	University of Mauritius, Mauritius
UMcGill	McGill University, Canada
UMelb	University of Melbourne, Australia
UMinn	University of Minnesota, USA
UMont	University of Montreal, Canada
UNag	Nagoya University, Japan
UNM	University of New Mexico, USA
UNSW	University of New South Wales, Australia
UOx	University of Oxford, UK
UPad	University of Padova, Italy
UPenn	Pennsylvania State University, USA
UQld	University of Queensland, Australia
URuhr	Ruhr-Universitaet, Germany
URutg	Rutgers University, USA
USAND	University of St Andrews, UK
USNA	US Naval Academy, USA
USNO	US Naval Observatory, USA
USouth	Southampton University, UK
USQld	University of Southern Queensland, Australia
UStan	Stanford University, USA
USU	Ural State University, Russia
USuss	University of Sussex, UK
USyd	University of Sydney, Australia
UTamk	Tamkang University, Taiwan
UTas	University of Tasmania, Australia
UTex	University of Texas, USA
UTor	University of Toronto, Canada
UTS	University of Technology, Sydney, Australia
UVictoria	University of Victoria, Canada
UVil	Villanova University, USA
UVir	University of Virginia, USA
UW	University of Wales, UK
UWA	University of Western Australia, Australia
UWash	University of Washington, USA
UWis	University of Wisconsin, USA
UWol	University of Wollongong, Australia
UWS	University of Western Sydney, Australia
Yale	Yale University, USA

F: ATNF media releases, 2004

First-known double pulsar opens up new astrophysics	09 January
Squirty star imitates black hole	15 January
CSIRO "camera" now boosting world's largest telescope	28 April
Australian telescopes to take part in Huygens space-probe experiment	09 December
Double pulsar discovery makes science's "top ten" of 2004	23 December

ATNF media releases can be found on the web at www.atnf.csiro.au/news.

G: 2004 publications

Papers using ATNF data, published in refereed journals

Papers which include ATNF authors are indicated by an asterisk

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Drake, C., "Radio-excess IRAS galaxies", PhD thesis, Asutralian National University

Huynh, M., "Constraining the star formation history of galaxies in the Hubble Deep Feild South region with sensitive radio data", PhD thesis, Australian National University

Mitchell, D., "Interference mitigation in radio astronomy", PhD thesis, University of Sydney

Muller, E., "High resolution studies of the HI in the western Magellanic bridge", PhD thesis, University of Wollongong

Ricci, R., "High-frequency properties of extragalaxtic radio sources", PhD thesis, SISSA/ISAS, Italy

Ryan-Weber, E., "Neutral hydrogen in galaxies and the intergalactic medium", PhD thesis, University of Melbourne

H: Postgraduate students co-supervised by the ATNF

As of December 2004

Bouchard, A., "The evolution of dwarf galaxies in nearby groups", RSAA, Australian National University

Chippendale, A., "High dynamic range imaging with many baseline synthesis interferometry", University of Sydney

Deacon, R., "Planetary nebulae - origin of morphology", University of Sydney

Ford, A., "GASS: The Galactic All-Sky-Survey", Swinburne University

Godfrey, L., "Dynamics of large-scale extragalactic Jets: A multi-wavelength study of X-ray bright jets", Australian National University

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Hayman, D., "Densely packed focal plane arrays", Macquarie University

Hotan, A., "Pulsar observation and timing", Swinburne University of Technology

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I: Abbreviations

AARNET	Australia's Academic and Research Network.
ACA	Australian Communications Authority.
ALFA	Arecibo L-band Feed Array.
ALMA	Atacama Large Millimetre Array.
APT	Asia-Pacific Telescope.
ASKACC	Australian SKA Consortium Committee.
ATCA	Australia Telescope Compact Array.
ATNF	Australia Telescope National Facility.
ATOA	Australia Telescope Online Archive.
ATUC	Australia Telescope Users Committee.
CABB	Compact Array Broadband.
CIP	CSIRO Industrial Physics.
CMOS	Complementary Metal Oxide Semiconductor.
CO	Carbon Monoxide.
COSPAR	Committee on Space Research.
CPSR	Caltech-Parkes-Swinburne Recorder.
CSIRO	Commonwealth Scientific and Industrial Research Organisation.
DAS	Data Acquisition System.
DFB	Digital Filter Bank.
DSN	Deep Space Network.
FITS	Flexible Image Transport System.
FPGA	Field Programmable Gate Array.
GASS	Galactic All Sky Survey.
HEMT	High Electron Mobility Transistor.
HI	Neutral Hydrogen.
HIPASS	HI Parkes All Sky Survey.
HVC	High-velocity Cloud.
IAU	International Astronomical Union.
ICRF	International Celestial Reference Frame.
ICT	Information and Communications Technology.
IF	Intermediate Frequency.
ISM	Interstellar Medium.
ISPO	International SKA Project Office.
ISSC	International SKA Steering Committee.
IT	Information Technology.
ITU	International Telecommunications Union.
IUCAF	Scientific Committee on the Allocation of Frequencies for Radio Astronomy and Space Sciences.
InP	Indium Phosphide.
JIVE	Joint Institute for VLBI in Europe.
LBA	Long Baseline Array, used for Australian VLBI observations.
LFD	Low Frequency Demonstrator.
LNA	Low Noise Amplifier.
LO	Local Oscillator.
MMIC	Monolithic Microwave Integrated Circuit.

MNRF	Major National Research Facilities.
MSX	Midcourse Space Experiment.
NASA	National Aeronautics and Space Administration.
NTD	New Technology Demonstrator.
OHS	Operational Health & Safety.
OTF	On The Fly.
PCB	Printed Circuit Board.
SETI	Search for Extra Terrestrial Intelligence.
RAFCAP	Radio Astronomy Frequency Committee in the Asia Pacific Region.
RFI	Radio Frequency Interference.
RQZ	Radio Quiet Zone.
RVS	Remote Visualisation Server.
SGPS	Southern Galactic Plane Survey.
SIS	Semiconductor-Insulator-Semiconductor.
SKA	Square Kilometre Array.
TAC	Time Assignment Committee.
URSI	International Union of Radio Science.
VLBI	Very Long Baseline Interferometry.
VO	Virtual Observatory.
VSOP	VLBI Space Observatory Program.
WCS	World Coordinate System.
WRC	World Radiocommunication Conference.
XNTD	Extended New Tehcnology Demonstrator.
ZOA	Zone of Avoidance.

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CSIRO Australia Telescope National Facility
PO Box 76
Epping NSW 1710
Australia
Tel: +61 2 9372 4100
Fax: +61 2 9372 4310

Parkes Observatory
PO Box 276
Parkes NSW 2870
Australia
Tel: +61 2 6861 1700
Fax: +61 2 6861 1730

Paul Wild Observatory Narrabri
Locked Bag 194
Narrabri NSW 2390
Australia
Tel: +61 2 6790 4000
Fax: +61 2 6790 4090

atnf-enquiries@csiro.au
www.atnf.csiro.au