Australia's National Science Agency

Australia Telescope National Facility

Annual Report 2018–19


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CSIRO Australia Telescope National Facility
Annual Report 2018–19

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This is the report of the CSIRO Australia Telescope National Facility for the period 1 July 2018 to 30 June 2019 and is approved by its Steering Committee.

Editor: Nic Svenson

Science highlights: Helen Sim

Cover image: The Australia Telescope Compact Array.
Photo: Alex Cherney.

Inside cover image: The Prime Minister of Australia, the Hon. R. J. L. (Bob) Hawke AC, opens the Australia Telescope Compact Array on 2 September 1988.
Photo: CSIRO radio astronomy image archive.

Chair's report

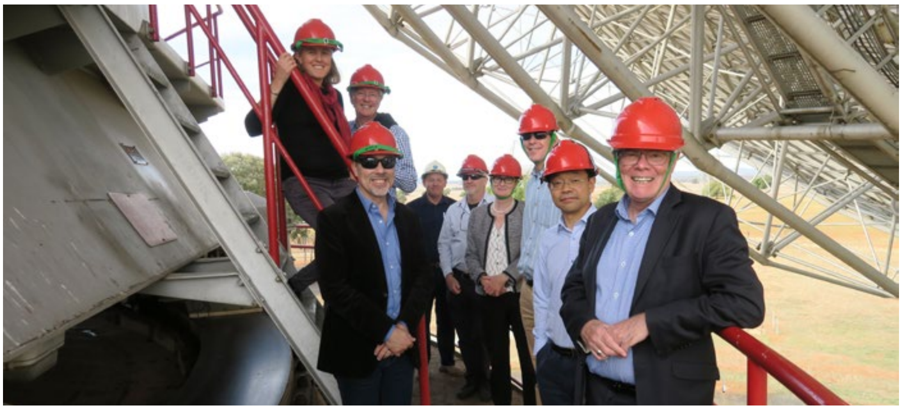
Prof David Skellern
Chair, ATNF Steering Committee
Photo: John Sarkissian.

The Australia Telescope National Facility Steering Committee (ATSC) met twice this year. The May 2019 meeting was preceded by a day-trip to the Parkes radio telescope, allowing members a close-up look at the new Ultra-Wideband receiver that is now in operation. During our meeting at the ATNF's Sydney headquarters, we toured the laboratories and workshops and met the teams who design, test and manufacture these world-leading instruments.

Meeting the engineering teams alongside the ATNF astronomers and operations staff, all of whom know their instruments backwards, brought home to ATSC members the integral role that all three elements of the ATNF (engineering, operations and astrophysics) play in achieving its ongoing success. It is this more than any other single factor that leads us again to recommend that this internationally significant facility and flagship of Australian science be maintained.

The ATSC has made many recommendations over its 30-year history. But seldom do we see them pay off so spectacularly as our recommendation that a portion of precious ASKAP commissioning time be devoted to finding more fast radio bursts (FRBs) in the hope of pinpointing the origin of one. Our congratulations to Dr Keith Bannister and the Commensal Real-time ASKAP Fast Transients (CRAFT) team for doubling the number of known FRBs and achieving the world's first localisation of one.

We have also seen our recommendations on commercialisation acted upon with the appointment of an experienced commercialisation specialist, a former ATNF staff member, Dr Ilana Feain. This has been the impetus for greatly increased work on identifying commercialisation opportunities that would leverage ATNF system engineering capabilities, and existing and emerging technologies: some hold great promise. All face the mighty challenge of transferring the requisite knowledge and skills to commercial entities without significant disruption to the ATNF's core activities of developing and operating the National Facility. We urge the ATNF both to increase its efforts on articulating and elaborating commercial opportunities for its radio astronomy technologies and to find the new approaches and funding sources that will be needed for successful technology transfer that leaves the ATNF able to sustain the achievements for which it is renowned. As one Member put it: "it can't just be another cottage industry".



The ATSC at the Parkes radio telescope in May 2019. Photo: John Sarkissian.

We commend the ATNF on its ongoing focus on developing an open, collaborative, innovative and respectful workplace culture. Many initiatives commenced this year, including the buddy and mentoring programs, and we have seen the commitment at all levels to maintaining this effort towards making the ATNF a workplace of choice. The ATSC also strongly supports the ATNF's developing plans to improve gender diversity among its technical and engineering staff.

On the operational front, the ATSC appoints the ATNF Users' Committee (ATUC) and the Time Assignment Committee (TAC). We are grateful for the connection to the community provided by ATUC and particularly value its Chair's annual report during our May meeting. On behalf of the ATSC, I thank members of both ATUC and TAC for their diligent and indispensable contribution to operation of the ATNF.

CSIRO and the nation have long been committed to the international SKA project. It is critical that adequate support is provided to realise the tremendous potential and to meet the international obligations that arise from Australia's position as an SKA host nation. The Committee recommends that the ATNF leadership team prepare options for transitioning from current capabilities to those needed for the SKA under a range of financial scenarios.

The ATSC is an advisory committee to the CSIRO Board. As such, we commend this Annual Report to the Board as a representative example of the hard work and achievement of this internationally renowned Australian national facility.

Director's report

Dr Douglas Bock
Director, ATNF
Photo: Wheeler Studios.

Over the last year, ASKAP transitioned from a construction and commissioning project into an operational telescope. Early Science (observations with sub-arrays of 12 and 16 antennas) successfully concluded, we made our first observation with all 36 antennas in February 2019 and are now preparing for pilot surveys which will test the telescope's readiness for full-scale surveys

The scientific highlight of the year is undeniably the results from ASKAP's fast transient detection and localisation program. On the way to securing the cover of Science magazine for localising an FRB (see Science Highlights), Nature Astronomy devoted an entire edition to FRBs. While ASKAP graced the cover and Keith Bannister wrote the lead article on his team's success using ASKAP to hunt for these flashes of high intensity radio waves, the papers inside tell a deeper story. Eight of the 13 articles were written either by Australian astronomers or by those who had spent substantial proportion of their careers here – often with our telescopes. These results can be traced back to the innovative technology needed for first the multibeam receiver built for our Parkes radio telescope, and now ASKAP's phased array feed receivers, so we are naturally very proud of our decades-long history of innovation and delivery.

2018 marked the 30^{th} anniversary of the Australia Telescope Compact Array (ATCA), and we include here a feature article by the founding Director, Ron Ekers – who was this year made an Officer of the Order of Australia for his distinguished service to astronomy. ATCA expanded Australian radio interferometry into the millimetre-wave band, providing the first detailed Galactic and extra-galactic pictures of interstellar molecules and dust in the southern sky. It was also at the forefront of digital signal processing: ATCA's original correlator chip was the foundation of the fast Fourier transform chip that ultimately led to CSIRO's invention of fast WiFi – the greatest commercialisation legacy in the Organisation's 100-year history.

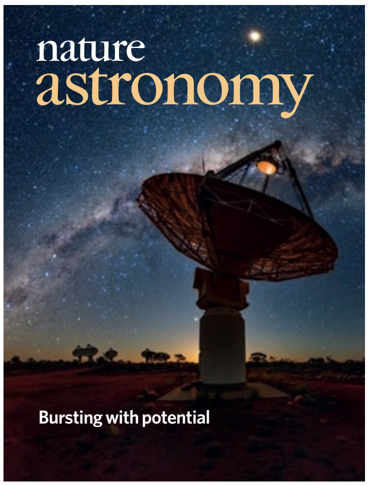
CSIRO engineers designing ATCA pioneered wide bandwidth receivers: and we remain world-leaders in that field. Today we have the first in a proposed suite of ultra-wideband receivers in use on the Parkes radio telescope, the system performance of which is quite remarkable in its sensitivity across the 3330 MHz-wide band.

With the generous cooperation of those who had already been awarded time on Parkes, we were excited to make our Dish available to NASA to track Voyager 2 as it left our Solar System. It is far from the first spacecraft to be tracked by Parkes and we trust it will not be the last.

This year we farewelled senior astronomer, Dr Lisa Harvey-Smith, to become Australia's first Women in STEM ambassador. We welcome the Australian Government's establishment of this position which includes among its objectives to see more women choosing science and engineering careers. Our new ATNF Chief Scientist, Prof Elaine Sadler, was recognised for her work in gender equity, and astronomy research, with the award of Officer of the Order of Australia. Gender equity among the technical disciplines is a particular focus for us. While our current staffing reflects the proportion of female graduates in these areas, we nevertheless seek to grow the proportion of women working for us and, perhaps ambitiously, to influence the number of women choosing to study engineering.

A highlight of the year was the execution by seven member nations of the international Square Kilometre Array (SKA) Convention which is the first formal step to formation of the intergovernmental organisation (the SKA Observatory) that will oversee construction and operation of the SKA telescopes. Australia's delegation to the ceremony in Rome included Australia's SKA Director, David Luchetti, the Chair of the SKA Council Preparatory Taskforce, Patricia Kelly, and our Aboriginal Liaison Officer, Leonie Boddington, who represented the Wajarri Yamatji: traditional owners of the Murchison Radio-astronomy Observatory (MRO) in Western Australia where the SKA's low frequency telescope will be built. During the year we supported Critical Design Reviews for several SKA work packages and continued our preparations to host SKA-Low at the MRO.

My thanks to the ATSC, ATUC and TAC for their advice and guidance over the year, also to my management team and the staff of the ATNF.



Keith Bannister's exposition on searching for FRBs with ASKAP made the cover of a special edition of *Nature Astronomy* in November 2018: later voted cover of the year. His FRB localisation paper went on to make the cover of *Science*. Image: *Nature* magazine.

Management team

ATNF Director and Director CSIRO Astronomy and Space Science

Douglas Bock

Deputy Director

Sarah Pearce

ATNF Chief Scientist

Elaine Sadler

Program Director, SKA

Antony Schinckel

Program Director, Technologies for Radio Astronomy

Tasso Tzioumis

Program Director, ATNF Science

Phil Edwards

Program Director, ATNF Operations

John Reynolds

Strategic Planning and Major Project Specialist

Phil Crosby

Research Operations Manager

Warren Bax

About us

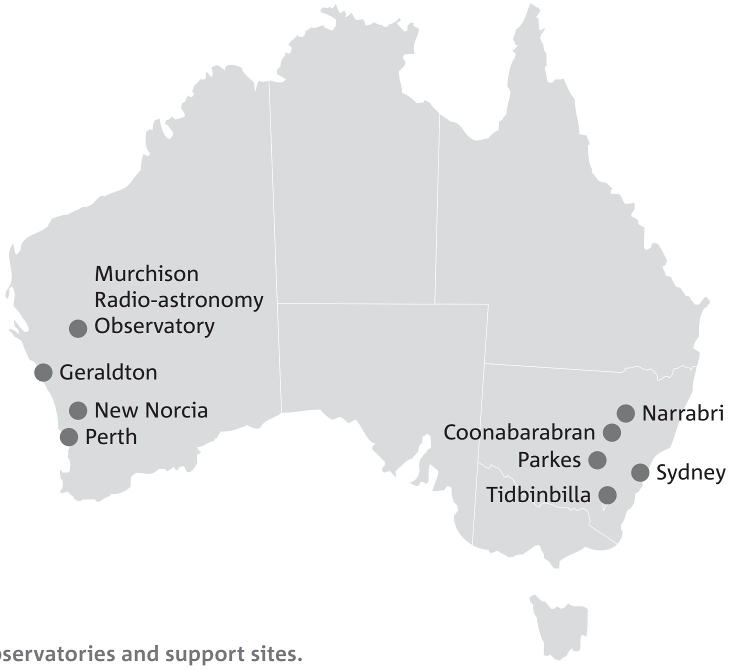
Looking toward the galactic plane from one of the ATCA dishes. Photo: Jamie Stevens.

We operate world-class radio astronomy facilities for users from across Australia and around the world. We are global leaders in technology and research, exploiting the world's premier radio quiet site. We attract and retain the best staff.

The Australia Telescope National Facility (ATNF) is operated by Australia's national science agency, CSIRO (the Commonwealth Scientific and Industrial Research Organisation). The ATNF is made up of the Parkes radio telescope, Australia Telescope Compact Array (ATCA), the Australian Square Kilometre Array Pathfinder (ASKAP), the combination of instruments forming the Long Baseline Array (LBA), and associated research and development activities[1].

ATNF telescopes support studies of pulsars and fast radio bursts (FRBs), galactic astrophysics, extragalactic star formation and gas evolution, cosmology, active galactic nuclei, and magnetism and polarimetry.

The ATNF comprises the major part of CSIRO Astronomy and Space Science (CASS), a Business Unit within CSIRO. CASS also operates NASA's Canberra Deep Space Communication Complex (CDSCC) at Tidbinbilla and manages Australian astronomers' access to CDSCC antennas and has this year taken over operation of the European Space Agency's (ESA) tracking station at New Norcia north of Perth. CASS now also leads CSIRO's space research, such as CSIRO's Earth observation capability which includes managing Australian scientists' access to the NovaSAR Earth observation satellite.



ATNF observatories and support sites.

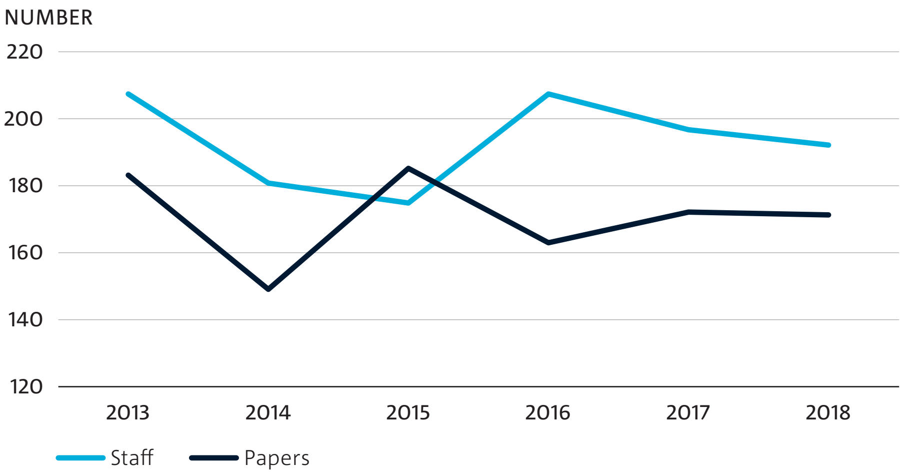


Figure 1: Total publications by staff over time.

ASKAP
Collecting area 36 x 12 m
Frequency range 0.7-1.8 GHz
Bandwidth 288 MHz
Field of view 30 deg^2

ATCA
Collecting area 6 x 22 m
Frequency range 1-105 GHz
Bandwidth 4 GHz
Configurable antenna location

Parkes Radio Telescope
Diameter 64 m
Frequency range 0.7-26 GHz
Bandwidths up to 1 GHz

1 Our 22-m Mopra telescope near Coonabarabran is not offered as part of the ATNF; it is operated under contract for a consortium of universities.

The New Norcia tracking station now operated by CSIRO Astronomy and Space Science. Photo: ESA.

Mission

To develop and operate world-class National Facilities in radio astronomy.

- Operate the ATNF as a financially viable and user-focused research facility for the benefit of the Australian and international communities.
- Play a key role in the international Square Kilometre Array (SKA) project, covering in-country operations, science leadership and technology development.
- Deliver world-class science through exploitation of our southern location and technological advantages.
- Develop, apply and commercialise our innovative technologies and big data processing techniques.
- Foster a diverse and creative workforce.

Operations

The ATNF affords astronomers all over the world the opportunity to use its telescopes free of charge. Access is based on the scientific merit of the proposed observing project. Australian astronomers have access to many overseas facilities on the same principle.

Telescope access can also be purchased (within limits), with the funds used to defray operating costs during the observations. We have agreements with, for example, the Breakthrough Prize Foundation and the National Astronomical Observatories of China.

Twice a year a call for observing proposals is made to the international astronomical community. In recent years about 100 observing proposals have been received each semester, representing over 500 astronomers. The largest number of proposers are affiliated with Australian institutions. Beyond Australia, the countries with the largest numbers of proposers are the USA, UK, Germany and Italy.

In 2018, 131 papers using data from ATNF telescopes were published in refereed journals. Overall, our staff published 171 refereed papers, including those using data from other facilities (Fig. 1).

Governance

The Director of CASS is also the ATNF Director and is ultimately responsible to the Minister for Industry Innovation and Science via the CSIRO Executive and the CSIRO Board.

The CSIRO Board appoints the ATNF Steering Committee (ATSC) which provides high-level advice to the Director, and CSIRO, on the ongoing delivery of radio astronomy capabilities for the nation.

The ATSC appoints the ATNF Users Committee (ATUC), which represents the interests of astronomers who use ATNF telescopes, and the Time Assignment Committee (TAC), which reviews observing proposals. Committee membership is at Appendix A.

Staff and funding

The ATNF received $35.1m in funding from CSIRO: $1.2m for capital expenditure and $33.9m for operations (including overheads but not depreciation of assets). This is supplemented with $13.8m funding from external sources, such as sale of receivers and telescope time and funding for our SKA work (Fig. 2). A financial summary appears in Appendix B.

As at 30 June 2018, CSIRO employed 202 staff on activities related to radio astronomy around Australia (Fig. 3). The list of staff is at Appendix C.

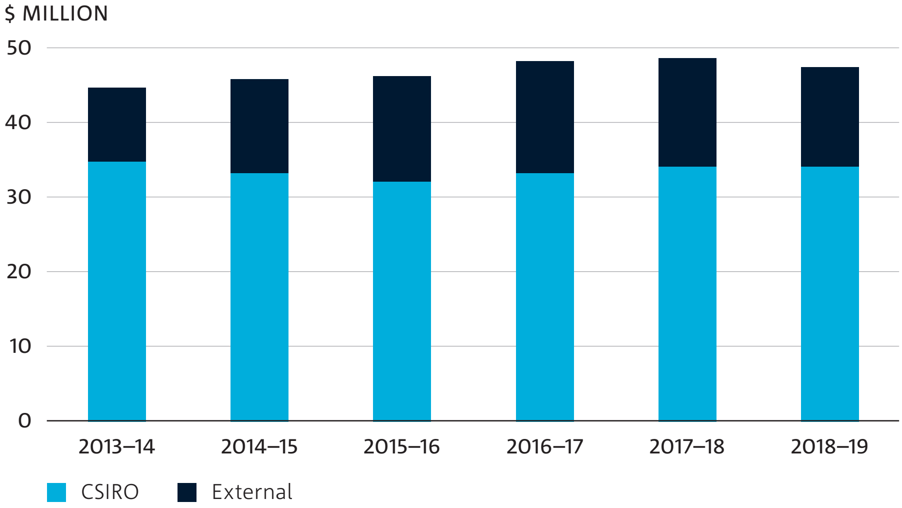


Figure 2: Funding by source over time.

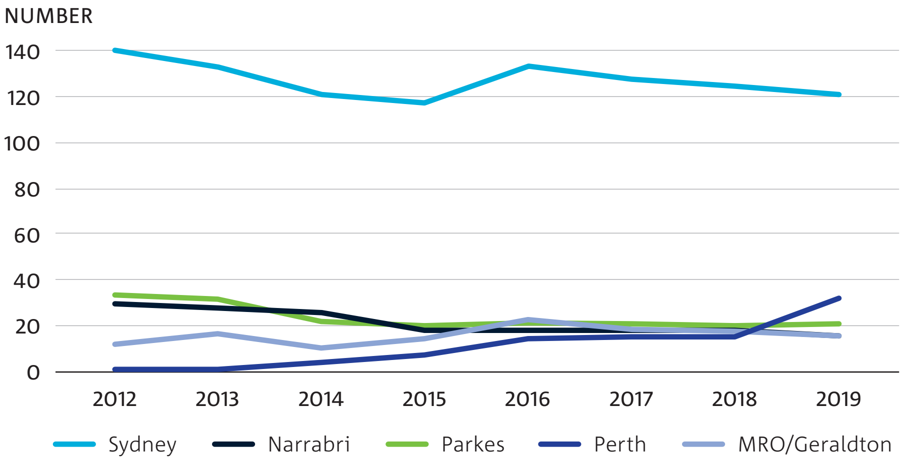


Figure 3: ATNF staff by site over time.

Traditional owners

We acknowledge the Traditional Owners of the land of all our sites and pay our respects to their Elders past, present and future:

- Marsfield, Sydney, Wallamuttagil people of the Gurringai nation
- Paul Wild Observatory, Narrabri, Gomeroi
- Parkes Observatory, Wiradjuri
- Mopra, Coonabarabran, Gamilaroi
- CDSCC, Ngunnawal and Ngambri
- Kensington, Perth, Whadjuk people of the Noongar nation
- Geraldton, Wilunyu and Nhaguja
- Murchison Radio-astronomy Observatory and Boolardy Station, Wajarri Yamatji.

All CSIRO sites, such as the Parkes radio telescope, will soon be flying the Aboriginal and Torres Strait Islander flags alongside the Australian flag. All sites now also have permanent plaques acknowledging the traditional owners. Photo: John Sarkissian.

Performance indicators

The Parkes radio telescope.
Photo: Alex Cherney.

Telescope usage

Over the two observing semesters covered by this Report 235 observing proposals were received: 112 for April to September 2018 and 123 for October 2018 to March 2019.

The oversubscription rate (the factor by which proposals exceed available telescope time) was 1.8 for the Parkes radio telescope and 1.9 for ATCA (after excluding allocations for ATCA Legacy Projects). The LBA continued to be in demand, with proposals exceeding available time by a factor of 2.0.

In this reporting period, observing proposals were received from 856 individual researchers from 35 countries. ATNF staff led 15% of these proposals, 26% were led by staff of other Australian institutions and 59% by overseas researchers.

On both ATCA and Parkes, up to 10% of time is made available as Director's Time. This is time that is initially not allocated in the published version of the schedule, but which can be made available later for approved observing projects. In this reporting period, Director's Time has been used for triggered NAPA (Non A Priori Assignable) and Target of Opportunity proposals, makeup time (where proposals have lost time for various reasons), extensions of existing projects, and small pilot studies or test observations.

The key performance goals for ATCA and Parkes are:

- at least 70% of telescope time be successfully used for observing
- no more than 5% of observing time be lost through equipment failure.

In this reporting period, time successfully used for observing at Parkes rose to 77%, as did ATCA (Fig. 4). Time lost to maintenance or through equipment failure and idle time was stable; however, bad weather again had more of an impact at Parkes (4%) than ATCA (1%).

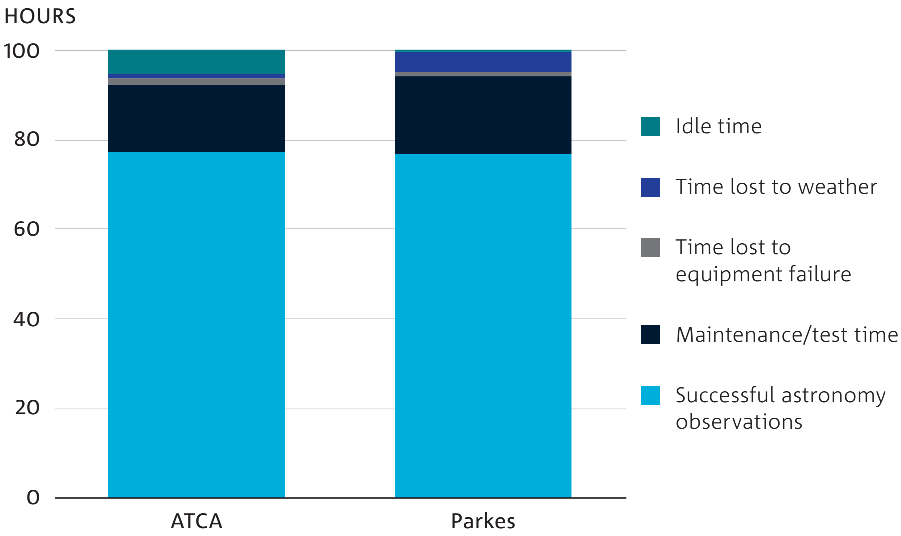
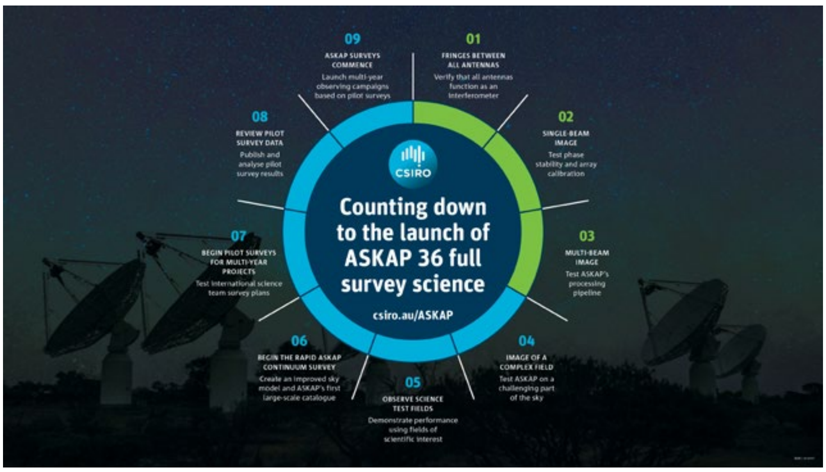


Figure 4: Use of ATCA and Parkes in this reporting period.

Over this time, ASKAP successfully concluded its Early Science phase. Hundreds of hours of observations were performed with sub-arrays of 12 and 16 antennas, with highlights including the EMU cosmology survey (now available on the public data archive) and four WALLABY Early Science fields, which resulted in a series of refereed publications. Since our first observation with all 36 antennas in February of 2019, we have developed a plan for a series of pilot surveys to test the telescope's readiness for full-scale surveys (shown below). Our fast transient detection and localisation program continues to operate alongside other regular observing. Test observations are being scheduled alongside ongoing maintenance, aimed at improving the telescope's reliability in advance of multi-year survey campaigns.

In addition, the ATNF handles proposals requesting observations with the 70-m and 34-m antennas of the CDSCC, which are available for mutually agreed periods under the Host Country arrangement between CSIRO and NASA. In this reporting period, 165 hours were used for observing under these arrangements: 77 hours for 'single dish' observing and 88 hours as part of the LBA.



ASKAP progress towards the commencement of full science surveys.

Time allocation

For the period from 1 April 2018 – 31 March 2019, 111 proposals were allocated time on ATCA or the Parkes radio telescope (counting each proposal only once each even though a number were submitted in both semesters): 67 proposals were given time on ATCA and 44 on Parkes. These numbers are lower than in the past due to the four on-going Legacy Projects on ATCA (which together take up ~35% of the available observing time), the Breakthrough Listen project at Parkes (which is allocated 25% of available observing time), and the sale of Parkes telescope time to the Chinese Academy of Sciences. Also in this period, 20 proposals were allocated time on the LBA and 1 on the CDSCC. Successful proposals are listed in Appendix D.

Time allocated to observing teams using ATCA and Parkes, and broken down in different ways, is shown in Figures 5-8 (where each year captures the observing semesters that end in that year, except for 2017 which captures October 2016 – March 2018). It is notable that ATNF staff are overrepresented as primary investigators (PIs) on Parkes proposals and that, in recent years, ATCA figures have a significant increase in 'other Australian' time allocation amongst all investigators. The latter increase can be attributed to the ATCA Legacy Projects, which involve large teams with strong Australian representation.

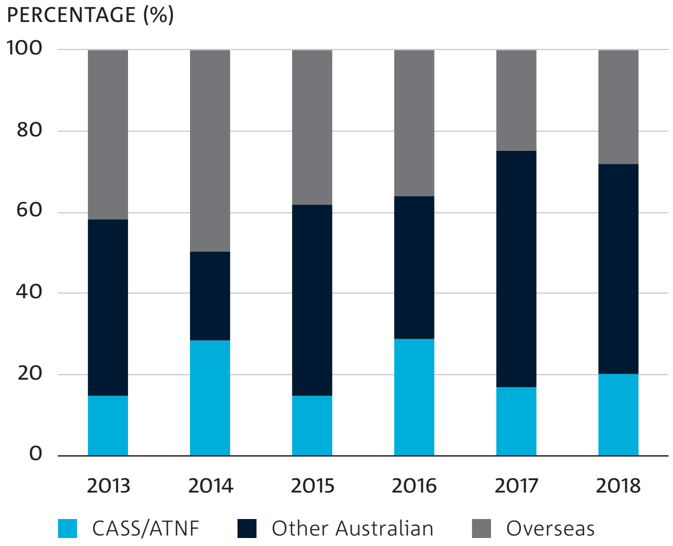


Figure 5: ATCA time allocation by PI.

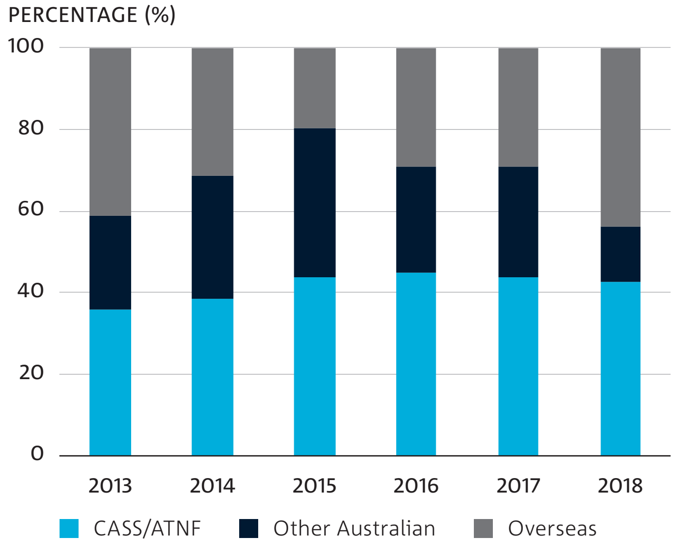


Figure 6: Parkes time allocation by PI.

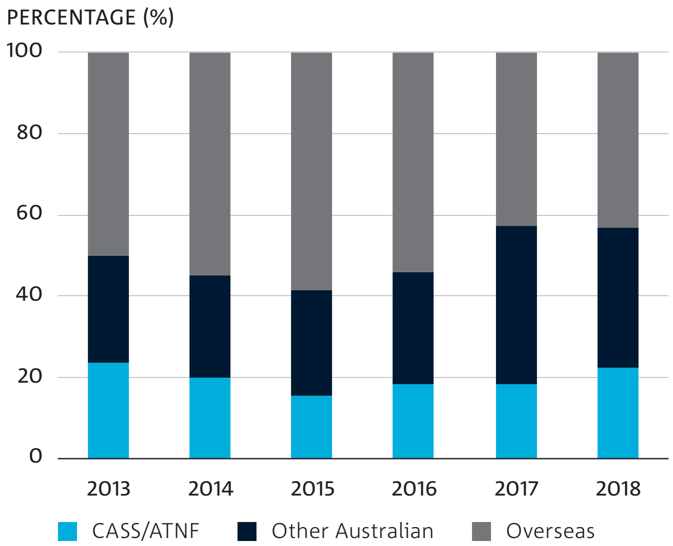


Figure 7: ATCA time allocation by all investigators. Time allocated to each proposal has been divided evenly between all authors on the proposal.

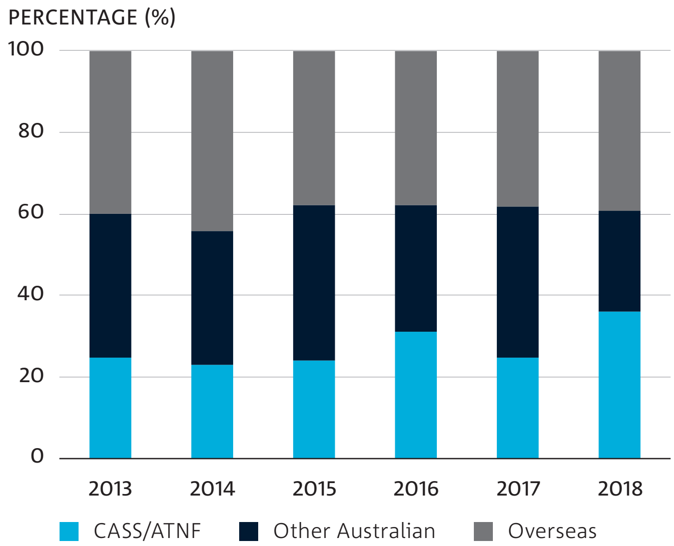


Figure 8: Parkes time allocation by all investigators. Time allocated to each proposal has been divided evenly between all authors on the proposal.

Publications

In 2018, 131 papers using data from ATNF telescopes were published in refereed journals. Of these, 64% included a CSIRO author or authors.

In 2018 there were 171 refereed publications by ATNF staff, including scientific papers with data from other facilities. In total, 224 refereed journal papers and 38 conference papers – both those using National Facility data and other papers by our staff – were published during the year. They are listed in Appendix H.

Publication counts have bounced back to levels comparable with preceding years as ASKAP publications accumulate following completion of the Early Science program.

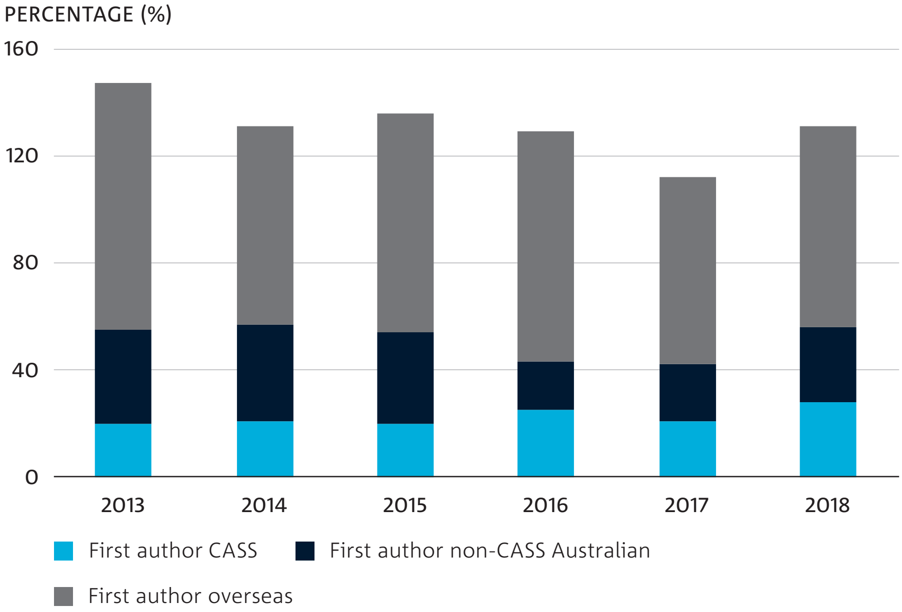


Figure 9: Publications that use data from ATNF telescopes by year.

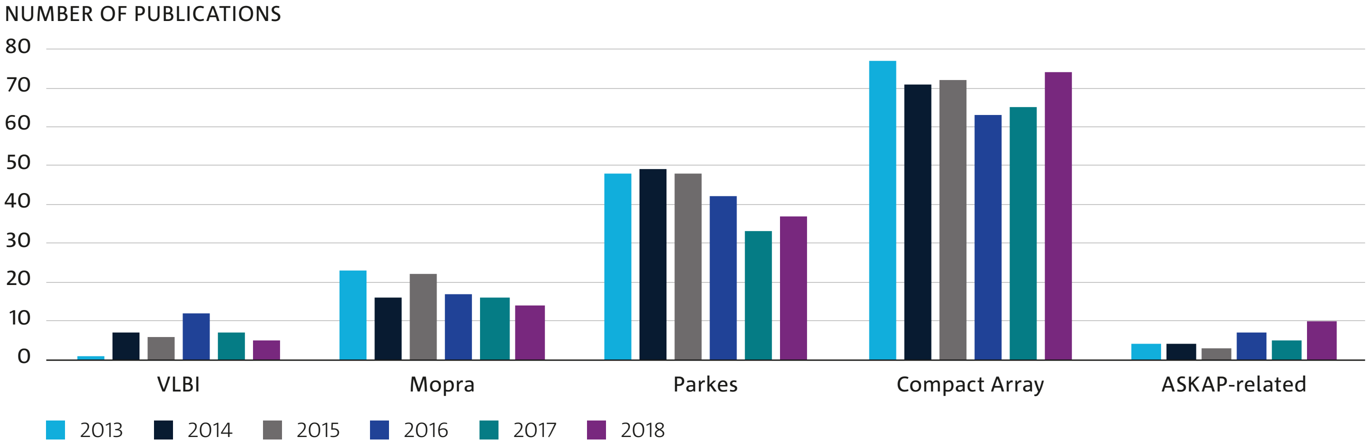


Figure 10: Publications in refereed journals that include data from ATNF telescopes grouped by telescope. A few papers with data from more than one instrument are counted more than once.

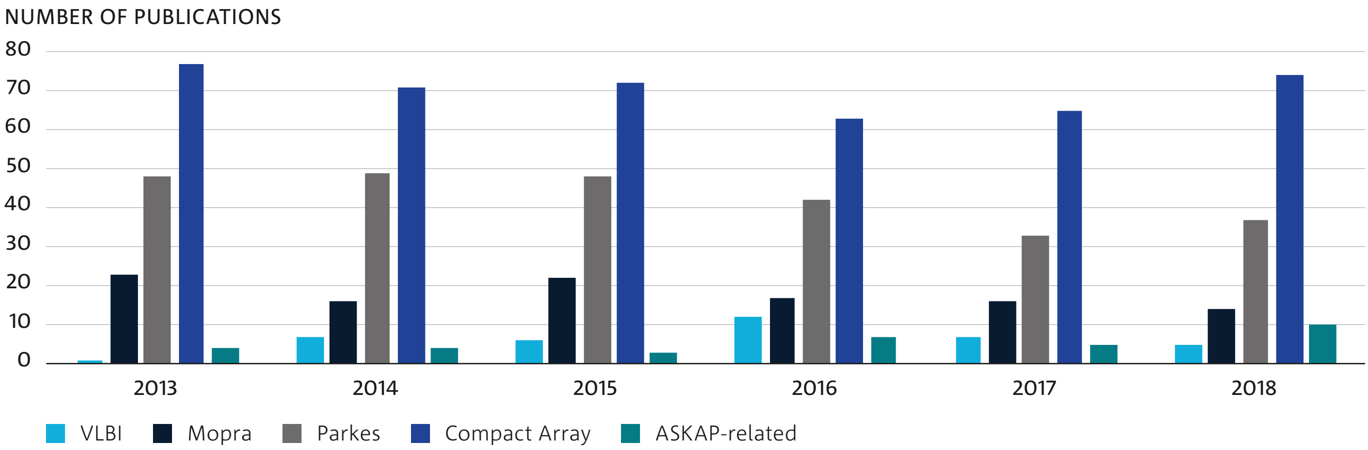


Figure 11: Publications in refereed journals that include data from ATNF telescopes grouped by year. A few papers with data from more than one instrument are counted more than once.

Science highlights

The ASKAP FRB localisation paper made the cover of *Science* magazine. Photo: Alex Cherney.

ATCA hunts for markers of the Galaxy's structure

Trey Wenger
University of Virginia

A new ATCA survey has found hundreds more of the regions that trace our Galaxy's spiral arms.

Spiral galaxies are often dotted with glowing pink patches. Those patches, called HII regions, mark spots in the galaxy's spiral arms where massive stars have just been born. The young stars emit ultraviolet radiation that ionises nearby hydrogen gas, knocking the atoms' electrons away from their partner protons. When the electrons and protons recombine, the atoms emit red light, creating the pink patches.

It's easy to pick out spiral arms in other galaxies. Mapping the structure of our own Galaxy is harder, because we're inside it. But HII regions can help, as they trace out the arms of the Galaxy like strings of lights.

Astronomers search for HII regions by looking for the radiation they emit. At first they looked for red light, but this is often blocked by dust, hiding some HII regions. But when ionised hydrogen atoms recapture their electrons, they also emit radio waves of specific frequencies – radio recombination lines. Radio waves are not blocked by dust and so can let us find many more HII regions.

By 2000 we'd identified about a thousand HII regions in our Galaxy. But few were in the outer part of the Galaxy; it seemed some had been missed. So astronomers started a new radio recombination line survey, which improve on previous surveys in two ways. Recent infrared telescopes such as WISE (Wide-field Infrared Survey Explorer) have found many candidate HII regions for follow-up. And radio telescopes can now observe across much wider bandwidths meaning we can look for many radio recombination lines at the same time.

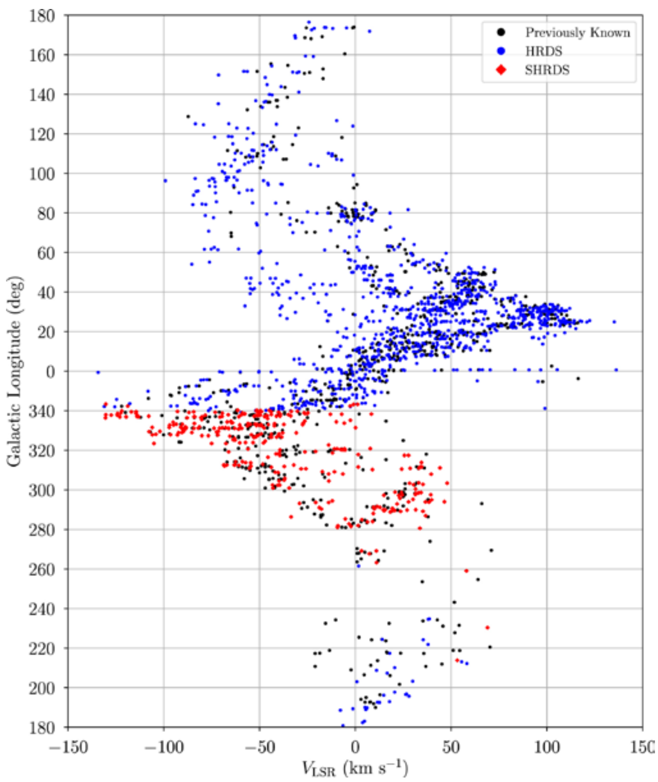
In the last decade astronomers using the Green Bank and Arecibo telescopes identified another 887 HII regions in the HII Region Discovery Survey (HRDS), more than doubling the number previously known in the northern sky. Using ATCA, Trey Wenger (University of Virginia) and his collaborators have extended HRDS to the southern sky as the Southern HII Region Discovery Survey (SHRDS). In February 2019 they published the survey's first data release, the SHRDS Bright Catalog.

Wenger et al. observed 282 ATCA fields in the third and fourth quadrants of the Galaxy (259° < *l* < 344°). ATCA's C/X-band receiver covers 4-10 GHz and the Compact Array Broadband Backend allows several windows within the band to be observed simultaneously. Wenger and his collaborators looked for both radio continuum emission and recombination line emission from hydrogen.

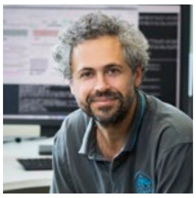
The survey targeted known or candidate HII regions less than 265 arcseconds in diameter at 6 GHz. Candidate sources also had to have a predicted continuum flux density greater than 60 mJy/beam at 6 GHz. The ATCA fields held only 100 known HII regions and 279 candidates that met these criteria. The SHRDS Bright Catalog lists 256 new HII regions, nearly doubling the number known in the longitude range 259° < *l* < 344° and appears to be complete for bright HII regions in the area surveyed.

In contrast with the northern survey, this first phase of SHRDS found only a few HII regions with velocities along the line of sight greater than 50 km per second. Such sources would be in more distant spiral arms and therefore fainter than close ones. SHRDS will next target HII regions that are fainter and so perhaps also further away.

Wenger, T.V.; Dickey, J.M.; Jordan, C.H. et al. "The Southern HII Region Discovery Survey. I. The Bright Catalog". ApJ Supplement Series, 240:24 (2019).



HII regions by Galactic longitude and velocity (V_{LSR}). All known Galactic HII regions with $|V_{LSR}|$ <150 km s^{-1} are shown. Black points are HII regions known prior to HRDS, blue points are HII regions discovered by the GBT and Arecibo HRDS and their extensions, and red diamonds are HII regions in the SHRDS Bright Catalog. (From Wenger et al. 2019)



A fast radio burst tracked to its lair

Keith Bannister
CSIRO

Astronomers using ASKAP have been the first to pinpoint the origin of a non-repeating fast radio burst (FRB). FRBs are spikes of radio energy that arrive from all directions of the cosmos and last just a few milliseconds. The first one was discovered in 2007, in data from the Parkes telescope. Dozens more followed in the next decade. It's now clear that they come from great distances – some from halfway across the universe. But their cause is still unknown.

Astronomers want to locate the bursts' starting points, for two reasons. First, a burst's home environment might rule out some possible causes or favour others. Second, finding the bursts' starting points would let us use them to learn about matter in intergalactic space – matter that is hard to learn about in other ways.

Until recent work with ASKAP only one burst had been tracked to its home galaxy: FRB 121102. This is one of just a few FRBs known to repeat. Locating a one-off burst is much harder.

ASKAP has been hunting for fast radio bursts since 2017 as part of the CRAFT (Commensal Real-time ASKAP Fast Transients) survey, which is jointly led by Keith Bannister (CSIRO), Jean-Pierre Macquart (ICRAR/ Curtin University) and Ryan Shannon (Swinburne University of Technology).

At first ASKAP hunted for bursts with eight antennas pointed in different directions. By mid-2018 it had discovered 26.

The CRAFT team then set out to both find and localise FRBs using 24 ASKAP antennas in a more orthodox mode, with all antennas pointed in the same direction. Used like this, the array had a field of view of 30 square degrees and angular resolution of 10 arcseconds. This resolution meant bursts with a high signal-to-noise ratio could be localised to better than an arcsecond. (An arcsecond is how big an apple looks from 16 km away.)

Localising a burst had two steps. A real-time detection pipeline summed the spectra from the antennas then searched the result for signs of an FRB. Meanwhile, data from all ASKAP's beams were stored for three seconds. If the pipeline identified an FRB candidate, the telescope would download the stored data for analysis.

The system swung into action on 24 September 2018 when ASKAP detected a burst (FRB 180924). The CRAFT team made an image from the downloaded data and used that to determine the burst's position. Because the burst had boomed in with a signal-to-noise ratio of almost 200, the uncertainty in its position was just 0.1 arcseconds.

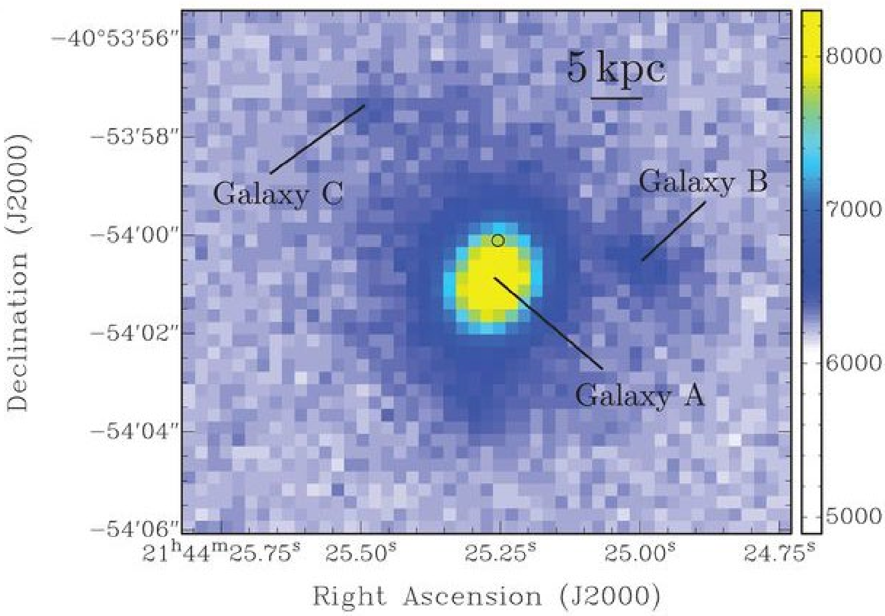
The researchers examined an optical image from the Dark Energy Survey and found a galaxy at exactly the right spot. They then triggered observations with large optical telescopes, getting deeper images of the field with ESO's Very Large Telescope (VLT), spectroscopy with the Gemini South Telescope, and integral-field spectra with the Keck-II telescope and the VLT.

All evidence points to the burst having come from the massive galaxy DES J214425.25–405400.81, which lies 3.6 billion light-years away. What's more, the burst started life not at the galaxy's centre but about 13,000 light-years out, in the galactic suburbs.

This galaxy is different from the home of repeater FRB 121102: it is more massive and 30 times brighter, but is forming fewer stars. The difference implies that either bursts have more than one kind of progenitor or their progenitors can occur in diverse environments.

At present ASKAP is the only telescope that can both find and localise large numbers of fast radio bursts.

Bannister, K.W.; Deller, A.T.; Phillips, C. et al. "A single fast radio burst localized to a massive galaxy at cosmological distance". Science, 365, 565–570 (2019). Published online in Science 27 June 2019, doi:10.1126/science.aaw5903.



The host galaxy of FRB 180924, imaged with ESO's Very Large Telescope. The FRB came from within the small circle. (From Bannister et al. 2019)

Supernova 1987A starts a new chapter

Yvette Cendes
University of Toronto

On 23 February 1987 an old star exploded in the southern sky forming Supernova 1987A. The explosion took place in the Large Magellanic Cloud, one of the small satellite galaxies that orbit our Milky Way. It was the closest supernova astronomers had seen since optical telescopes were invented four hundred years ago – close enough to study in great detail.

Two days after the explosion the Molonglo Observatory Synthesis Telescope (MOST) near Canberra detected an initial outburst of radio waves. This faded within weeks. But, in mid-1990, both MOST and ATCA saw radio emission reappear. ATCA has imaged the evolving supernova remnant (SNR 1987A) regularly since 1991.

The radio emission comes from electrons in clumps of gas around the site of the progenitor star, which are accelerated by the supernova shock wave. The emission was faint at first but grew brighter. The brightening was greatest on the radio remnant's eastern side, implying that the shock wave was moving fastest in that direction.

By the mid-1990s the shock wave had reached a ring of denser material around the explosion site. This ring seems to be the edge of an ionised region inside a larger bubble of gas shed by the progenitor star. When the shock wave reached it, the ring started to glow more brightly in visible light. Around the same time, the radio emission also began brightening faster.

PhD candidate Yvette Cendes (University of Toronto) and her collaborators have now reviewed ATCA observations of SNR 1987A, made from 1992 to 2017 at frequencies around 9 GHz. Like previous researchers, they modelled the emission as a truncated sphere to determine the shock wave's speed and other parameters. They find that the shock wave was expanding at ~2300 km s^{-1} until around 2012 but then sped up to ~3610 km s^{-1}.

The radio remnant is still brightest on its eastern side, but the western side is beginning to brighten. Its south-eastern part is starting to fade. Similar changes have been seen at optical wavelengths and in X-rays. This changing pattern of brightness and the increase in speed of the shock wave suggest that the shock wave is leaving the central ring, exiting first at the south-east.

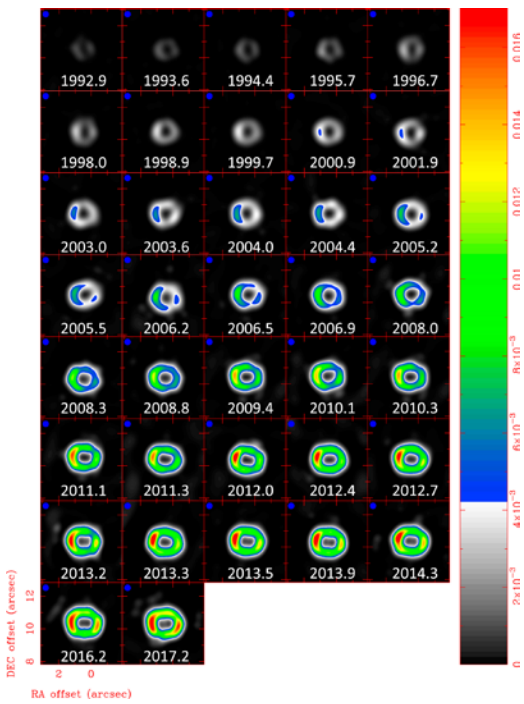
The shock wave is now moving into thinner gas shed by the progenitor star beyond the central ring. We know little about this material, but how the shock wave behaves from now on will give us clues and tell us more about the progenitor star.

In a separate ATCA project, Giovanna Zanardo (ICRAR/University of Western Australia) and her collaborators have become the first to measure linear polarisation in SNR 1987A and use it to map the remnant's magnetic field. SNR 1987A is the youngest nearby supernova remnant known, so this is our first look at the magnetic field of an early-stage remnant.

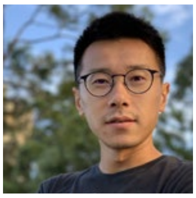
Older supernova remnants tend to have fields that run parallel to remnant's outer surface; many young ones have fields that radiate outwards. Zanardo et al. found that in SNR 1987A the central field is aligned along a north-west to south-east axis, while the outer field is radial and extends right across the ring of radio emission (that is, the entire region where the emitting electrons are accelerated). SNR 1987A gives us a unique opportunity to watch this field evolve.

Cendes, Y.; Gaensler, B.M.; Ng, C.-Y.; Zanardo, G.; Staveley-Smith, L.; and Tzioumis, A.K. "The reacceleration of the shock wave in the radio remnant of SN 1987A". ApJ, 867:65 (2018).

Zanardo, G.; Staveley-Smith, L.; Gaensler, B.M.; Indebetouw, R.; Ng, C.-Y.; Matsuura, M.; and Tzioumis, A.K. "Detection of linear polarization in the radio remnant of Supernova 1987A". ApJL, 861:L9 (2018).



False-colour images of SN 1987A made from ATCA observations at 9 GHz taken from 1992 (top) to 2017 (bottom). North is up and east is left. The scale at the right indicates intensity (in Janskys/ beam). The blue dot in the corner of each image is the beam size. (From Cendes et al. 2018)



A magnetar revives at radio wavelengths

Shi Dai
CSIRO

The new ultra-wideband receiver on the Parkes radio telescope has captured evidence that may help explain how some magnetars create radio emission.

Magnetars are neutron stars with extraordinarily strong magnetic fields (10^{14-15} G) that power outbursts of X-rays. We usually spot magnetars by detecting those outbursts.

Radio pulsars too are neutron stars. They are defined by their regular pulses, the result of a beam of radio waves sweeping repeatedly over Earth as the pulsar spins.

Magnetars and pulsars seem a little different. On average, magnetars spin more slowly and their spin rate decreases more quickly. But four special magnetars show radio pulsations, suggesting that magnetars are in fact a subclass of pulsars.

The first of these four objects to be known was magnetar XTE J1810–197. Astronomers noticed it in 2003, when it produced a burst of X-rays. In 2006 they found it was also emitting radio pulses. Those pulses lasted for 20 months, fading away in 2008. But they came back in late 2018.

Shi Dai (CSIRO) and his collaborators observed XTE J1810–197 with the Parkes radio telescope over a week in December 2018, using the telescope's newly installed ultra-wideband receiver. The receiver covers 704-4032 MHz; Dai et al. observed in 26 sub-bands within that range.

The radio pulses showed sub-structure, with leading and trailing components flanking the main pulse. The overall shape of the pulse profile did not change much during the week of observations, but individual pulses varied dramatically.

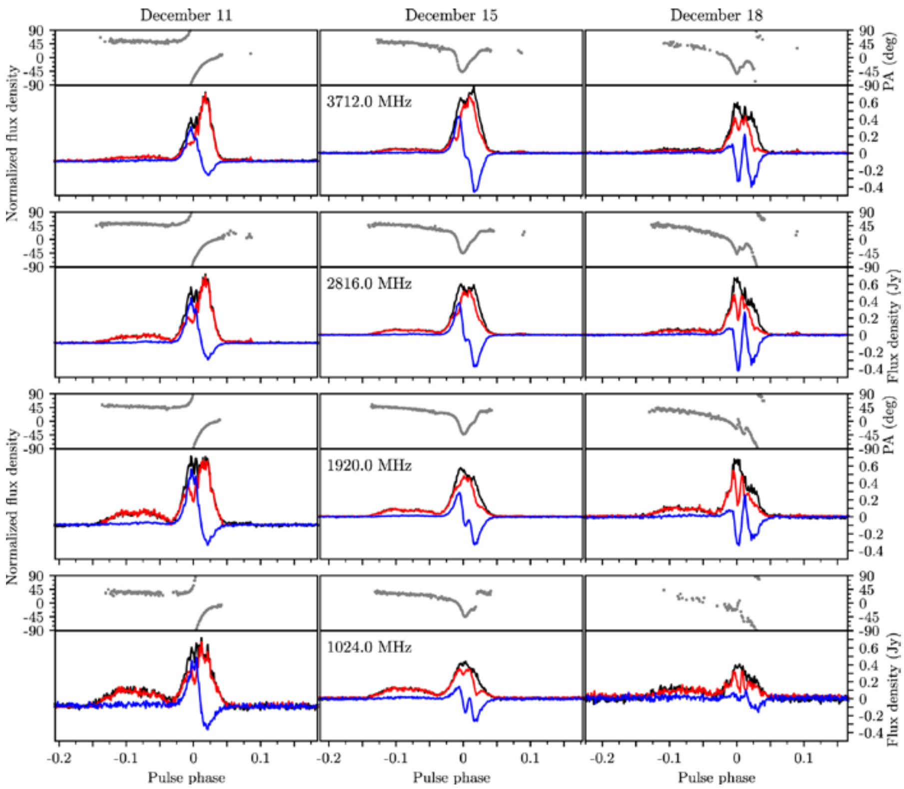
A radio pulsar's pulses are usually polarised: linearly, circularly or both. During the week Dai et al. observed XTE J1810–197 they saw its main pulse vary in both linear and circular polarisation. In particular, the direction of the linear polarisation changed in a way that didn't square with a simple model of pulsar emission. Such changes weren't seen in 2006-07: at that time the polarisation of the main pulse was stable.

Polarisation tells us about the geometry of magnetic fields. Dai et al. think the variations they saw probably arose from shifts in the structure of the star's magnetosphere, a region of magnetic field around the star full of charged particles.

An X-ray outburst could have caused shifts in the magnetosphere and also triggered the radio pulses. But even a stable magnetosphere is known to be able to alter the polarisation of radio waves travelling through it, so the observed changes might instead arise from these propagation effects.

While XTE J1810-197 is an ongoing puzzle, the observations of Dai et al. showed the worth of the Parkes ultra-wideband receiver, which was able to capture the changes taking place in this dynamic object over a much wider range of frequencies than had previously been possible.

Dai, S.; Lower, M.E.; Bailes, M. et al. "Wideband polarized radio emission from the newly revived magnetar XTE J1810–197". ApJL, 874:L14 (2019).



Averaged polarisation pulse profiles centred on 3712, 2816, 1920 and 1024 MHz, each with a bandwidth of 128 MHz. In each panel, the black line shows total intensity, red linear polarisation, and blue circular polarisation; the position angle of the linear polarisation is shown above. The observation on December 11 was not flux calibrated and the normalised flux density is shown. (From Dai et al. 2019)

An ATCA survey gives a detailed view of the magnetic fields in our Galaxy

Dominic Schnitzeler
Max Planck Institute for Radio Astronomy

Magnetic fields permeate the Universe. We know a little of what they do – how they control the distribution and density of cosmic rays (charged particles) in space, for instance – but we're still unsure how they affect forming stars. We also want to know when and how magnetic fields formed in the early Universe, and how they've evolved since then. To understand magnetic fields better we need to measure their strength and location in more detail.

Radio waves are a key tool for doing this. Some radio sources emit radio waves that are polarised (the waves are aligned in a particular direction). When polarised waves travel through a magnetic field, the field rotates the plane of polarisation – an effect called Faraday rotation. Measuring this gives us the field strength. The total amount of Faraday rotation that we observe comes from magnetic fields in three places: the galaxy the radio waves came from, our own Galaxy, and the space in between.

To study cosmic magnetic fields, Dominic Schnitzeler (Max Planck Institute for Radio Astronomy) and his collaborators have surveyed the southern sky for compact radio sources that emit polarised radio emission and measured their Faraday rotation. This work, carried out with ATCA, draws on an earlier survey for polarised emission done with the Parkes radio telescope: S-PASS, the S-band Polarisation All Sky Survey.

S-PASS was a ground-breaking survey: it revealed giant streams of magnetised gas flowing from the centre of our Galaxy, for instance. But it was not ideal for measuring Faraday rotation because it was made over a small range of frequencies (a bandwidth of 256 MHz at 2.3 GHz); Faraday rotation is better measured over a wide range. So Schnitzeler and his collaborators selected radio sources from S-PASS and observed 4563 of them with ATCA over 1.3-3.1 GHz.

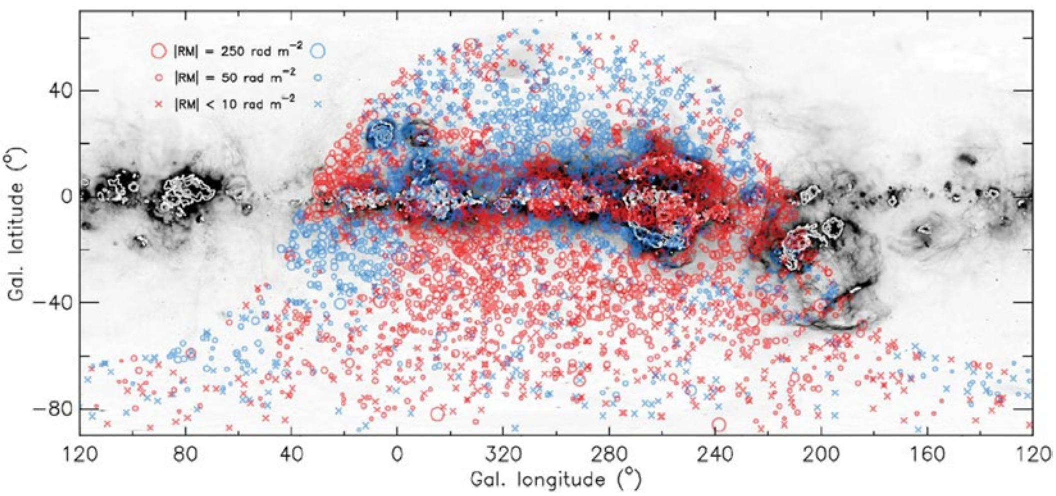
This wide bandwidth (the widest for any southern hemisphere survey of this kind) meant the S-PASS/ATCA survey could measure rotation measures more accurately than S-PASS. The new survey also identified sources, such as double-lobed galaxies, that show different amounts of Faraday rotation in different parts of their structure.

The S-PASS/ATCA rotation measures are generally negative above the Galactic plane and positive below it. This pattern is caused by the Galaxy's large-scale magnetic field. It has been seen since the earliest studies of rotation measures but S-PASS/ATCA reveals it more clearly in the southern sky. The new data complement a major catalogue of northern-sky rotation measures made by Taylor, Stil & Sunstrum (2009) using data from the Very Large Array in the United States.

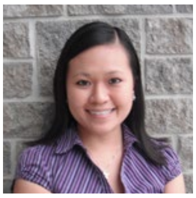
The closer extragalactic sources are to the Galactic plane, the greater their rotation measures, meaning that the Galaxy is boosting the Faraday rotation. To calculate how much it adds, Schnitzeler et al. compared the rotation measures of sources that were close together on the sky. They concluded that extragalactic sources probably have very small intrinsic rotation measures and the Galaxy causes most of the Faraday rotation we observe. The Galaxy's contribution also appears to be smooth on very small scales.

In line with previous studies, S-PASS/ATCA found that 45-60% of its sources had a single rotation measure. This means that most of the rotation measures determined in the past from narrowband observations can still be used with confidence.

Schnitzeler, D.H.F.M.; Carretti, E.; Wieringa, M.H.; Gaensler, B.M.; Haverkorn, M.; and Poppi, S. "S-PASS/ATCA: a window on the magnetic universe in the Southern hemisphere". MNRAS, 485, 1293–1309 (2019).



Rotation measures in the southern sky from S-PASS/ATCA, overlaid on an Hα image of the Galactic plane (Finkbeiner, D.P., 2003, ApJS, 146, 407). Colour shows the sense of the rotation (blue is negative, red positive). (From Schnitzeler et al. 2019)



WALLABY Early Science examines galaxy 'villages'

Karen Lee-Waddell
CSIRO

The team running WALLABY, one of ASKAP's key surveys, has made the survey's first Early Science observations: studies of small groups of galaxies.

WALLABY (the Widefield ASKAP L-band All-Sky Blind Survey) will look for neutral hydrogen gas, a key component of galaxies, across 75% of the entire sky. This survey will give us the distances of 600,000 galaxies plus the masses of neutral hydrogen gas and dark matter they contain – measurements that will help us understand what drives change in galaxies over time.

To prepare for the full survey, the survey team has made Early Science observations to produce useful science and validate ASKAP's data-reduction pipeline.

The team made its first observations on small groups of galaxies. Most galaxies in the nearby universe live in such groups, or 'villages', of at most a few tens of galaxies. These environments are not very dense, but the galaxies may still 'jostle' each other, sometimes colliding or making near misses. Buffeted about like this, galaxies can gain or lose neutral hydrogen gas – a major component of most galaxies, and the one that ultimately forms stars. So a galaxy's neighbourhood determines how much it will interact with the surrounding galaxies and thus influences how it will evolve.

Radio telescopes can detect streams of neutral hydrogen pulled out of interacting galaxies by 'tidal' forces. These streams are clues as to how the galaxies have interacted with each other.

Although small groups are the most common environments for local galaxies, astronomers have not studied them much. More often they've looked at larger 'town-like' clusters made up of over a thousand galaxies. That's because it takes more telescope time to observe a large number of galaxies if they are in small, low density groups.

With its wide field of view, ASKAP is set to change that. WALLABY will let astronomers study many galaxy groups in detail and draw general conclusions about how these environments shape galaxy evolution.

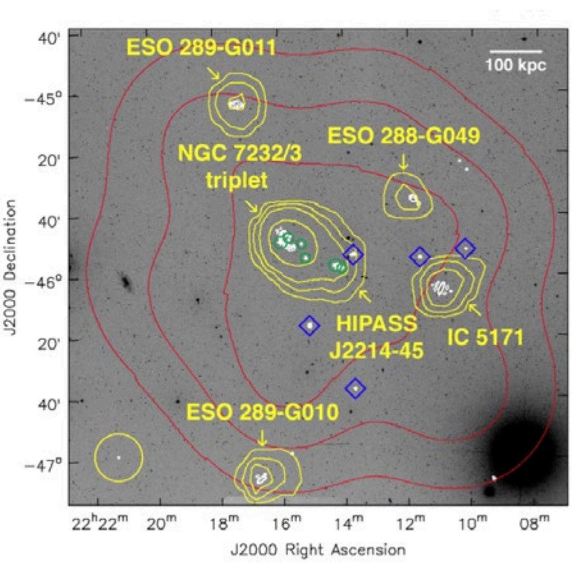
The two first WALLABY Early Science papers arise from a single set of ASKAP observations, led by Karen Lee-Waddell (CSIRO), that cover a field centred on the NGC 7232 galaxy group, a triplet of spiral galaxies: NGC 7232, NGC 7232B and NGC 7233. Lee-Waddell and her collaborators made about 180 hours of observations over 16 nights, using 12 ASKAP antennas and limited bandwidth (48, 192, and 240 MHz rather than the full ASKAP bandwidth of 304 MHz).

ASKAP detected 17 HI sources close to the NGC 7232/3 triplet. Six of these detections are well-known, HI-rich galaxies; five are galaxies whose stars have been seen, but which ASKAP has detected in HI for the first time. The other six HI detections are new and are probably tidal debris from the NGC 7232/3 triplet. One of these six sources may be a new dwarf galaxy that is starting to form from tidal debris.

The same ASKAP field holds another galaxy group whose largest member is NGC 7162. PhD candidate Tristan Reynolds (ICRAR/University of Western Australia) led the analysis of this group. He and his collaborators detected six galaxies in neutral hydrogen, increasing the number of galaxies known in the group from four to seven. ASKAP's high resolution also let them calculate the dark matter content of the group's four spiral galaxies. These objects turn out to be dominated by dark matter, which accounts for 81-95% of their masses.

Lee-Waddell, K.; Koribalski, B.S.; Westmeier, T. et al. "WALLABY Early Science – II. The NGC 7232 galaxy group". MNRAS, 484, 5248–5262 (2019).

Reynolds, T.N.; Westmeier, T.; Staveley-Smith, L. et al. "WALLABY early science – I. The NGC 7162 galaxy group". MNRAS, 482, 3591–3608 (2019).



The NGC 7232 galaxy group. White contours show HI intensity measured by the WALLABY Early Science observations; yellow contours are from the earlier HI Parkes All-Sky Survey (HIPASS); the background is an archival optical image. Blue diamonds mark new ASKAP HI detections that appear to have stellar counterparts while green circles indicate probable tidal debris with no detectable stellar counterparts. Red contours represent sensitivity levels (15, 50 and 90 per cent of peak sensitivity). The circle and dot at bottom left show the telescope beam sizes and the scale bar at upper right shows physical size. (From Lee-Waddell et al. 2019)

VLBI pins down details of exotic binary

James Miller-Jones
Curtin University

In 1992 astronomers using the Parkes radio telescope found an unusual double star system in our Galaxy. Now a set of telescopes including Parkes has made precise measurements that shed light on how the system creates gamma rays.

The system's two stars are an odd couple. One is a radio pulsar (a small, dense star), PSR B1259–63; the other a bright, hot star at least 15 times the mass of the Sun. The pulsar loops around its massive companion in a highly eccentric orbit. Streams of particles flow from both stars. When the pulsar swoops close to its partner, the streams collide, creating a flare of high-energy gamma rays.

Astronomers have studied this system – one of just seven known gamma-ray binaries – for decades. But they'd been unable to work out some details of how the gamma rays are produced because they lacked exact measurements of the system's distance and the tilt of its orbital plane.

Now a team led by James Miller-Jones (ICRAR/Curtin University) has measured the pulsar's orbit precisely, using a technique called very long baseline interferometry (VLBI). This involves observing simultaneously with a set of widely separated radio telescopes and comparing their observations. VLBI can resolve very small details on the sky and so is good for measuring small changes in an object's position.

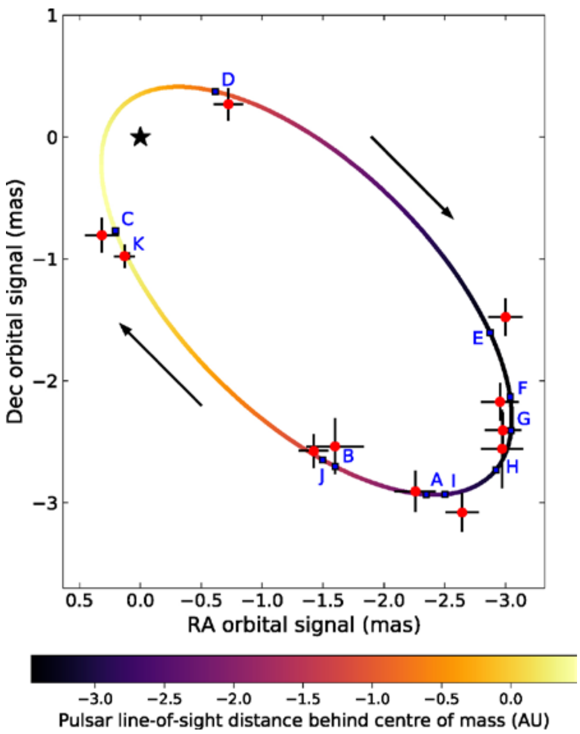
PSR B1259–63 orbits its companion once every 3.4 years. Miller-Jones and his collaborators tracked its motion on the sky over a slightly longer period, 4.4 years, observing its position on the sky 11 times. To do this, they used the used the Long Baseline Array and antennas in New Zealand and South Africa.

The pulsar's apparent motion on the sky has three causes. One is its long, looping orbit around its companion. A second is how the pulsar and its partner are moving as a pair through space – their so-called proper motion. The third is parallax, the system's apparent motion caused by observing it from different points along the Earth's own orbit (that is, at different times of year). Fortunately, these three components can be disentangled.

Miller-Jones and his collaborators used the parallax to determine a new distance to the system that, unlike previous ones, does not rely on any assumptions. The new value, 8500 light-years (2.6 kpc), is slightly larger than the previous one. This means that the gamma-ray flares must also be intrinsically brighter than we'd thought, probably as a result of a process called Doppler boosting.

The researchers determined the angle between the plane of the pulsar's orbit and our line of sight, 154±3°, which better pins down the individual masses of the pulsar and its companion. They also obtained a new value for the system's proper motion through space (26±8 km s^{-1}) that is ten times more precise than the previous estimate, and used this to determine the system's birthplace. As previous work had suggested, the pulsar and its partner seem to have started life in a loose group of hot stars called the Centaurus OB1 association, about 25 light-years from their present position.

Miller-Jones, J. C. A.; Deller, A.T.; Shannon, R.M. et al. "The geometric distance and binary orbit of PSR B1259–63". MNRAS, 479, 4849–4860 (2018).



The observed orbital motion of PSR B1259–63. The solid line is the best-fitting orbit. Colours indicate the pulsar's distance along the line of sight during its orbit: yellow marks where the pulsar is furthest from us, black where it is closest. Red circles show the measured positions (with 1σ error bars) while blue squares are predicted positions. The black star marks the system's centre of mass. The pulsar moves clockwise around its orbit. (From Miller-Jones et al. 2018)

Observatory reports

The Australia Telescope Compact Array turned 30 in 2018. Photo: Jamie Stevens.

Parkes radio telescope

Science highlights include:

- The first scientific paper describing data taken with the new low frequency Ultra-Wideband receiver: UWB-L (Dai et al. 2019 ApJ 874, 14).
- Continued contribution to the rapidly evolving field of FRBs with further detections by numerous projects (Petroff et al. 2019 MNRAS 482, 3109, Caleb et al. 2018 MNRAS 478, 2046, Price et al., 2019 MNRAS 486, 3636, Oslowski et al. 2019 MNRAS 488, 868).
- Several high-profile publications from our contracted telescope time, including Breakthrough Listen's Fast Radio Burst detection (referenced above) and the first pulsar discovered by China's Five hundred metre Aperture Spherical Telescope (FAST), as confirmed by Parkes (Qian et al. 2019 Sci. China-Phys. Mech. 62, 959508), plus further new detections (Zhang et al. 2019 ApJ 877, 55).

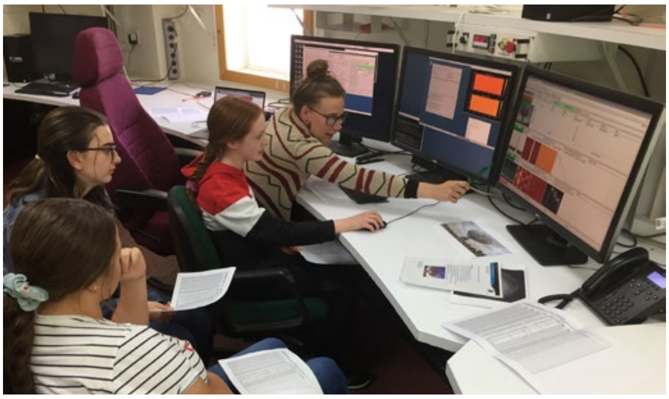
Long-running projects continue to have scientific impact, for example: the 15th publication from the High Time Resolution Universe Pulsar Survey (Burgay et al. 2019 MNRAS 484, 5791), new constraints from the Parkes Pulsar Timing Array (Porayko et al. 2018 Physical Review D 98, 10), and significant data releases from the Galactic Magneto-Ionic Medium Survey (Dickey et al. 2019 ApJ 871, 106) and S-band Polarisation All Sky Survey - SPASS (Carretti et al. 2019 MNRAS, accepted).

One of Parkes' largest projects this year was collaboration with NASA to track Voyager 2 as it passed through the heliopause (the boundary of our Solar System). We began in November 2018 and went through to February 2019, spending approximately 900 hrs on the project (on average, around 10 hours per day for 11 out of 14 days per fortnight), successfully tracking the craft as it left the influence of our Sun for interstellar space. This project would not have been possible without the generous co-operation of Breakthrough Listen, the Chinese Academy of Sciences and the many astronomers who had been awarded telescope time, all of whom willingly accepted a delay in their scheduled observations. Even with this one-off dedication of telescope time, more than 60% of Parkes' time was still available for merit-based access.

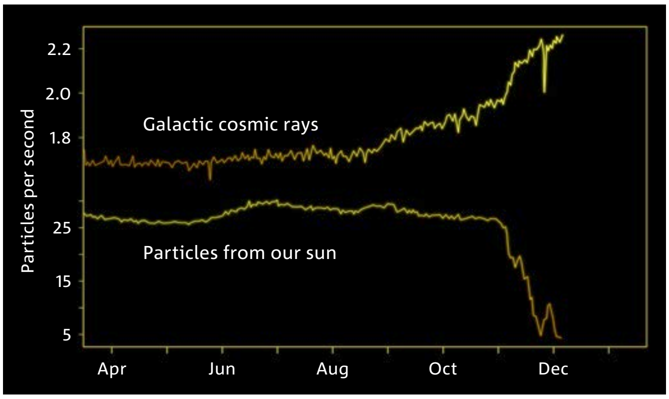
The Breakthrough Listen project (Price et al. 2018 PASA 35, 41) this year completed its first pass of a Galactic plane survey and has undertaken searches for extra-terrestrial intelligence with the UWB-L.

Following the Master Equatorial and switchboard work reported last year, telescope operations have continued their path to greater efficiency with the telescope lubrication system undergoing a significant upgrade with installation of a dedicated platform and handrail, removing the need to hire elevated work platforms and for staff to be harnessed. Parkes' receiver technology continued its evolution with the UWB-L undergoing extensive commissioning through the year and the replacement for the multibeam receiver, the cryogenically cooled Phased Array Feed, or CryoPAF, undergoing further design work (see Technology development).

The GPU-based backend MEDUSA was supplemented with its sibling, EURYALE, a data-staging server to facilitate data handling and archiving (including the evolving new data format for UWB-L spectral line data, the Single Dish Hierarchical Data Format, SDHDF). There is now well over 1 PB of Parkes data in the Data Access Portal and it has led to the discovery of two new pulsars in 47 Tucanae (Pan et al. 2016 MNRAS 459L, 26) and many other results (see Data archives).



Jane Kaczmarek and students of Trundle Central and Aurora Colleges in the control room at Parkes – only the second time a PULSE@Parkes session has been run at Parkes. Photo: Rob Hollow.



Voyager 2 crosses the heliopause on 5 November 2018, as tracked by Parkes. Top curve: Galactic cosmic rays. Bottom curve: particles from our Sun. Image: NASA Goddard Space Flight Center.

Australia Telescope Compact Array

Science highlights include:

- Deep radio imaging at 2.1 GHz of the 25 square degree ultimate XMM extragalactic survey south field. The XMM X-ray satellite was used to conduct a deep survey of this field, with ATCA observations forming part of an international campaign to characterise the sources at different wavelengths. This ATCA survey of 6287 sources is the largest to be conducted at such a low noise level: 41 µJy per beam (Butler et al. 2018. Astronomy & Astrophysics, 620, A16).
- A polarimetry survey of the southern sky using the 16-cm receivers showed that the primary contributor to rotation measures for compact background sources is the Galactic foreground (Schnitzeler et al. 2019 MNRAS 485, 1293).
- The long-running longitudinal study of the remnant of supernova 1987A this year published results (see Science highlights). A separate project was the first to map the remnant's magnetic field (Zanardo et al. 2018 ApJL 861, L9).
- This year ATCA joined Parkes in selling telescope time. The first contract project started as a NAPA project (that is, one given observing time at short notice in response to detection of a defined trigger). Originally granted 24 hours' time on a NAPA basis, the project was then scheduled another 24 hours to look for flux density evolution in the Circinus X-1 binary system over two of its 16.6-day orbits.

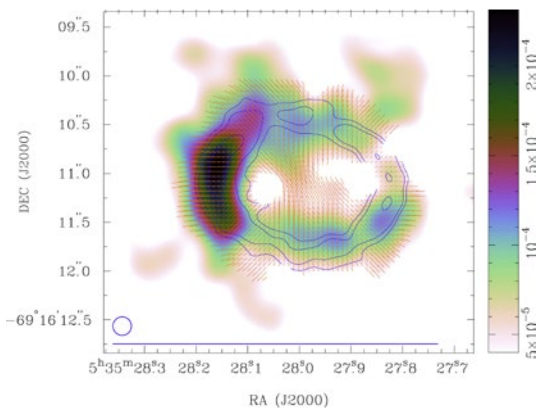
First use of the rapid response over-ride system was made in January 2019 to observe a star that was observed to flare in X-rays from the Swift/MAXI instrument (project C3200). ATCA was pointing at the star and taking data within six minutes of the detection of the flare and saw several peaks in the radio flux density within the first hour.

ATCA Legacy Projects (large investigations, not reproducible by combining smaller projects, and which are intended to generate data of lasting importance) continued to be supported with roughly 35% of observing time over the reporting period. The two highest priority projects, GAMA Legacy ATCA Southern Survey (GLASS) and Imaging Galaxies Intergalactic and Nearby Environment (IMAGINE), are making good progress with data reduction and analysis and should be finishing their observing campaigns within the next year.

Our atmospheric seeing monitor (which measures water vapor in the lower atmosphere that interferes with observing at ATCA's higher frequencies and thus informs the scheduling of observations) underwent a complete redesign this year. The work was prompted by our old satellite service, Optus C1, moving out of its geosynchronous orbit to conserve fuel and prolong its life. The new seeing monitor went live in May 2019 and uses a 19 GHz beacon on the National Broadband Network's Skymuster 2 satellite.

Maintaining the electrical safety of our ageing infrastructure continues to be a priority. The mains switchboard in the control building was replaced in early 2019. On the antennas, the power cables that connected an antenna to a station post (providing power and communications) have been replaced with a new system which removes several potential safety hazards and has mechanical advantages during antenna reconfigurations.

Our visitor centre continues to be popular and increasingly so at night, with visits by photography enthusiasts up markedly in recent times. To help deal with the increase in radio frequency interference (RFI) from visitors leaving their phones on, a new RFI detector has been designed based on the open source HackRF-One system. This new detector scans for signals in mobile phone, WiFi and Bluetooth frequency ranges, and broadcasts a recorded announcement asking people to put their devices into flight mode. If this proves successful, similar detectors may be rolled out to our other observatories.



The first map of the magnetic field in the remnant of Supernova 1987A, made with ATCA. Orange vectors show the field's direction. The colour scale shows the intensity of polarised radio emission at 44 GHz; blue contours show the total emission intensity. Photo: Zanardo et al.

This year we farewelled Robin Wark who led the observer support team for essentially the entire life of the telescope, nurturing generations of astronomers and made countless vital contributions to the success of the telescope.

ATCA history and significance

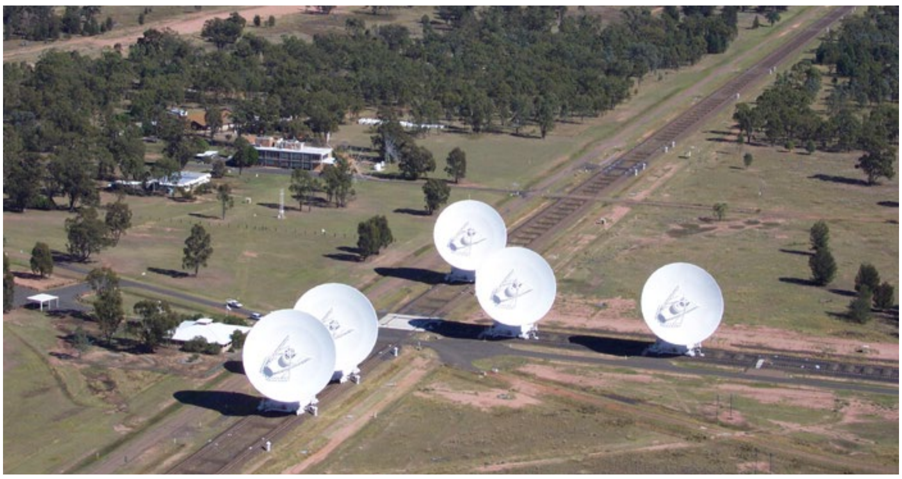
It was 1981 and radio astronomy in Australia was at a critical point. Do we invest more and build on the success of the pioneering radio astronomers who flourished under the tutelage of scientists who came here during the Second World War to work on radar and associated research, or do we let it go? CSIRO brought in a new leader for its Division of Radiophysics, R.H. (Bob) Frater, and ordered him to 'sort it out'. Frater was either to develop a successful proposal for a new facility and attract funding, or close radio astronomy.

Frater hand-picked a team of largely ex-pat experts and in 1982 successfully put to Government a proposal for what we now know as the Australia Telescope Compact Array (ATCA): six 22-m antennas, five on a 3 km east-west railway track and one fixed 3 km further west. The location was to be near Narrabri (site of the radio heliograph, which was slated for closure in 1984), plus another dish near Coonabarabran on a property called Mopra. It was pitched as a landmark Bicentennial Project – as a project that was looking to the future, and which had to be finished by 1988.

The aim was to operate ten bands from 0.3-116 GHz which would expand Australian radio astronomy into millimetre wavelengths and make the most of a location where the centre of our Galaxy passes directly overhead. ATCA would complement both Australia's optical facilities, such as the Anglo-Australian Telescope, and northern hemisphere radio telescopes such as the US Very Large Array (VLA).

ATCA was to provide a showpiece of Australian technology so was overwhelmingly Australian in design and construction. As we later found with ASKAP, this required considerable effort upskilling local companies to meet the stringent requirements of a cutting-edge radio telescope. CSIRO also kick-started commercial production of microwave monolithic integrated circuits (MMICs) in Australia.

ATCA also pioneered wide bandwidth receivers, which have had a massive impact on astronomy and in which CSIRO remains the world leader. The Overseas Telecommunications Commission took the antenna design and used it to break into the Asian market. This was later found to be the greatest economic return from ATCA's $31m funding, estimated by the Bureau of Industry Economics at $100m.



Throughout construction ATCA garnered a massive amount of interest. Its Visitor Centre (centre left) opened in 1990. This image taken soon after the northern spur opened in 1998. Photo: CSIRO radio astronomy image archive.

Coming in on time and on budget, ATCA was opened by the Prime Minister of Australia, the Hon. R. J. L. (Bob) Hawke AC, on 2 September 1988 (see inside cover). ATCA made its first image in May 1989 with a subset of antennas and commenced operating as a National Facility in April 1990 with five antennas. By March 1991 the sixth antenna was completed and full operations were underway with the initial offering of four bands (1.5, 2.3, 5.0 and 8.6 GHz). In early 1988 Frater lured me from the VLA to be the inaugural Director of the ATNF, combining ATCA, the Parkes radio telescope, and Mopra into a single National Facility.

Continuous improvement

In 1995 CSIRO secured $11m from the Australian Government's new Major National Research Facility program to upgrade ATCA to higher frequencies. Receivers were added at 16-25 GHz (15-mm) and 85-105 GHz (3-mm). Beginning with installation of a protype 12-mm receiver in 1999 and proceeding in stages of design, production and installation, this work was complete by March 2003.

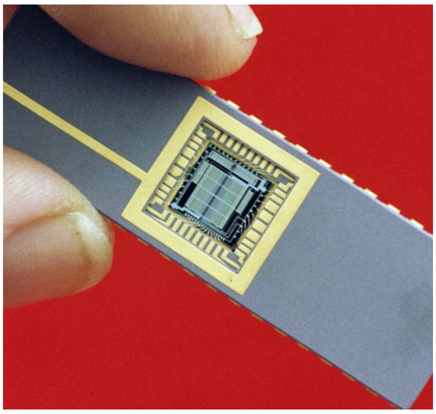
A north spur of track was added in 1998 which allowed instantaneous two-dimensional coverage of the image plane and for observations at short wavelengths to be completed at higher antenna elevations, where atmospheric absorption is less of a concern. The solid dish surface was also extended out to 22 m, providing a greater collecting area at the highest frequencies.

In 2005 CSIRO secured a contract with NASA to provide back-up tracking for a growing number of missions expected to use the 7-mm band for data downlink. While NASA only needed a relatively narrow band at 32 GHz, our engineers designed a wideband system that met the NASA specifications and provided broad bandwidths from 30-50 GHz for astronomers to exploit. This new system was operational by May 2007.

ATCA's backend system (which combines data from the antennas and outputs information astronomers can use), while state-of-the-art when it was built, provided limited sensitivity especially at the higher frequencies. In 2001 CSIRO secured further funding to create the Compact Array Broadband Backend (CABB) as a demonstration of the technology needed for the SKA. After a year testing a prototype system in parallel with the new backend, scheduled observing commenced on 22 April 2009 with the new wide-bandwidth correlator.

CABB was significantly more versatile and powerful than the original correlator. It offered a 16-fold increase in bandwidth, higher mapping speed, greater sensitivity and superior image fidelity (among other things). And it was SKA technology: CABB provided challenging input to a new generation of off-line data reduction and imaging software tools we then developed for ASKAP and are working on for the SKA.

In 2010 the 1.5 GHz (20-cm) and 2.3 GHz (13-cm) bands were combined into one broad band covering 1.1-3.1 GHz (effectively 10-30-cm, known as the 16-cm band). By 2013, another upgrade to 4-12 GHz allowed access to even greater bandwidth and sensitivity and gave consistent performance across the frequency range.



The CSIRO-designed correlator chip for ATCA was the foundation of the fast Fourier transform chip which led, ultimately, to CSIRO's invention of fast WiFi. Photo: CSIRO radio astronomy image archive.

Science

The telescopes of the ATNF were made freely available to the best scientific proposals from around the world and, from its earliest days, ATCA was in high demand; its international user base grew from fewer than 10 to over 110 in six years. Under this global policy, known as open skies, Australian astronomers have reciprocal rights to overseas observational facilities.

In terms of publications using ATCA data, independent analyses consistently ranked ATCA just behind the much larger VLA. The most influential papers from ATCA are those describing neutral hydrogen (HI) mosaic images of the Large and Small Magellanic Clouds (such as Kim et al. ApJ 1998 503, 674). These are the most detailed images of the distribution of atomic gas in any external galaxy and are the most dramatic examples of the mosaicing technique pioneered by ATCA.

In the radio continuum we have the striking large-scale mosaic of the largest radio galaxy in the sky, Centaurus A, which spans nearly 10 degrees, dwarfing the full Moon. It is also the brightest radio source in the southern sky so obtaining sufficient dynamic range to see the fine structure in its much fainter outer lobes was challenging.

ACTA is the only southern hemisphere array working across mm and cm wavelengths so provides crucial information for multi-wavelength experiments. One highly cited example is ATCA observations of the extragalactic supernova SN1998bw. This was the era when satellites were starting to pinpoint gamma-ray bursts with sufficient accuracy that they could be followed up at radio wavelengths. This work was not just the study of the accompanying radio outburst but the position of the afterglow determined with ATCA provided the first crucial evidence that these gamma ray bursts were linked to supernovae. The demand for multiwavelength coverage continues, exemplified by recent ATCA follow-up of the gravitational wave event: now the most highly cited paper using data from ATCA.

Legacy

ATCA was an iconic Bicentennial Project that captured the heart of the nation. It went on to be one of the most scientifically successful instruments in the world and has enabled us to negotiate access to overseas facilities and be involved in international projects. Its impact on Australian industry was large and its global impact on radio astronomy engineering persists to this day. The ultra-wideband receiver now on Parkes and the cutting-edge high-speed digital signal processing for Parkes, ASKAP and now the SKA, can trace their histories back to ATCA.

Ron Ekers AO
Foundation Director of the ATNF

Composite image of the radio glow from the galaxy Centaurus A in comparison to the full Moon. Image: Ilana Feain, Tim Cornwell & Ron Ekers. ATCA northern middle lobe pointing R. Morganti (ASTRON), Parkes data N. Junkes (MPIfR), ATCA and the Moon Shaun Amy.

Australian Square Kilometre Array Pathfinder

Over the last year, ASKAP has transitioned from a construction and commissioning project into an operational telescope. Although there are still many improvements and updates to make as we learn more about the instrument and its performance, the array is now online and recording data.

All 36 antennas have their full complement of digital electronics and we have verified that data from all antennas can be synchronised and correlated. This was achieved in February 2019 by obtaining interference fringes between all 630 possible pairs of antennas while observing a bright source.

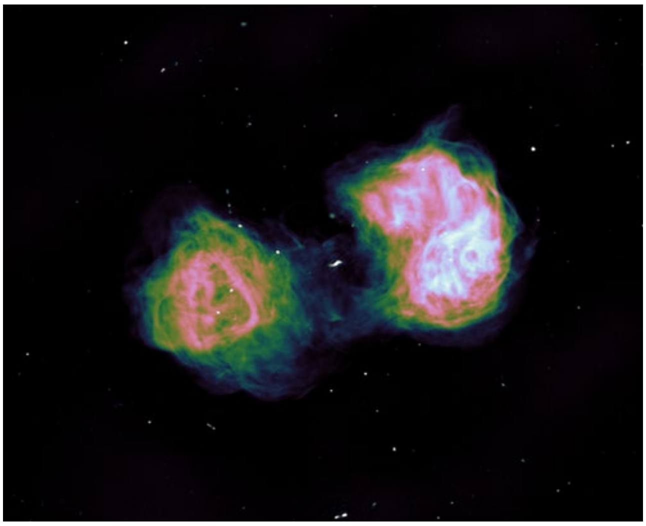
Since then, we have been working to verify the telescope's readiness for pilot surveys. An infographic (see page 10) shows the steps between completing construction and starting survey science. This highlights a sequence of milestones that use the telescope in increasingly complex ways, culminating with the start of full survey operations. The first milestones involve observing known sources or fields to verify the correctness of the telescope's output and we have accomplished three milestones already. The single-beam image of Fornax A was presented in the opening talk at the SKA key science forum in early 2019.

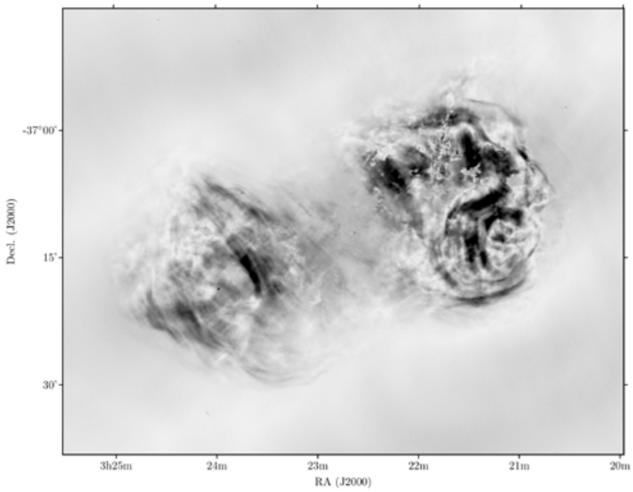
The first release of science data from the full array occurred in June 2019. We observed the GAMA23 test field – a region covered in previous optical surveys – and used the data as a test of the ASKAP data processing pipeline. With all antennas operational, data volumes have increased along with the sensitivity and resolution of the telescope, providing new challenges for the software. Over a period of a few months, members of the science teams worked with the ASKAP operations and science data processing teams to optimise the parameters used to make images from the raw data. The finished product is a combination of two tiles covering roughly 60 square degrees, within which we detect about 40 000 radio sources. These images and catalogues are available to the public on the CSIRO ASKAP Science Data Archive (CASDA).

Alongside ASKAP's major survey science projects (involving many international collaborators), we have identified the need for 'observatory projects' that are smaller in scope, but of broad interest to the astronomy community. The first such project is the Rapid ASKAP Continuum Survey (RACS). This was designed to highlight ASKAP's greatest strength – its wide field of view and rapid survey speed. RACS is a survey of the entire southern sky visible to ASKAP. With roughly 900 fields, each observed for 15 minutes, ASKAP surveyed the sky to a depth and resolution significantly better than any existing Southern hemisphere data. RACS was designed to provide similar levels of sensitivity to the current state-of-the-art NVSS catalogue in the northern hemisphere, a sky survey made with the US National Radio Astronomy Observatory Very Large Array. While NVSS was observed over a period of several years, we completed the first full RACS observations in roughly two weeks. Data processing is underway and we plan to release an extensive set of results to the public over the next year, including images, source catalogues and interactive sky maps.

With current computing resources, ASKAP operations are likely to be limited by the rate at which we can process data. Significant software optimisations have been made over the past year, but full spectral resolution data still takes roughly twice as long to process as to observe. In the short term we plan an expanded disk array for storing raw data and intermediate products. Long term, we are actively involved in planning the procurement of a replacement supercomputer as part of the Pawsey Supercomputing Centre's refresh project. This should improve our processing capacity significantly in late 2020.

We have also released the first version of the ASKAP science observation guide, a user's manual for astronomers planning surveys or downloading data from CASDA. The document describes ASKAP's performance in detail, providing the facts and figures necessary to determine optimal observing strategies. Updates to this document will be made available as we refine our understanding during the pilot surveys, which are expected to begin later in 2019.





Top: this image of the radio galaxy Fornax A was the first to be made with all 36 ASKAP antennas and highlights ASKAP's ability to detect details in extended, diffuse emission. Below: all ASKAP data provides useful polarisation information as X-Y phase alignment is performed automatically at beam formation using the on-dish calibration system. The results shown here compare well with VLA data. Images: Emil Lenc and Craig Anderson.

Murchison Radio-astronomy Observatory

The Murchison Radio-astronomy Observatory (MRO) in Western Australia is 300 km from the coastal town of Geraldton on the former pastoral property, Boolardy Station. CSIRO acknowledges the Wajarri Yamatji as the traditional owners of the observatory site.

The Murchison region is ideal for radio astronomy as its low population density means less radio frequency interference (RFI) that can drown out or mimic the weak signals radio telescopes are trying to detect. The radio quiet environment is primarily protected by a series of concentric zones established by the Australian Communications and Media Authority (ACMA). Within 70 km of the centre of the MRO, radio astronomy is the primary user of spectrum (see Spectrum management). CSIRO also has strict on-site standards and RFI monitoring to keep local interference to a minimum.

The MRO is powered by a hybrid power station with a 1.85 MW solar component. It is designed to run for a large part of the day without recourse to diesel.

The MRO also hosts the:

- Murchison Widefield Array (MWA), a low frequency instrument of 4096 dipole antennas operated by Curtin University on behalf of an international consortium of some 21 organisations, including CSIRO.
- Experiment to Detect the Global Epoch of Reionisation Signature (EDGES), a radio spectrometer operated by Arizona State University and the Massachusetts Institute of Technology's Haystack Observatory.
- SKA test arrays, the Aperture Array Verification System (testing prototype SKA1-Low antennas) and the Early Development Array (using MWA antennas in the configuration of an SKA1-Low station).

The ASKAP radio telescope at the MRO. Photo: Aidan Hotan.

Long Baseline Array

The Long Baseline Array (LBA) is a network of telescopes across Australia and the southern hemisphere used together for simultaneous observations, a technique called very long baseline interferometry (VLBI). The core elements of the LBA are our Parkes, ATCA and Mopra telescopes; the University of Tasmania's 26-m antenna in Hobart and 30-m antenna in Ceduna, South Australia; the Hartebeesthoek 26-m antenna in South Africa; and Auckland University of Technology's 12-m and 30-m antennas in Warkworth, New Zealand. These are augmented by the 70-m and 34-m antennas at the CDSCC near Canberra and the University of Tasmania's 12-m AuScope antennas in Yarragadee, Western Australia, and Katherine in the Northern Territory. The LBA is also part of an ad hoc global VLBI array with telescopes from Asia and Europe and regularly observed as part of the ground array supporting the Russian-led RadioAstron space VLBI mission.

The LBA typically observes for 25 days per year, mostly scheduled as four- or five-day sessions, interspersed with single observations as required. From April 2018-March 2019 there were 20 LBA experiments (comprising 30 individual imaging observations and 19 one-hour RadioAstron survey and monitoring observations and two RadioAstron imaging experiments), involving five unique Australian principal investigators (PIs) and 15 unique overseas PIs and using a total of 445 hours of observing time. Australian collaborators were part of 13 of the 15 experiments with overseas PIs. Three of the experiments utilised the LBA as part of global VLBI observations, one was a 3-day continuous observation using networks in Europe, East Asia and the United States. At the end of 2018 the RadioAstron satellite reached the end of its operating life.

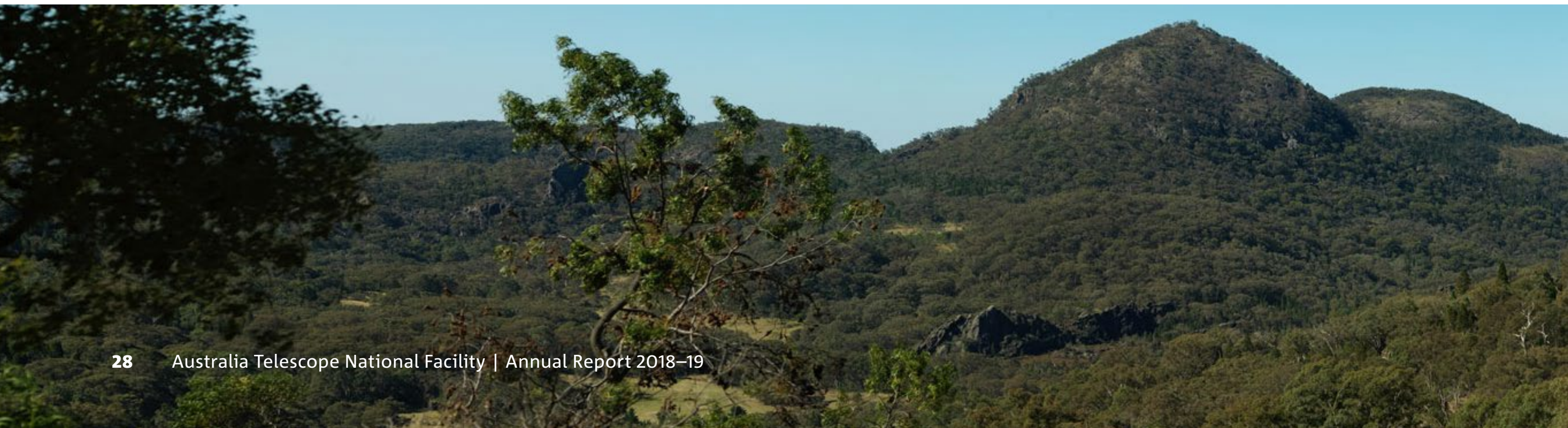
LBA experiments (other than RadioAstron and global experiments) are correlated by CSIRO staff using the Distributed FX Correlator (DiFX) software correlator running on the Magnus supercomputer at the Pawsey Supercomputing Centre in Perth. A total of 26 user projects were correlated representing ~414 hours of observations. This system has been running smoothly, with a median time of 56 days between observation and release of data. The processing time is dominated by the time taken to transfer data (median 36 days), largely because some stations do not have high-speed data networks so disk modules must be physically shipped. A total of 200 104 hours of CPU time was used on Magnus. All correlator output is routinely uploaded to the Australia Telescope Online Archive once verified (see Data Archives).

The LBA continues to support a range of Galactic and extra-galactic science goals, with increasing requests for inclusion in global experiments. The large number of international PIs demonstrates the strong interest in southern hemisphere VLBI.

Mopra

Since 2013 the Mopra radio telescope has been operated by CSIRO under contract to a consortium of Australian and international universities. Under these arrangements CSIRO recovers all routine operating costs and Mopra continues to participate in LBA observing, typically for two five-day sessions in each Semester. The most recent contract with the University of Adelaide terminated upon completion of its major survey in October 2018. Discussions with other research groups interested in making use of Mopra are underway.

The Mopra telescope. Photo: Balthasar Indermuehle.



Data archives

ATNF data archives include the Australia Telescope Online Archive (ATOA), the Parkes Pulsar Archive – a principal component of CSIRO's Data Access Portal (DAP) – and the CSIRO ASKAP Science Data Archive (CASDA). They continue to grow in size and impact.

The ATOA dataset is now 270 TB in size, with growth expected to reach 30 TB per year as spectral line data is ingested from the new low frequency Ultra-Wideband (UWB-L) receiver at the Parkes radio telescope. Looking at the past year, more than 8000 ATOA files are downloaded in a typical month.

The DAP is now 1.8 PB in size, with pulsar data comprising over 90% of this and of which over ~800 TB are publicly available. The archive has grown by about 50% in the last year and is expected to grow at ~800 TB annually, the majority coming from UWB-L observations. The DAP's ability to manage large data volumes, along with the newly introduced rapid publication of data after observation, ensures that it is now the primary access point for the majority of new pulsar observations. On average about 11 000 pulsar files per month are downloaded from DAP, the overwhelming majority of users being within Australia.

The next stage of CASDA development started in May 2019. In collaboration with colleagues at CSIRO Information Management and Technology we made improvements to the user interface, updates to the Virtual Observatory services and undertook further performance testing.

New ASKAP datasets in CASDA are:

- EMU Early Science cosmology fields, continuum images, visibility data and source catalogues.
- WALLABY Early Science NGC7232 HI spectral line cubes (48 MHz, full resolution, 36 beams).
- First ASKAP 36 dish continuum images, visibility data and source catalogues of the GAMA 23 field.
- WALLABY Early Science uploads of user-generated HI spectral line cubes.

Archival data continues to be in demand with eight refereed papers in this reporting period drawing on ATOA data. For example, the long-awaited Local Volume HI Survey (LVHIS), which used archival data to study the overall HI gas distribution, mean velocity field, velocity dispersion, and far-infrared radio correlation in 82 gas-rich local galaxies (Koribalski et al. 2018 MNRAS 478, 1611). Six more papers arose from the Parkes Pulsar Archive, including a new FRB detection (Zhang et al. 2019 MNRAS 484, 147) from the datasets containing the so-called Lorimer burst – the first FRB to be described, in 2007.

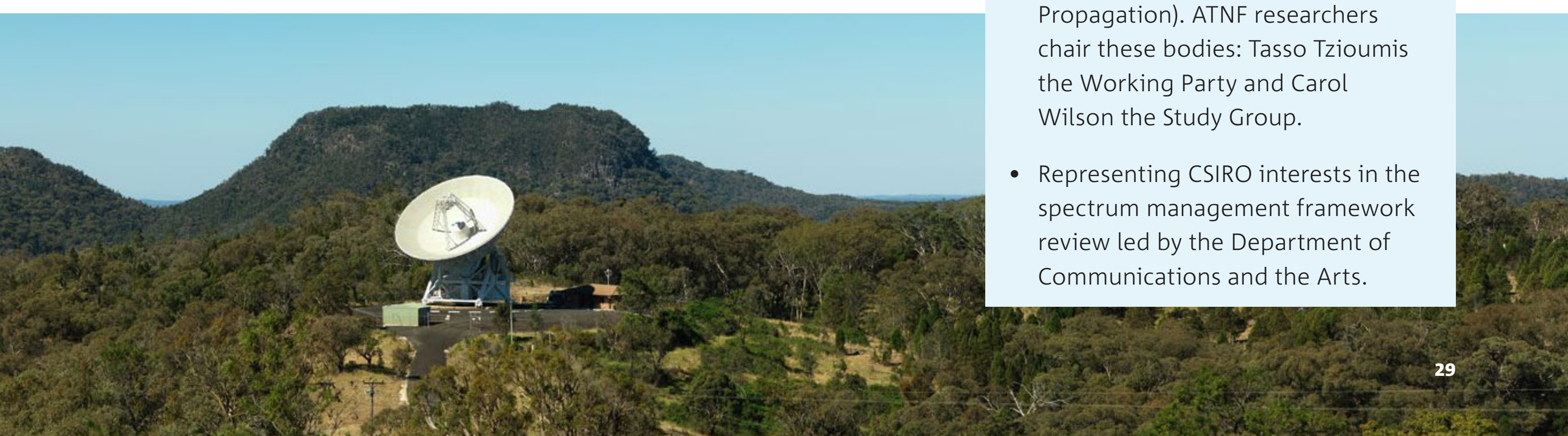
Spectrum management

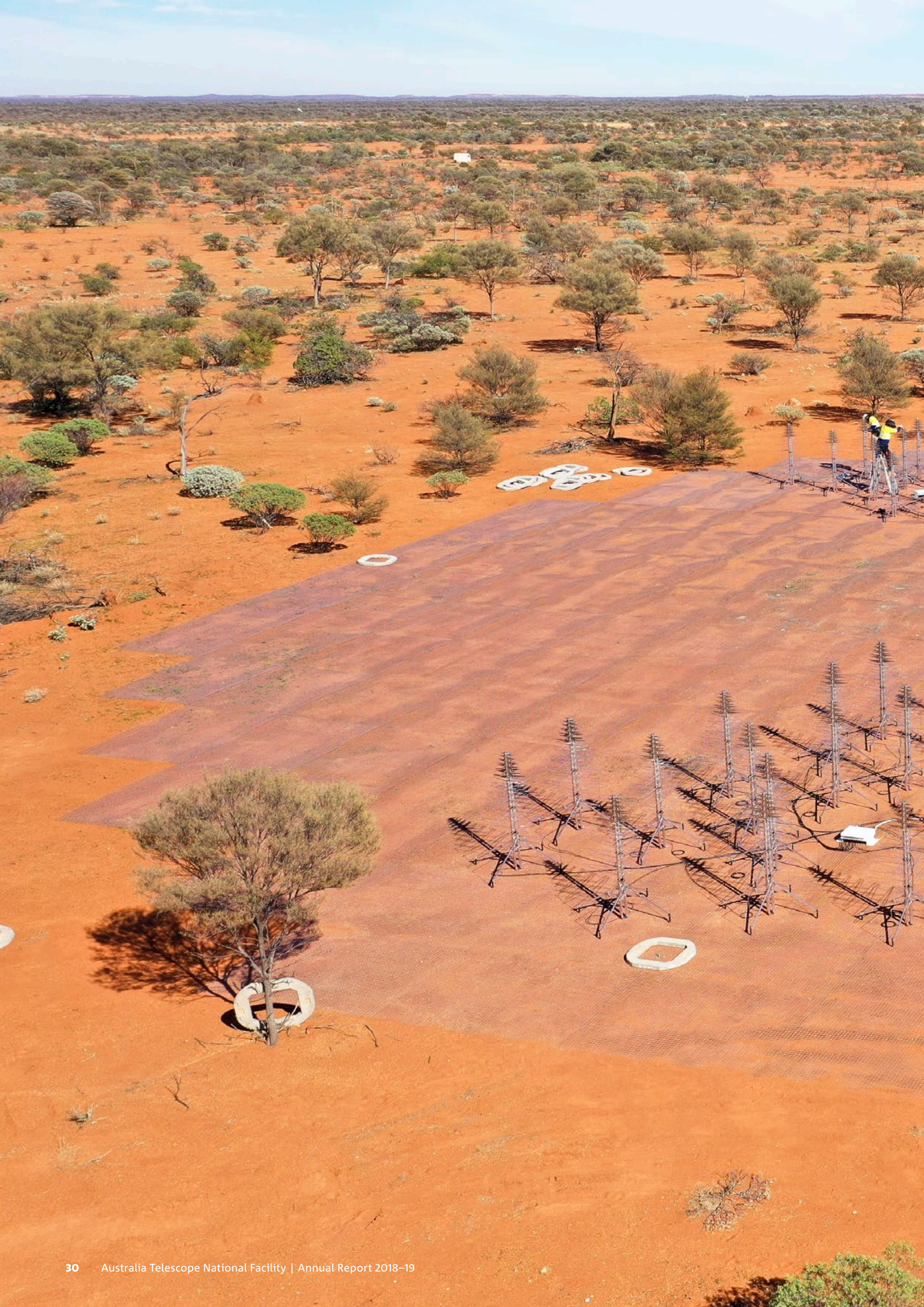
CSIRO works towards global protection of spectrum for radio astronomy and space research and maintains specific protection measures for our own facilities. We have worked with governments to develop radio quiet measures for the MRO and Radio Notification Zones around our other facilities. Under these measures, CSIRO must be notified of proposed radio licences within frequency and distance limits specific to each site. This requires that CSIRO maintains a good relationship with both regulators and major users of spectrum.

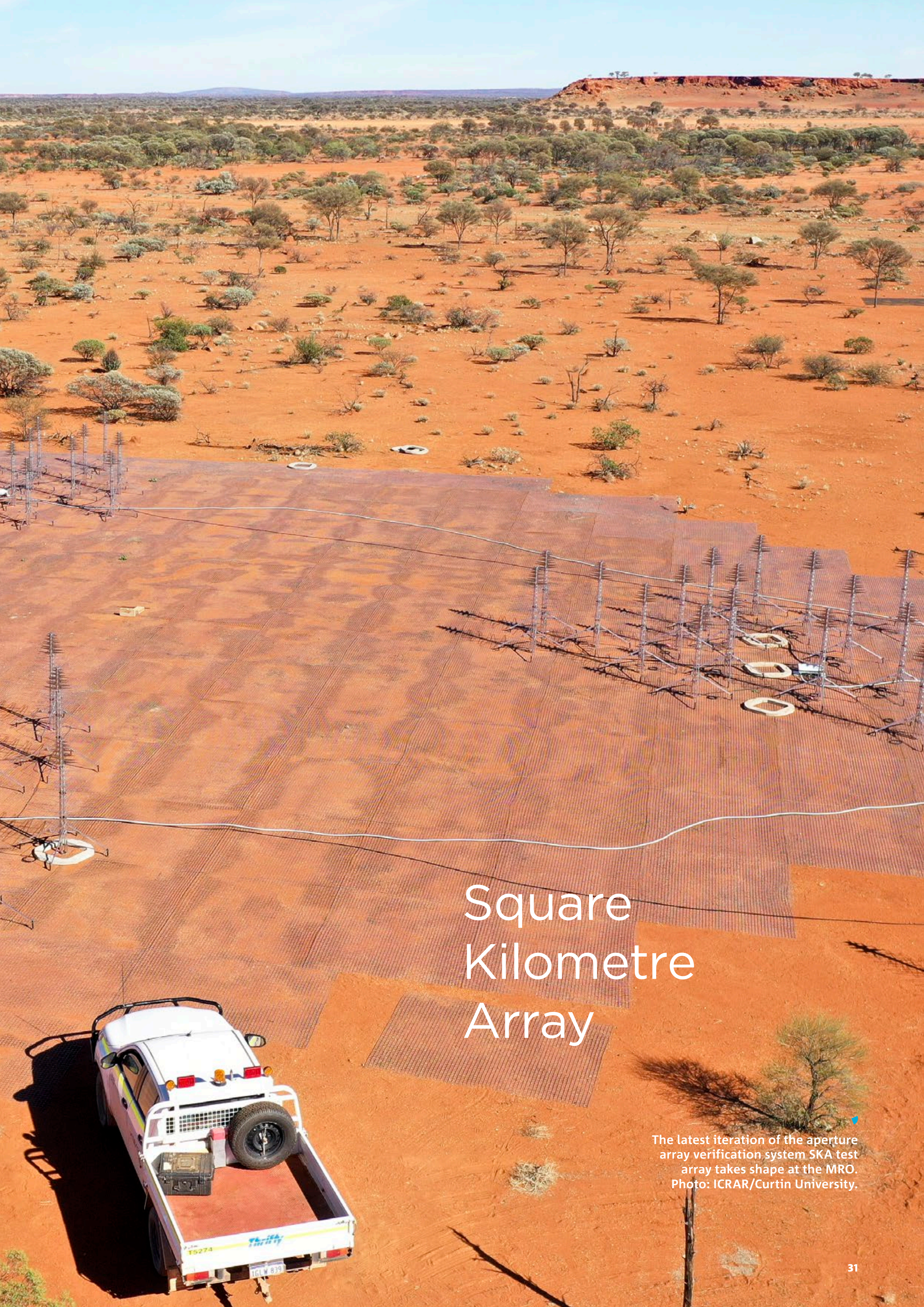
Radio spectrum is regulated internationally by the Radio sector of the International Telecommunication Union (ITU-R). The Radio Regulations treaty is updated every four years, via a World Radiocommunication Conference (WRC), to reflect changing priorities and new technology. In Australia, spectrum is managed by the Australian Communications and Media Authority (ACMA).

We are currently:

- Finalising positions for the WRC in October 2019. CSIRO has been actively involved with the ACMA and other stakeholders in developing Australia's position on agenda items which could affect radio astronomy or space research.
- Leading studies in ITU-R Working Party 7D (Radio Astronomy) and ITU-R Study Group 3 (Radiowave Propagation). ATNF researchers chair these bodies: Tasso Tzioumis the Working Party and Carol Wilson the Study Group.
- Representing CSIRO interests in the spectrum management framework review led by the Department of Communications and the Arts.







Square Kilometre Array

The latest iteration of the aperture array verification system SKA test array takes shape at the MRO. Photo: ICRAR/Curtin University.

The SKA and Australia

CSIRO's Murchison Radio-astronomy Observatory (MRO) will soon be home to the low frequency telescope of the Square Kilometre Array (SKA) project: SKA1-Low. It will comprise up to 132 000 dipole antennas grouped into 512 stations along spiral arms running the length and breadth of Boolardy Station, as well as a large central processing facility and a power station. Construction is scheduled to commence in 2021.

Australia's Science Director on the SKA Board is Douglas Bock and Sarah Pearce is a member of the Council Preparatory Task Force (overseeing the transition of the SKA Organisation to an international body). Phil Edwards chairs Australia's SKA Science Advisory Committee, Warren Bax undertook another secondment to the SKA Organisation before accepting the position of Finance Manager, Antony Schinckel continued his secondment as Head of SKA Construction Planning in Australia and Senior Engineer, Mark Bowen, returned at the completion of his secondment.

Bridging

With the design (Preconstruction) phase of the SKA virtually complete, effort has transitioned to ensuring that design documentation is progressed to the stage where tenders for construction can be released: a phase known as Bridging.

Work on the correlator and beamformer for SKA1-Low has progressed significantly, with prototype digital signal processing boards now in production. An Integrated Test Facility has been established at our Sydney laboratory and the interface between the telescope array and the central signal processor has been demonstrated.

We are developing a new Monitoring Control Calibration System software prototype for the array and are also contributing to calibration and imaging software. A prototype based on ASKAP software has been built and named Yanda, which, in acknowledgement of the traditional owners, is the Wajarri word for image. We are now working on the interface between the science data processor (the first port of call for data that has left the observatory) and the Regional Centre, where further processing can be done and data products released (see below).

For site infrastructure we have re-worked designs and technical specifications in response to evolving SKA requirements. Informed by indigenous heritage surveying of the land (see Site establishment), several suitable locations have been found for the Central Processing Facility (similar to the current MRO Control Building only double the size) and the temporary construction camp. We have also provided technical advice to an approach to industry in relation to powering SKA1-Low that is being prepared by the SKA Organisation.

Site establishment

Work continued with colleagues in the Australian SKA Office of the Department of Industry, Innovation and Science (DIIS) on those activities necessary to allow SKA1-Low to be built and operated here.

The most important of these is the Indigenous Land Use Agreement (ILUA) with the Wajarri Yamatji traditional owners. While there is an ILUA for the current MRO, the footprint of SKA1-Low will cover virtually all of Boolardy Station (albeit very lightly), necessitating negotiation of a new ILUA. Antony Schinckel is CSIRO's lead in this negotiation. Legal representatives of the parties are finalising technical details and it is hoped that the ILUA will commence the registration process in the first half of 2020.

A new lease is also required as the land is currently deemed to be for pastoral use, not radio astronomy. The terms of the new lease to CSIRO from the Western Australian State Government are close to being agreed. These two activities will see the definition of the MRO expand to refer to the entirety of Boolardy Station.

This year has seen significant progress with surveying the land for artefacts or sites of significance to the traditional owners. Over 60% of the land to be occupied by SKA infrastructure has been surveyed and we are working to locate SKA infrastructure accordingly.

Surveying Boolardy Station for items of significance to the traditional owners. Photo: Antony Schinckel.

Artist's impression of the supercomputing facility for SKA1-Low at CSIRO's MRO in Western Australia. Image: Aurecon Australasia.

The Australian delegation attending the SKA Convention signing ceremony. L to R: Steven Tingay (Curtin University) Douglas Bock (CSIRO), Ambassador Greg French, Leonie Boddington (CSIRO and Wajarri Yamatji representative), David Luchetti (Australian SKA Director, DIIS), Sarah Pearce (CSIRO), Deputy Ambassador Jo Tarnawsky and Patricia Kelly (Chair, SKA Council Preparatory Task Force). Photo: SKA Organisation.

Regional data processing

The SKA Board has established the SKA Regional Centre (SRC) Steering Committee to oversee establishment of SRCs around the world to deliver computing and software resources for the astronomy community to be able to fully exploit SKA data and achieve world-class science (as the SKA construction program is not scoped to deliver these). Within Australia, an AusSRC Management Committee has been formed which reports to the Australia/NZ SKA Co-ordination Committee.

The AusSRC will be a consortium of the partners (CSIRO, ICRAR, the Pawsey Supercomputing Centre and Astronomy Australia Limited), with initial funding of $4.2m over three years sourced from DIIS and CSIRO. In its first three years of 'start-up' operation the AusSRC will act as a proto-SRC, delivering useful data and computing projects for ASKAP and the MWA, and deliver a design for a full-scale AusSRC.

The Australia-China ERIDANUS project, now in its second year, continued work designing prototype data-intensive research infrastructure capable of addressing SKA-class data and processing challenges.

International spheres

The first formal step in transitioning the SKA Organisation into an intergovernmental body was the signing of the SKA Convention on 12 March 2019. This document will now be ratified by member nation's parliaments – Australia's by the end of 2019.

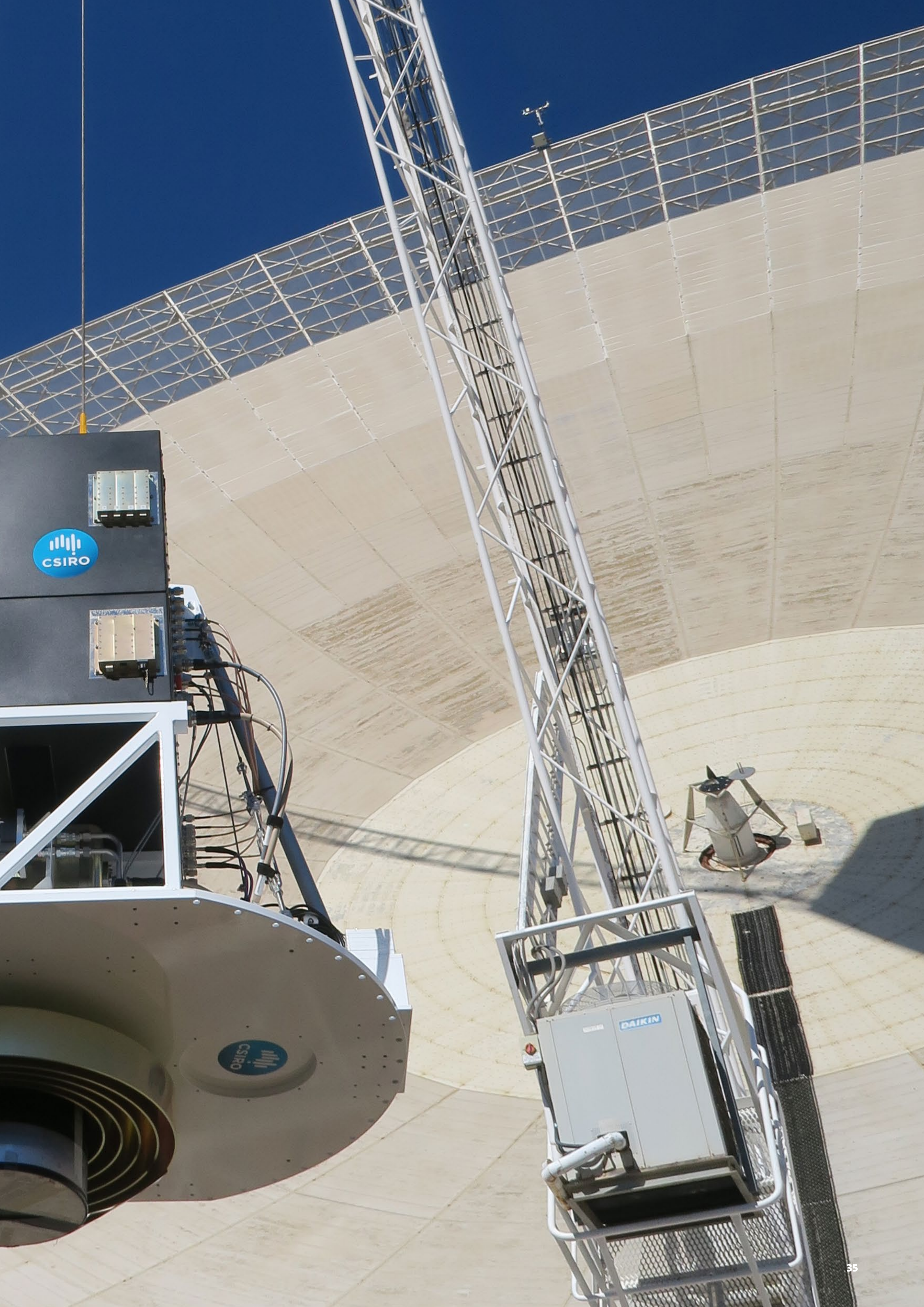
As the host country of SKA1-Low, a Hosting Agreement between Australia and the SKA Observatory is required to allow the new facility to operate here. We, and our colleagues in DIIS, are working with the SKA Organisation to the terms of the Hosting Agreement which will be signed once the Convention is ratified.

Operations partnership

Australia and fellow SKA host country, South Africa, are in discussion with the SKA Organisation over how the SKA might be operated in our respective nations. It is agreed that there will be a 'one observatory' approach spanning the two host countries and the UK headquarters. The SKA Observatory will have functional control of SKA telescope operations through a partnership with CSIRO.

Technology development

The low frequency ultra-wideband receiver is installed on the Parkes radio telescope. Photo: John Sarkissian.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Technology development

Ultra-wideband

The low frequency ultra-wideband receiver (UWB-L) is now the primary receiver system on the Parkes radio telescope and science results are starting to be published, the first being a wide bandwidth study of a magnetar (Dai et al. 2019 ApJL 814, L14 see Science highlights). The noise performance (sensitivity) of the new receiver system is outstanding: similar to narrow band systems. Comparison with Parkes' previous receiver suite (the 10/50 cm dual band receiver and the multibeam receiver) clearly shows that the UWB-L provides a much wider band and lower system temperatures. The new receiver also comes with new digitisers and a new astronomy processing system that enables observing modes not possible with previous instruments. This new capability has excited the astronomy community and many teams are now submitting proposals for observing time with this world-leading receiver.

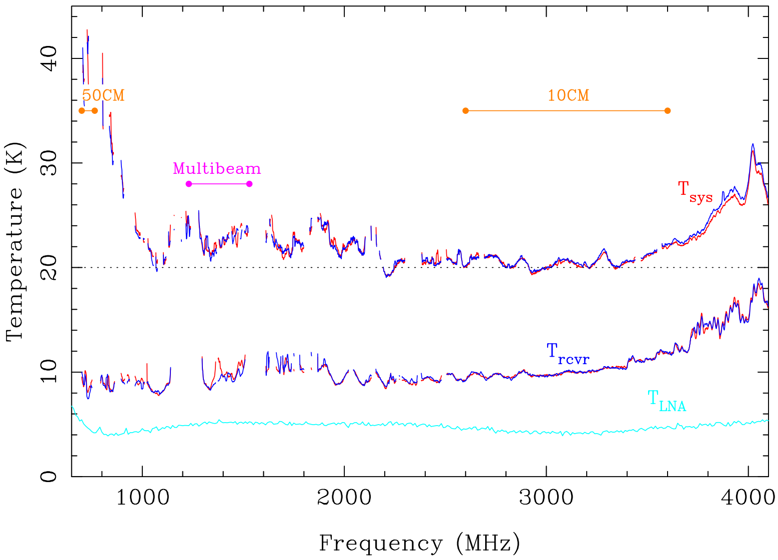
19-beam receiver

The 19-beam receiver made for China's Five hundred meter Aperture Spherical Telescope (FAST) has been operating almost continuously since installation in May 2018 and is now the primary receiver for FAST. For the most part the system has operated flawlessly and CSIRO having access to the monitoring system has proven to be an excellent tool when it comes to answering customer questions.

The key performance parameter for the system is the system equivalent flux density and, at 1.1 Jy, it is expected to be the lowest (best) of any telescope in this band for a very long time.

The system temperature has been confirmed to meet the specification of 20 K (Jiang et al. 2019, Sci. China-Phys. Mech. Astron. 62, 959502).

FAST is being used primarily in drift scan mode, where the telescope is fixed as the sky passes overhead. With the multibeam feed system, the survey sensitivity is enhanced by candidate sources being tracked as they pass through more than one beam. While this observing mode is only in the prototype stage, the system is already producing some exciting results: it has found 51 pulsar candidates so far, 16 of which have been confirmed as new pulsars, 7 by the Parkes radio telescope.



System temperature (Tsys) as a function of observing frequency for the UWB-L (top curve) with comparisons of indicative Tsys and frequency coverage for the dual band receiver (orange line) and multibeam (pink line). The contributions to Tsys from the LNAs and the receiver (Trcvr) are also shown. Image: George Hobbs.

The massive 19-beam receiver is hoisted into position above the surface of FAST. Photo: Doug Hayman.

CryoPAF

Development of a cryogenic Phased Array Feed (CryoPAF) for the Parkes radio telescope is progressing, with the concept design completed and many prototype components being manufactured. These prototypes will be used to verify and characterise sub-systems of the CryoPAF, prior to finalising the design for its subsequent manufacture, which is forecast to begin in mid-2020.

The CryoPAF design will be modular; implementing 26 eight-channel low noise amplifier (LNA) modules within the cryostat and a corresponding number of 'warm' electronic modules outside of the cryostat providing additional amplification and filtering before being digitised on the PAF using new, commercially available Radio Frequency System on a Chip (RFSoC) devices. Additional warm electronics modules will be used for calibration and RFI mitigation.

A prototype MMIC LNA is being fabricated in a European foundry to provide the first stage of amplification from 700 – 1900 MHz, while a discrete transistor LNA is also being investigated. Both LNAs will soon be ready for characterisation at cryogenic temperatures to determine which version will be used.

A Structural and Thermal Model of the 1.2 m diameter CryoPAF cryostat, which contains the receiver's distinctive 'rocket' elements and LNAs, is being manufactured to allow thermal load and vacuum tests to be conducted. It will be re-tasked as the basis for the final CryoPAF receiver.

Transparent feed legs

Several years ago, members of the ASKAP Commissioning and Early Science (ACES) team proposed that the performance of ASKAP could be improved by replacing the steel legs that hold the PAF receiver with legs that are transparent at radio frequencies. The prototype fibreglass foam sandwich and fibreglass skin legs were installed on antenna 32 in June 2018.

Interferometric and single-dish performance tests reveal an approximately 10% improvement in sensitivity below 1 GHz and a noticeable improvement in the rotational symmetry of the beam. This improvement is significant, but not as large, or as wide-band, as previously hoped. Antenna 32 is used as part of normal array operations and is usually the best-performing antenna, however, data to date is insufficient to warrant array-wide conversion to these legs and analysis continues.

Digital

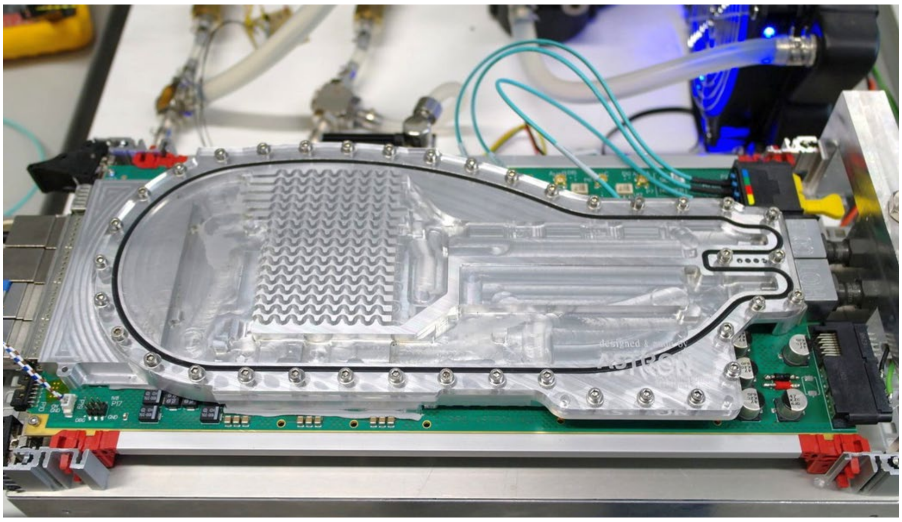
The digital team has been supporting commissioning of UWB-L and ASKAP and scoping the work that would be required to extend ASKAP's observing modes, specifically those relating to transient sources.

We are leading development of the correlator/beamformer for SKA1-Low, named Perentie after an Australian lizard. Together with ASTRON in the Netherlands and Auckland University of Technology in New Zealand, we have developed the Gemini high performance signal processing board which forms the heart of the Perentie system that is set to process 5.8 Terabits of data per second from SKA1-Low.

Each of the 288 Gemini boards that make up the correlator features a cutting-edge Xilinx Field Programmable Gate Array (FPGA). The board is liquid cooled and covered by a monolithic heatsink to dissipate the considerable amount of heat generated by the electronics (each Gemini card is expected to consume about 200 W and FPGA temperatures will climb to around 70°C).

The Gemini board is a significant advance on the ASKAP system in terms of computing power, high bandwidth memory, communications, physical size (it is one sixth the volume), cooling technology and power consumption, yet at a similar cost.

We are also investigating the new and highly promising RFSoC technology for SKA1-Low, to upgrade ATCA's aging digital backend hardware and as a sampler and digital signal processor for the Cryo PAF, among other potential applications for this game-changing technology.



Prototype Gemini digital signal processing chassis for SKA1-Low. Photo: ASTRON.

We were proud to support CSIRO's inaugural participation in the Sydney Gay and Lesbian Mardi Gras Parade by lighting ASKAP antennas in the colours of the rainbow. The image was a key part of CSIRO's campaign and provided a symbolic connection between our world-leading science facilities and our commitment to inclusion and diversity. Photo: Alex Cherney.

People and community

Staff

There are currently 202 people working on radio astronomy in CSIRO: that is, in the ATNF and our SKA activities (Appendix C). In line with our strategy, WA continues to be our area of growth. Across this reporting period 18 people joined and 22 people ceased employment and there were 6 joint appointments.

We exceeded CSIRO's target of 3% indigenous employment with 8 staff identifying as indigenous. However, our statistics on gender are a particular area of focus for us (Appendix E). We have analysed staff by gender, type of work (administration, technical services etc) and level of employment over time. This revealed many more women than men at lower employment levels and very few among the higher ranks. Also, our gender ratio across employment types has changed little over time: women only outnumber men in administration, communications and general services and do not come close to parity anywhere else. We are looking to address this imbalance, and gender targets for CASS are in the process of being set as part of CSIRO's Science in Australia Gender Equity program.

Culture, diversity and inclusion

Our Diversity and Inclusion Committee celebrated its fifth anniversary of commitment to ensuring a safe, respectful, inclusive and diverse environment for staff and visitors. Committee membership is drawn from all teams and most sites. Significant effort was made this year to increase awareness of the Committee and its actions, including development of a dedicated intranet page.

One of the Committee's major actions has been establishment of a mentoring program for staff. The program identifies mentors and mentees, makes appropriate matches and provides training. All staff are able to participate as mentees, while mentors are encouraged from within the ATNF, other parts of CSIRO, supporting departments (such as DIIS) and from our honorary fellows and visiting scientists.

The Committee has also created new pathways for all who visit our facilities to provide anonymous feedback about their experiences of being here.

This past year also saw Jane Kaczmarek appointed inaugural Diversity Champion. This newly created role comes with a time allocation of 20% FTE, allowing for adequate support and time to plan, implement and deliver actions aimed at improving diversity, inclusion and equity.

In February 2019, we undertook a wellbeing survey of our workforce. This resulted in the creation of initiatives aiming to address different dimensions of wellbeing in the workplace. For example, our staff raised concerns about our ageing workforce, so members of the Committee teamed up with CSIRO's Human Resources function and the broader organisation to support existing staff, establish transition to retirement pathways and ensure transfer of a lifetime of knowledge and skills.

In April 2019, the Committee began a follow-up to the 2016 Culture Survey to help us assess the impact of the original project. External analysis of responses is currently underway.

In October 2018 we farewelled Lisa Harvey-Smith who was appointed Australia's first Women in STEM Ambassador. Photo: Rob Hollow.

Andrew Cameron is awarded the Otto Hahn Prize. Photo: Ausserhofer – Max Planck Society.

Dick Manchester delivers the 2019 Matthew Flinders Lecture.
Photo: Australian Academy of Science.

Awards

Our award winners include:

- Elaine Sadler – Officer in the Order of Australia (AO) for distinguished service to science as an astrophysicist, in the field of galaxy evolution, and to gender equality.
- Ron Ekers – Officer in the Order of Australia for distinguished service to science as a radio astronomer, to scientific education, and to astronomical and international organisations.
- Richard (Dick) Manchester – Australian Academy of Science Matthew Flinders Medal and Lecture for his work on pulsars.
- Andrew Cameron – Max Planck Society Otto Hahn Medal for outstanding scientific achievement by a young scientist for his work on pulsars.
- Shivani Bhandari – Astronomical Society of Australia (ASA) Louise Webster Prize for early career scientist for her work on FRB follow-up.

Shivani Bhandari winner of the 2019 Louise Webster Prize.

Also, the Peter McGregor prize for astronomical instrumentation development was awarded to the DiFX correlator team, which includes Chris Phillips and Cormac Reynolds.

Indigenous engagement

Recognising that it is important to not just attract, but to retain and to develop, indigenous staff, we have developed an Indigenous Talent Management Plan to grow the options available. For example, we have established a mechanism to support indigenous talent, development and mobility which has this year translated to one indefinite appointment. Also, indigenous cadets, Savannah McIntosh (Geraldton WA) and Kyasha Palmer (Parkes NSW) were each awarded $20 000 in professional development funding from the Indigenous Capability Development Program.

We have significant engagement with the Wajarri Yamatji, traditional owners of the MRO, principally through the Indigenous Land Use Agreement in areas such as:

- educational support, such as mentoring and visits to the MRO
- contracting, employment and training opportunities
- acknowledgement of traditional owners in science publications using data from the MRO
- an indigenous heritage induction for all who work on or visit the MRO.

Health, safety and environment

ATNF staff again reported no medical treatment injuries, that is, no injuries that required medical treatment beyond first aid, and one lost time injury (LTI), that is, where one or more whole days was lost from work after an injury occurred. The LTI was due to a vehicle rolling over on the journey from Geraldton to the MRO. There were no major physical injuries and those involved have received support. A full investigation was undertaken and recommendations implemented.

Health, safety and environment incidents over time.

PERIOD	E INCIDENTS	H&S INCIDENTS	LTI	MTI
Jan-Dec 2013	1	10	1	3
Jan-Dec 2014	1	14	1	0
Jan-Dec 2015	2	4	3	2
Jan-Dec 2016	0	12	0	2
Jan 2017 - Jun 2018	1	23	1	0
Jul 2018 - Jun 2019	0	8	1	0

E = environmental, H&S = health and safety, LTI = lost time injury, MTI = medical treatment injury

Education

Postgraduate students

This reporting period saw ATNF staff co-supervise 29 PhD students and 6 Masters students (Fig. 12). The University of Tasmania is again the leading source of students; however, the number of students from Chinese observatories has more than doubled – perhaps as a result of our development of the receiver for their new FAST telescope (Fig. 13). In this reporting period 3 students were awarded PhDs. Student affiliations and thesis titles are listed in Appendix F and Appendix G.

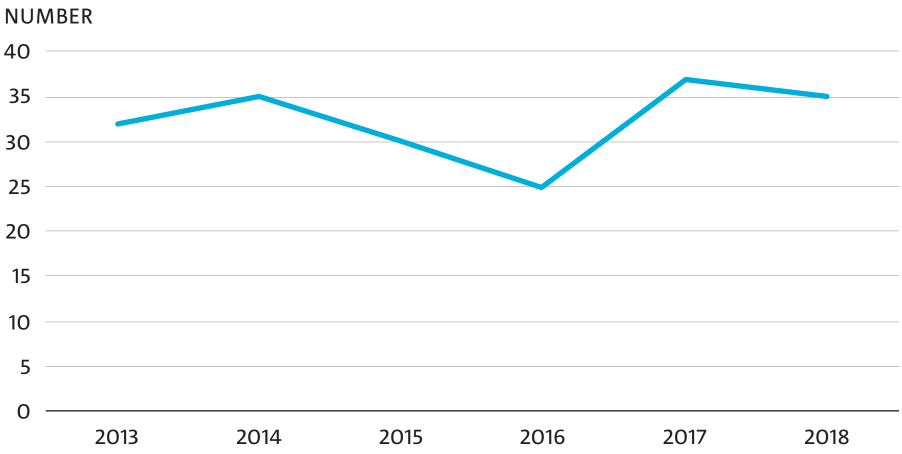


Figure 12: Postgraduate students co-supervised by ATNF staff over time.

Undergraduate vacation scholars

The 2018-19 Undergraduate Vacation Scholarship program had 10 Australian and New Zealand scholars, plus 2 from South Africa as part of our collaboration with the South African Radio Astronomy Observatory. 8 were based in Sydney, 3 in Perth and one was at the CDSCC. Scholars tackled a range of research projects involving data from all our facilities and visited ATCA in January for group-based observing projects. The program concluded with the annual Student Symposium in February where each student presented their research.

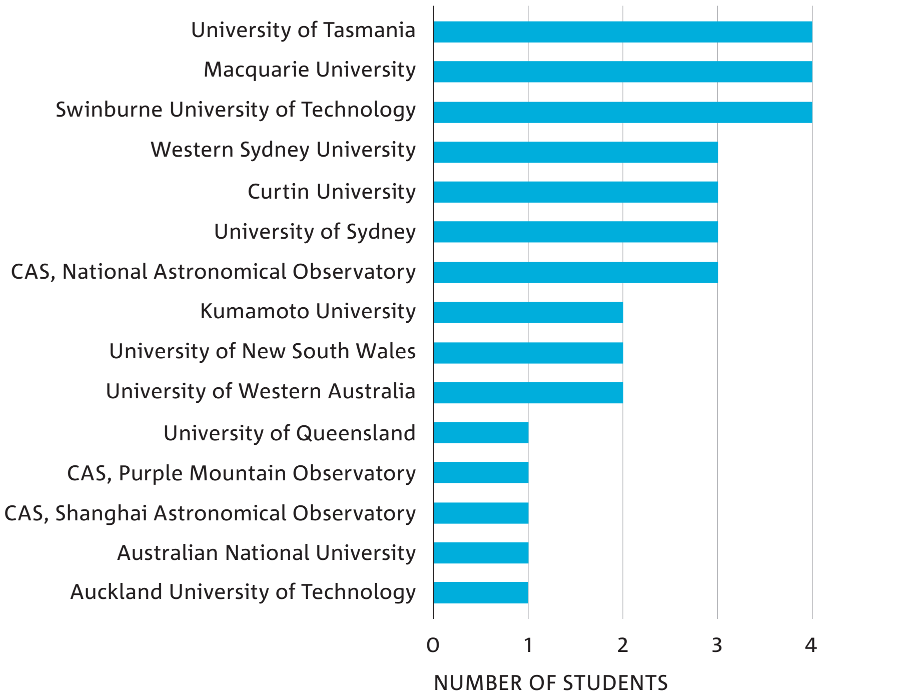


Figure 13: Affiliation of ATNF co-supervised postgraduate students.

This year's Sydney-based summer vacation scholars set to attend a Christmas party. Photo: Leanne Edwards.

Radio school

The annual Radio Astronomy School has traditionally focused on ATCA and Parkes, but the growing capability of Australia's newest radio telescopes, ASKAP and the MWA, requires specialised skills unique to analysis of survey-scale data from these modern facilities. To address this changing landscape, CSIRO partnered with the International Centre for Radio Astronomy Research (ICRAR), a joint venture between Perth's University of Western Australia and Curtin University, to jointly host the 2018 Radio Astronomy School in Geraldton. The school featured lectures and tutorials that covered radio astronomy fundamentals along with specialised topics unique to Australia's SKA precursor facilities.

The School had just over 60 participants, both at the student and postdoctoral level. Guided by 18 local and international experts, participants focused their attention on data reduction and the role of the Pawsey Supercomputing Centre, scientific synergies between ASKAP and the MWA, and the tools and techniques likely to be useful for analysis of data from the SKA. About 90 participants, lecturers and guests also took up the offer of a site trip to the MRO. It was a long day, but very rewarding, especially for those who have used data from ASKAP and the MWA but had never travelled to the MRO.

Teacher workshops

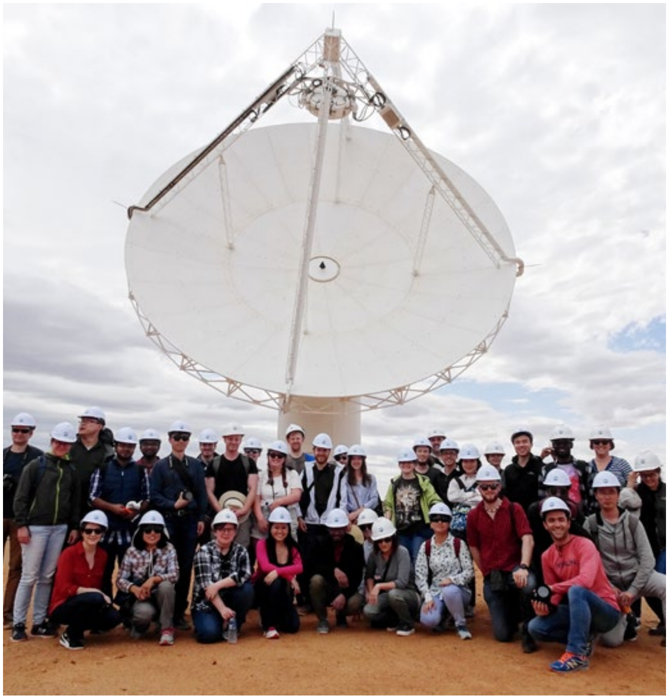
Our Astronomy from the Ground Up teacher workshop at the Parkes radio telescope in May 2019 attracted teachers from across the country. There was a mix of talks about current research, practical activities, discussion about the pedagogy of engaging students through astronomy, a night of stargazing and a tour of the Dish itself. Education specialist, Rob Hollow, also ran workshops at science teacher conferences in WA, NSW and Victoria.

PULSE@Parkes

This year we ran 12 PULSE@Parkes observing sessions with 125 students and teachers from 13 schools, 7 of which were new to the program. One highlight was the session held at Parkes itself for students from schools and colleges in the region. This was only the second time we've run a session at the Dish itself.

PULSE@Parkes is usually an educational program for school groups, but in March 2019 we ran an open session as part of Perth Astrofest which attracted around 100 people keen to be part of a real observing program on a real telescope in real-time.

We again took PULSE@Parkes offshore; in September 2018, Rob Hollow and Shi Dai ran observing sessions in Auckland and at Warkworth Observatory, as part of a tour in collaboration with Auckland University of Technology. The team also ran a well-received teacher workshop in Auckland.



Attendees at this year's Radio Astronomy School made a site visit to the MRO. Photo: Rob Hollow.

Shi Dai runs a PULSE@Parkes observing session for students in New Zealand. Photo: Rob Hollow.

Outreach and media

Capturing the imagination of the public this year were FRBs. Our promotion of the special edition of *Nature Astronomy* and its cover story of ASKAP doubling the number of FRBs found garnered extensive coverage. And we closed the reporting period with even more when our paper pinpointing of the origin of an FRB was published in *Science* – and made the cover.

We 'got our geek on' promoting Dame Jocelyn Bell Burnell's visit to Australia and our Parkes radio telescope, and sponsoring a celebration of the centenary of Trevor Pearcey's birth (Pearcey being instrumental in developing Australia's first digital computer, CSIRAC). At this event, Baerbel Koribalski took the audience on a journey through her history of astronomy data collection and computing – complete with disks and tapes – and Sarah Pearce spoke of the future computing requirements of the SKA.

We again took a joint approach to many media activities. For example, working with ANU to promote the *Nature Astronomy* paper describing the use of ASKAP and the Parkes radio telescope to image the Small Magellanic Cloud in exquisite detail, and with NASA to deliver an Australian angle on the global Voyager 2 story.

A key partner with whom we worked closely was the SKA Organisation. We provided staff for interview and supplied other content for its promotion of Women in Engineering Day and the International Day of Women and Girls in Science. We made live video crosses from the UK to the MRO and our headquarters in Sydney for the globally influential G7 science advisors' meeting on the SKA.

Our staff were 'the face' of CSIRO's National Science Week activities; they continued their strong involvement in the STEM Professionals in Schools program and volunteered their time to outreach events such as Astrofest. It was the tenth anniversary of the Perth Astrofest and the event broke attendance records, with around 6000 people streaming through. While smaller than Perth, the Sydney event continues to grow and the crowd kept our team busy well into the night with their questions.

The willingness of our staff to share their knowledge and experience with the public is admirable. Jamie Stevens and Rob Hollow spoke at a Pint of Science event in Sydney in May, drawing a sell-out crowd despite competing with the *Game of Thrones* finale. Rob, Minh Huynh and Charlotte Sobey also spoke at a Scinapse community event hosted at our Murchison Support Facility in Geraldton.

We held the first public open days at the MRO (5-6 October), working closely with Curtin University (MWA), DIIS, the SKA Organisation and the Wajarri

Xiang Zhang staffing our stand at Astrofest in Perth. Photo: Astronomy WA Astrofest.

The FRB team: Ryan Shannon (OzGrav/Swinburne University), Keith Bannister (CSIRO) and Jean-Pierre Macquart (ICRAR/Curtin University). Photo: Inspireworks.

Yamatji traditional owners. Targeted at the residents of Geraldton, we met our target with around 200 people attending across the weekend.

The Parkes radio telescope team again supported local events such as the annual Elvis Festival and Jane Kaczmarek ran nine days of talks for primary school students which engaged with more than 1000 people ranging in age from 4 to 90 years of age. And this year Parkes hosted Cricket Australia's launch of its junior cricket program where young players strode to the crease on the surface of The Dish to face the stars of the Big Bash Leagues.

Another important aspect of our outreach work is our visitors' centres at the Parkes radio telescope and ATCA (see table). The visitors centre at Parkes turned 50 on 14 February 2019, having welcomed more than five million visitors over the years making it CSIRO's number one point of contact with the public.

Attendees at the MRO open day. Photo: Kurt Warhurst.

Number of visitors to ATCA and the Parkes Radio Telescope.

SITE	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19
Parkes	84 698	68 427	95 212	83 851	105 085	112 224
ATCA	12 500	10 971	11 511	10 965	12 081	10 363

Aboriginal Liaison Officer, Leonie Boddington, at her Wajarri language stand at the MRO open day. Photo: Steve Hathway.

The Parkes team and friends celebrate the 50th birthday of the visitors' centre. Photo: John Sarkissian.

Astronomy community

The ATNF User Committee (ATUC) represents the users of the instruments of the ATNF and meets twice a year. ATUC meetings are a forum for users to raise problems with the operation of the facility and to discuss and recommend priorities for future development of the ATNF.

Karen Lee-Waddell opens the 2019 SKA Science Meeting in Manchester with the fist image from the full ASKAP array. Photo: Phil Edwards.

Meetings, workshops, conferences and colloquia

The scientific meetings we have hosted, or in which we have had significant participation, include:

AP-RASC. The triennial Asia Pacific Radio Science Conference (part of URSI, the international radio science union) was held in Delhi, India 9-15 March. Vice-Chair of Commission J (radio astronomy), Douglas Bock, was co-chair of a session and many staff presented their work.

ASKAP Community Workshop. A two-day workshop in October to review progress of the Early Science program and facilitate planning of ASKAP Pilot Surveys.

Busy Weeks. The ASKAP Commissioning and Early Science (ACES) team held a number of week-long workshops in this reporting period for members to focus on particular aspects of ASKAP commissioning.

Astronomical Society of Australia (ASA). We hosted a Town Hall meeting as part of the ASA's Annual Scientific Meeting, to give the broader astronomy community an opportunity to provide feedback on our performance.

C3DIS. Within the annual Collaborative Conference on Computational and Data Intensive Science, co-hosted by CSIRO in May, were talks by ATNF staff on machine learning for galaxy identification and the application of the Scaled Agile Framework (SAFe) to the SKA.

Data Reduction Workshop. This week-long event in August saw CSIRO staff provide advice and guidance to radio astronomers seeking to more efficiently and effectively handle large data sets or work through complexities in data reduction.

GPU Hackathon. The Pawsey Supercomputing Centre ran the second of these week-long mentored workshops in March. Teams (including one from ASKAP) collaborate to demonstrate the power of GPU technology in solving big data problems.

IAU General Assembly. The 100th anniversary meeting of the International Astronomical Union was held in Vienna over two weeks in August. As well as presenting papers, workshops and special sessions, CSIRO supported the Australian Astronomy booth, which brought together CSIRO, universities, Astronomy Australia Ltd and the Australian SKA Office.

New Zealand SKA Forum. This four-day forum in February focused on the science and computing challenges presented by the SKA. CSIRO staff spoke of their experience with ASKAP data and their involvement in developing software tools to handle that of the SKA.

PAF Workshop. This annual workshop to showcase the latest development in PAFs for astronomy and their broader application was held at the FAST telescope in China in September. CSIRO staff spoke on topics including ASKAP, the SKA PAF Consortium and PAF digital systems.

PHISCC. The 12th SKA Pathfinder HI Survey Coordination Committee workshop was held in Perth in February. The focus of this three-day event (plus two days of focus session) was on the new HI science emerging from the much anticipated SKA precursors and pathfinders.

SPARCS. The 8th SKA Pathfinder Radio Continuum Science meeting, titled: Early Science, on the path to the SKA Pathfinders, was held in Canada in May.

SKA General Science Meeting and Key Science Workshop. The week in April was divided into a three-day science meeting, followed by two days of workshops. The science meeting focused on research with the SKA pathfinders and precursors. The level of activity in Australia is reflected in the fact that while roughly 10% of the 300 registered participants were from Australian institutions, they gave 30% of the talks.

Appendices

Families from the Murchison Shire visit the MRO. Photo: Shaun Amy.

A: Committee membership

ATNF Steering Committee

Chair

Dr David Skellern AO, CMCRC Ltd

Australian astronomy community

Prof Matthew Bailes, Swinburne University

Prof Naomi McClure Griffiths, Australian National University

A/Prof Cathryn Trott, Curtin University

International astronomy community

Prof John Carlstrom, University of Chicago

Prof Michael Wise, Netherlands Institute for Space Research

Prof Xiang-Ping Wu, National Astronomical Observatories of China

Australian stakeholder communities

Ms Catherine Livingstone AO

Dr David Skellern AO, CMCRC Ltd

Ex-officio

A/Prof Julia Bryant, University of Sydney

Mr Brendan Dalton, Chief Information Officer, CSIRO

Dr David Williams, Executive Director, Digital, National Facilities and Collections, CSIRO

Secretariat

Nic Svenson, CSIRO

ATNF User Committee

Chair

Dr James Miller-Jones, Curtin University

Members

Dr Miroslav Filipovic, Western Sydney University

Dr Shari Breen, University of Sydney

Dr Stefan Oslowski, Swinburne University

Dr Jo Dawson, Macquarie University/CSIRO

Dr Maria Rioja, University of Western Australia/CSIRO

Dr Ramesh Bhat, Curtin University

Student members

Dougal Dobie, University of Sydney

Lei Zhang, National Astronomical Observatories of China

Secretary

Dr Cormac Reynolds, CSIRO

ATNF Time Assignment Committee

Chair

Dr Martin Meyer, ICRAR/University of Western Australia

Voting members

Dr Barbara Catinella, University of Western Australia

Dr Adam Deller, Swinburne University

Dr Christene Lynch, ICRAR/Curtin University

Dr Elizabeth Mahony, CSIRO

Dr Chris Power, ICRAR/University of Western Australia

Dr Nick Seymour, ICRAR/Curtin University

Dr Stas Shabala, University of Tasmania

Dr Charlotte Sobey, CSIRO

Ex-officio

Dr Douglas Bock, CSIRO

Dr Hayley Bignall (TAC Executive Officer), CSIRO

Dr Jimi Green, CSIRO

Dr Jamie Stevens, CSIRO

Administration

Amanda Gray, CSIRO

B: Financial summary

The table below summarises revenue and expenditure applied to CSIRO's radio astronomy activities ($'000s).

	YEAR TO 30 JUNE 2014	YEAR TO 30 JUNE 2015[8]	YEAR TO 30 JUNE 2016	YEAR TO 30 JUNE 2017	YEAR TO 30 JUNE 2018	YEAR TO 30 JUNE 2019
Revenue						
External	10 179	13 209	14 377	15 418	14 889	13 806
CSIRO[1, 2]	41 803	40 473	42 094	44 631	46 269	45 873
Total	51 982	53 682	56 471	60 049	61 158	59 679
Expenditure						
Salaries	17 723	19 545	21 179	22 784[3]	20 959	22 289[4]
Travel	1325	1429	1981	1866	1713	1879
Other operating	7157	9334	8837	11 708	13 250[5]	10 562
Overheads[6]	14 709	14 506	13 711	13 492	13 316	14 947
Depreciation and amortisation	7095	7513	10 101	11 607	12 321	10 314
Total	48 009	52 327	55 809	61 457	61 559	59 991
Operating result[7]	3973	1355	662	-1408	-401	-312

1. Increases are to fund depreciation as a result of ASKAP construction.
2. Covers overheads, depreciation and a proportion of direct (operating) costs – shown below.

	YEAR TO 30 JUNE 2014	YEAR TO 30 JUNE 2015[8]	YEAR TO 30 JUNE 2016	YEAR TO 30 JUNE 2017	YEAR TO 30 JUNE 2018	YEAR TO 30 JUNE 2019
Direct CSIRO funding	22 323	18 454	18 282	19 533	20 632	18 927

3. Increase in 2017 is a result of redundancy provisions.
4. Increase in 2019 is primarily due to an increase in leave provisioning.
5. Increase in 2018 is due to CSIRO's contribution to the SKA Regional Centre.
6. Includes support services such as Human Resources, Health, Safety and Environment and Property Services.
7. Operating surplus in 2014 and 2015 due largely to actual depreciation costs being lower than forecast.
8. Figures for 2015 were incorrect in the 2016 Annual Report and have been corrected here.

C: Staff list

Staff contributing to radio astronomy: ATNF and the SKA as at 30 June 2019. Includes casual staff, joint appointments and honorary fellows, but not students or contractors.

SYDNEY (NSW)		
Ahmed	Azeem	SKA
Allen	Graham	SKA
Amy	Shaun	Operations
Anderson	Craig	Science
Bannister	Keith	Technologies
Baquiran	Mia	Technologies
Barker	Steve	Technologies
Bekiaris	Georgios	Science
Bengston	Keith	Technologies
Beresford	Ron	Technologies
Bhandari	Yukti	Operations
Bhandari	Shivani	Science
Bock	Douglas	Management
Bolin	Andrew	Technologies
Bourne	Michael	Technologies
Bouwhuis	Mieke	Technologies
Bowen	Mark	Technologies
Broadhurst	Steve	Technologies
Brothers	Michael	Technologies
Bunton	John	Technologies
Cameron	Andrew	Science
Carter	Nick	Technologies
Castillo	Santiago	Technologies
Chapman	Jessica	Science
Chekkala	Raji	Technologies
Chen	Yuqing	Technologies
Cheng	Wan	Technologies
Chippendale	Aaron	Technologies
Chow	Kate	SKA
Chung	Yoon	Technologies
Cooper	Adam	Technologies
Cooper	Paul	Technologies
Craig	Daniel	Operations
Dai	Shi	Science
D'Costa	Howard	SKA
de Jong	Maarten	Science
Death	Michael	Technologies
Doherty	Paul	Technologies
Drazenovic	Vicki	Operations
Dunning	Alex	Technologies
Edwards	Leanne	Operations
Edwards	Phil	Science
Ekers	Ron	Science
Feain	Ilana	Technologies
Fedeli	Jordan	Technologies
Ferris	Dick	Technologies
George	Daniel	Technologies
Gough	Russell	Technologies
Gray	Amanda	Science
Guntek	Edward	Operations
Hampson	Grant	Technologies
Hartmann	Carmel	SKA
Hayes	Michael	SKA
Hayman	Douglas	Technologies
Hobbs	George	Science
Hollow	Robert	Science
Howard	Eric	Operations
Humphrey	David	Technologies
Huynh	Minh	Technologies
Indermuehle	Balthasar	Science
Ingold	Brett	Technologies
Jeganathan	Kanapathippillai	Technologies
Johnston	Simon	Science
Kachwalla	Elsa	Operations
Kesteven	Michael	Technologies
Kiraly	Dezso	Technologies
Koribalski	Baerbel	Science
Kosmynin	Arkadi	Operations
Leach	Mark	Technologies
Lee-Waddell	Karen	Science
Lenc	Emil	Science

Lennon	Brett	Operations
Lichtman	Ben	Technologies
Lim	Boon	Technologies
Mackay	Simon	Technologies
Macleod	Adam	SKA
Madden	Cathy	Management
Maher	Tony	Operations
Mahony	Elizabeth	Science
Manchester	Dick	Science
Marquarding	Malte	Operations
McConnell	David	Science
McIntyre	Vincent	Operations
Mitchell	Daniel	Operations
Moss	Vanessa	Science
Norris	Ray	Science
O'Brien	Andrew	Science
Ord	Stephen	Operations
Pearce	Sarah	Management
Petranovic	Aeva	Operations
Phillips	Chris	Science
Pilawa	Mike	Technologies
Pope	Nathan	Operations
Raja	Wasim	Operations
Reilly	Les	Technologies
Reynolds	John	Operations
Rispler	Adrian	SKA
Roberts	Paul	Technologies
Roush	Peter	Technologies
Sadler	Elaine	Science
Schinckel	Antony	SKA
Severs	Sean	Technologies
Shaw	Robert	Technologies
Shields	Matt	SKA
Smart	Ken	Technologies
Smith	Stephanie	Technologies
Svenson	Nic	Management
Tam	Kam T	Operations
Tesoriero	Julie	Technologies
Toomey	Lawrence	Science
Troup	Euan	Operations
Tuthill	John	Technologies
Tuthill	Luke	Operations
Tzioumis	Tasso	Technologies
Voronkov	Max	Operations
Wark	Robin	Science
Whiting	Matthew	Science
Wieringa	Mark	Operations
Wilson	Carol	Technologies
Wu	Xinyu	Operations
NARRABRI (NSW)		
Bateman	John	Operations
Cole	James	Operations
Forbes	Kylee	Operations
George	Mike	Operations
Hill	Mike	Operations
Kelly	Pam	Operations
Lee	Kun	Operations
Mirtschin	Peter	Operations
Rex	Jordan	Operations
Stevens	Jamie	Operations
Sunderland	Graeme	Operations
Trindall	Jane	Operations
Wilson	Chris	Operations
Wilson	John	Operations
Wilson	Tim	Operations
PARKES (NSW)		
Abbey	Alex	Operations
Hoyle	Simon	Operations
Hunt	Andrew	Operations
Kaczmarek	Jane	Science
Kaletsch	Robert	Operations
Lees	Tom	Operations

PARKES (NSW) CONTINUED		
Lensson	Erik	Operations
Mader	Stacy	Operations
Mason	Hanneke	Operations
Milgate	Lynette	Operations
Palmer	Kyasha	Operations
Preisig	Brett	Operations
Reeves	Ken	Operations
Ruckley	Tim	Operations
Sarkissian	Maggie	Operations
Sarkissian	John	Operations
Sharwood	Warren	Operations
Smith	Mal	Operations
Trim	Tricia	Operations
Unger	Karin	Operations
Kitaeff	Slava	Operations
Mladineo	Mick	Operations
Prandoni	Isabella	Science
Reynolds	Cormac	Science
Riseley	Chris	Science
Ryan	Todd	Operations
Shaw	Cliff	Operations
Sobey	Charlotte	Science
Spade	John	Operations
Taylor	Zoe	Operations
Tobin	Craig	Operations
Tremblay	Chenoa	Science
Vernstrom	Tessa	Science
Zhang	Xiang	Science
Zonta	Danilo	Operations

PERTH & NEW NORCIA (WA)		
Bastholm	Eric	Operations
Bignall	Hayley	Science
Cassidy	Colin	Operations
Cloake	Beth	Operations
Croxall	Andrew	Operations
Ferguson	Kevin	Operations
Galvin	Tim	Science
Green	Jimi	Science
Gurkan Uygun	Gulay	Science
Guzman	Juan	Operations
Haskins	Craig	Operations
Heald	George	Science
Hotan	Aidan	Science
Huynh	Minh	Science
Jackson	Suzy	Operations
Jameson	Katie	Science

GERALDTON & MRO (WA)		
Boddington	Leonie	Operations
Cox	Tom	Operations
Desmond	Rochelle	Operations
Hannah	James	Operations
Harding	Alex	Operations
Hathway	Steve	Operations
Hiscock	Brett	Operations
McConigley	Ryan	Operations
McIntosh	Savannah	Operations
Merry	Clarence	Operations
Morris	John	Operations
Pena	Will	Operations
Puls	Lou	Operations
Reay	Michael	Operations
Rowan	Haydn	Operations
Warhurst	Kurt	Operations

D: Observing programs

Proposals allocated time on ATNF telescopes over the April – September 2018 and October 2018 – March 2019 semesters. A small number of target of opportunity observations are not listed. Proposal cover sheets are available through the proposal application system, OPAL.

ATCA

OBSERVERS	PROGRAM	Nº
Stevens, Edwards, Wark, Wieringa	ATCA calibrators	C007
Staveley-Smith, Cendes, Gaensler, Indebetouw, Matsuura, Tzioumis, Zanardo, Ng	Supernova remnant 1987A	C015
Corbel, Tzioumis, Kaaret, Tomsick, Orosz, Loh, Fender	Large scale radio/X-ray jets in microquasars	C1199
Ryder, Kool, Anderson, Filipovic, Stockdale, Kotak, Amy, Romero-Canizales	NAPA observations of core-collapse supernovae	C1473
Edwards, Stevens, Ojha, Kadler, Lovell, Mueller, Wilms	ATCA monitoring of Fermi gamma-ray sources	C1730
Filipovic, Wong, Maxted, Luken, de Horta	Evolution study of the youngest galactic SNR G1.9+0.3	C1952
Agliozzo, Phillips, Leto, Trigilio, Buemi, Umana, Pignata, Noriega-Crespo, Mehner, Ingallinera, Cavallaro, Cerrigone	Diving into the ejecta of the luminous blue variable RMC127	C1973
Cavallaro, Bufano, Umana, Ingallinera, Trigilio, Buemi, Leto, Norris, Franzen, Marvil, Riggi	Stellar radio emission in the SKA era: the SCORPIO project	C2515
Atri, Miller-Jones, Jonker, Maccarone, Nelemans, Sivakoff, Tzioumis	NAPA: constraining black hole formation with LBA astrometry	C2538
Russell, Miller-Jones, Sivakoff, Altamirano, Soria, Krimm	NAPA: jet-disc coupling in black hole X-ray binary outbursts	C2601
Maddison, Moor, Abraham, Kospal, Thilliez	PLATYPUS: a southern debris disk survey at 7 mm	C2694
Aravena, Spilker, Aguirre, de Breuck, Bethermin, Bothwell, Carlstrom, Chapman, Crawford, Fassnacht, Gonzalez, Jarugula, Ma, Marrone, Apostolowski, Malkan, Stark, Tothill, Vieira, Weiss, Strandet, Litke	A legacy CO survey of the brightest dusty star-forming galaxies at z=2-7 discovered by the SPT	C2818
Suarez, Gomez, Miranda, Bendjoya, Green, Niccolini, Cala	Monitoring the real-time birth of a planetary nebula	C2949
Dickey, Bania, Balser, Wenger, Armentrout, Jordan, McClure-Griffiths, Anderson, Dawson	Southern HII region discovery survey (SHRDS)	C2963
Papitto, Migliari, Rea, Torres, Bozzo, Ferrigno	NAPA: coupling accretion and ejection in transitional millisecond pulsars	C3007
Moss, Tingay, Sadler, Allison, Maccagni, Stevens, Edwards, Macquart, Morganti, Oosterloo, Glowacki, Musaeva, Shabala, Ekers, Beuchert, Wilms, Kadler, Callingham	Rocking the cradle: a continuing ATCA/XMM-Newton case study of continuum variability in PKS 1718-649	C3019
Russell, Altamirano, Ceccobello, Markoff, Miller-Jones, Russell, Sivakoff, Soria, Tetarenko	NAPA: The evolving jet properties of transient black hole X-ray binaries	C3057
Uscanga, Green, Gomez, Cala, Suarez, Qiao, Miranda, Trinidad, Anglada, Boumis	Unveiling the nature of the spectral energy distribution of very young planetary nebulae	C3095
Maddison, Wright, Pinte, van der Marel, van der Plas, van Dishoeck, Pinilla, Walsh, Agnew, Ansdell, Menard	Dust traps in transition disks	C3119
Huynh, Seymour, Davies, Robotham, Hopkins, Shabala, Norris, Sadler, Kapinska, Wong, Meyer, Prandoni, Delhaize, Chow, Collier, O'Brien, White, Riseley, Marvil, Murphy, Smolcic, Franzen, Butler, Turner, Drouart, Gurkanuygun, Swan, Rogers, Galvin	GAMA Legacy ATCA Southern Survey (GLASS): A Legacy 4 cm Survey of the GAMA G23 Field	C3132

ATCA continued

OBSERVERS	PROGRAM	Nº
Breen, Walsh, Rowell, Ellingsen, Cunningham, Jones, Burton, Contreras, Dawson, Schneider, Voronkov, Ott, De wilt, Green, Barnes, Longmore, Indermuehle, Fuller, Avison, Smith, Bronfman, Novak, Toth, Jordan, Hyland, McCarthy, Phillips, Federrath, Jackson, Fissel, Kainulainen	Dense gas across the Milky Way - the 'full-strength' MALT45	C3145
van Velzen, Miller-Jones, Jonker, Shappee, Arcavi, Holoien, Gezari, Anderson	NAPA: radio emission from stellar tidal disruption flares	C3148
Jackson, Barnes, Rathborne, Longmore, Contreras, Sanhueza, Hogge, Stephens, Whitaker, Walker, Smith, Krumholz, Kruijssen, Walsh, Caselli, Cunningham, Ott, Allingham, Killerby-Smith, Breen, Jordan	A comprehensive ATCA census of high-mass cores	C3152
Popping, de Blok, Chanapote, Dodson, Gannon, Heald, Koribalski, Lee-Waddell, Lopez-Sanchez, Spitler, Madrid, Moss, Meyer, Obreschkow, Pisano, Power, Rhee, Robotham, Staveley-Smith, Wang, Westmeier, Anderson, Wolf, Kleiner, Kaczmarek, Sardone, Vinsen, Wicenec, Wu	Imaging galaxies intergalactic and nearby environment	C3157
McCarthy, Ellingsen, Breen, Voronkov, Leurini, Chen	Investigating extragalactic star-formation through methanol emission	C3167
Galvin, Seymour, Norris, Marvil, Filipovic, Tothill, Bell, Huynh, Stevens, Murphy, Heywood, Heald, Jarrett, Banfield, Crawford, Collier, O'Brien, Grieve, Manojlovic	Exploring the high redshift universe at high frequency	C3171
Dannerbauer, Emonts, Smail, Huynh, Allison, Altieri, Aretxaga, Brandt, Chapman, Casey, de Breuck, Drouart, Hodge, Indermuehle, Kimball, Kodama, Koyama, Lagos, Lehnert, Mao, Miley, Narayanan, Norris, Rottgering, Schinnerer, Seymour, Swinbank, Thomson, Valtchanov, Wardlow, Simpson	COALAS: CO ATCA legacy archive of star-forming galaxies	C3181
Anderson, Bell, Hancock, Lynch, Miller-Jones, Bahramian, Bannister, Kaplan, Murphy, Ryder, Macquart, Plotkin	NAPA: ATCA rapid-response triggering on X-ray and gamma-ray superflares from the smallest stars	C3200
Anderson, Bell, Hancock, Miller-Jones, Bahramian, Bannister, van der Horst, Ryder, Macquart, Plotkin, Rowlinson	NAPA: ATCA rapid-response triggering on Swift detected short gamma-ray bursts: exploring the link with gravitational wave events	C3204
Shannon, Bannister, Macquart, Mahony, Bhandari, Deller, Dodson, Flynn, James, Oslowski, Prochaska, Sadler, Tejos	NAPA: radio continuum emission from ASKAP-localised Fast Radio Bursts	C3211
Fraga-Encinas, Stevens, Dodson, Zhao, Rioja, Jung, Sohn, Cho, Janssen, Roelofs, Brinkerink, Issaoun, Ros, Falcke, Krichbaum, Marti-Vidal, Mueller, Agudo	Constraining the size of Sagittarius A* with ATCA+KVN observations at 86 GHz	C3213
Bannister, Bignall, Stevens, Walker, Reynolds, Tuntsov, Md Said	TAILS: testing the association of intra-hour variability with local stars	C3214
Gomez, Uscanga, Suarez, Miranda, Anglada, Osorio, Trinidad, Bendjoya	A search for synchrotron emission in planetary nebulae	C3216
Galvin, Seymour, Heald, Norris, Marvil, Murphy, Filipovic, Banfield, Huynh, Tothill, Jarrett, O'Brien, Crawford	Unravelling the far infrared to radio correlation	C3221
Michalowski, Galbany, Hjorth, Kamphuis, Fynbo, Hunt, Kuncarayakti, Le Floc'h, Leloudas, Nicuesa Guelbenzu, Palazzi, Rasmussen, Rossi, Savaglio, Schady, Schulze, Thone, Vergani, Watson	Do SN Ic-BL signal recent inflow of gas from the intergalactic medium?	C3232
van Den Eijnden, Degenaar, Russell, Miller-Jones, Wijnands, Tudor	The first deep radio census of accreting X-ray pulsars	C3234
Foord, Gultekin, Plotkin, Hodges-Kluck	A candidate massive black hole in the Large Magellanic Cloud	C3237
Piro, Troja, Ricci, Wieringa, van Eerten, Ryan	The relativistic outflow of GW170817 and the nature of the central remnant with ATCA	C3240

OBSERVERS	PROGRAM	Nº
Aravena, Chapman, Ashby, de Breuck, Miller, Marrone, Stark, Spilker, Litke, Vieira, Weiss, Harnett, Apostolowski, Hayward	Cold molecular gas in the most massive protoclusters at z=4.3-5.8 selected by the South Pole Telescope	C3243
Heald, Alexander, Anderson, Basu, Brown, Callingham, Carretti, Crawford, Farnes, Filipovic, Gaensler, Galvin, Harvey-Smith, Johnston-Hollitt, Kaczmarek, Landecker, Leahy, Lenc, Mao, McClure-Griffiths, O'Sullivan, Pasetto, Purcell, Riseley, Rudnick, Schnitzeler, Sobey, Sun	The QUOCKA survey	C3244
Sun, Gaensler, Slane, West, Kothes	Magnetic fields in supernova remnants	C3246
Ma, Sun, Lenc, Mao	The 3D magnetic field structure of the nearby face-on barred spiral galaxy M83	C3248
Lee, Kohno, Hatsukade, Takekoshi, Nishimura	CO observation of a unique lensed submillimeter galaxy hosting a radio-loud AGN	C3249
Dobie, Murphy, Kaplan, Stewart, Lenc, Lynch, Bannister	Long term radio follow-up of GW170817	C3251
Leto, Pillitteri, Trigilio, Fossati, Ignace, Robrade, Buemi, Umana, Ingallinera, Cavallaro, Phillips, Leone, Agliozzo, Cerrigone, Riggi, Bufano, Jiri, Oskinova	ATCA observations of the first magnetic B2V star X-ray lighthouse: rho Oph A	C3255
Riseley, Anderson, Heald, Lenc	Untangling the magnetic field in the giant radio galaxy ESO422-G028	C3258
Livingston, McClure-Griffiths	Magnetic field structure in the Galactic centre	C3259
Pineda, Lynch, Moss, Zic, Lenc	Uncovering the population of radio ultracool dwarfs	C3261
McCarthy, Ellingsen, Breen, Voronkov, Chen, Brown, Parkash	Searching for extragalactic methanol maser emission	C3263
Troja, Ricci, Wieringa	ATCA observations of a candidate radio flare from a neutron star merger	C3264
Osten, Kowalski, Brown, Grady, Wisniewski, Lomax, Henry, Allred, Schneider	A unified understanding of flare heating	C3265
Callingham, Marcote, Pope, Tuthill	Sampling the orbit of the newly discovered and brightest non-thermal radio-emitting colliding wind binary	C3267
Leite, Messias, Martins, Molaro	Toward stronger fundamental physics tests in the matter era	C3272
Chomiuk, Ryder, Filipovic, Linford	E-nova project monitoring of Nova Muscae 2018 and Nova Carinae 2018	C3279
Plotkin, Miller-Jones, Bahramian, Reynolds, Gandhi	An ATCA-Gaia search for the weakest black hole jets	C3280
Lee, Kohno, Hatsukade, Takekoshi, Nishimura	CO(3-2) observation of a unique lensed submillimeter radio-loud galaxy	C3283

Parkes radio telescope

OBSERVERS	PROGRAM	Nº
Burgay, Kramer, Manchester, Stairs, Lorimer, Possenti, McLaughlin, Ferdman, Wex	Timing and geodetic precession in the double pulsar	P455
Hobbs, Coles, Manchester, Sarkissian, Wen, Zhang, Keith, Wang, Kerr, Dai, van Straten, Dempsey, Russell, Spiewak, Parthasarathy, Bailes, Bhat, Levin, Oslowski, Reardon, Shannon, Zhu, Toomey	A millisecond pulsar timing array	P456
Dai, Johnston, Kerr, Sobey, Shannon, Manchester, Hobbs, Weltevrede, Ilie, Possenti	Young pulsar timing: probing the physics of pulsars and neutron stars	P574
Hobbs, Hollow, Bannister, Dai, Green, Kaczmarek, Shannon, Toomey	PULSE@Parkes (Pulsar Student Exploration online at Parkes)	P595

Parkes radio telescope continued

OBSERVERS	PROGRAM	Nº
Hobbs, Manchester, Bailes, Reynolds, Johnston, Sarkissian, Shannon, Dai, Green, Kaczmarek, van Straten, Jameson, Sobey	Instrumental calibration for pulsar observing at Parkes	P737
Spiewak, Bailes, Barr, Burgay, Camilo, Champion, Cromartie, Eatough, Ferdman, Freire, Jankowski, Johnston, Keane, Keith, Kerr, Kramer, Levin, Lorimer, Morello, Ng, Possenti, Ransom, Stappers, Ray, Stairs, van Straten, Wex	Timing of binary and millisecond pulsars discovered at Parkes	P789
Mader	A search for methylidyne and hydroxyl in the Musca Dark Cloud	P798
Zhang, Manchester, Dai, Hobbs, Russell, Staveley-Smith	Search for a pulsar in SN 1987A	P834
Balakrishnan, Cameron, Champion, Kramer, Bailes, Johnston, Possenti, Stappers, Burgay, van Straten, Bhat, Petroff, Ng, Barr, Flynn, Jameson, Bhandari	Initial follow-up of pulsar discoveries from the HTRU Galactic Plane survey	P860
Hobbs, Shannon, Johnston, Hollow, Ward, Yuen, Ravi, Kerr, Dai, Wang	Analysis of state switching pulsars	P863
Camilo, Scholz, Reynolds, Sarkissian, Johnston	Understanding the remarkable behaviour of radio magnetars	P885
Keane, Bailes, Barr, Bhandari, Bhat, Burgay, Caleb, Eatough, Farah, Flynn, Green, Jameson, Jankowski, Johnston, Kramer, Levin, Morello, Ng, Petroff, Possenti, Primak, Spiewak, Stappers, van Straten, Tiburzi, Venkatraman Krishnan	SUPERBx – The SUrvey for Pulsars & Extragalactic Radio Bursts Extension	P892
Hobbs, Coles, Keith, Manchester, Sarkissian, Shannon, Kerr, Wen, Dempsey, You, Rosado, Lasky, Toomey, Zhang, Ravi, Wang, Russell, Spiewak, Bailes, Bhat, Burke, Oslowski, van Straten, Zhu, Dai, Reardon, Parthasarathy	Where are the gravitational waves?	P895
Alves, Green, Arzoumanian, Troland, Dawson, Robishaw, Bracco, Soler, Ogbodo	An OH Zeeman survey of molecular filaments in the southern sky	P899
Pisano, Sardone, Popping, Meyer, Staveley-Smith, Moss, de Blok, Lopez-Sanchez, Rhee, Heald, Kleiner	Mapping the extended HI environment of IMAGINE galaxies	P951
Moss, Mcclure-Griffiths, Lockman, Di Teodoro, Pisano, Price, Rees	The hidden iceberg structure of the halo with Parkes	P953
Shannon, Oslowski, Bannister, Macquart, Bhandari, Deller, Dodson, Flynn, Kerr, James, Qiu, Farah, Phillips, Zhang	Searching for repetition from ASKAP fast radio bursts	P958
Mader, Green, Sarkissian, Kaczmarek	Receiver characterisation	P960
Johnston, Kramer	Mapping the magnetosphere of interpulse pulsars	P963
Oslowski, Verbiest	Wideband timing observations of J1933-6211	P965
Sobey, Johnston, Bhat	Investigating mode-changing pulsars' magnetospheres using the UWL	P966
Staveley-Smith, Wang, Reynolds, Crocker, Ekers, James, Rhee, Westmeier	A search for antimatter in the Galactic Centre	P967
Dai, Johnston, Kerr, Camilo	Searching for millisecond pulsars towards unidentified Fermi sources using the Ultra-wideband receiver	P970
Venkatraman Krishnan, Reardon, Bailes, van Straten, Keane, Oslowski, Bhat, Flynn, Rosado	Orbital dynamics and the intra-binary medium of PSR J1141-6545	P971
Oswald, Karastergiou, Johnston	Single pulse studies with the Ultra-Wideband receiver: an unprecedented view of the pulsar magnetosphere	P972

OBSERVERS	PROGRAM	Nº
Kaczmarek, Allison, Mahony, Sadler, Phillips, Hotan, Moss	Parkes resolves the cold gas detected by ASKAP in distant radio galaxies	P973
Dawson, Bracco, Green, Joncas, Grenier, Hill, Lee, Mader, Wardle, Dame, Nguyen, Petzler, Miville-Deschenes, Krishnarao, Marchal	Simultaneous UWL observations of OH and CH in a pristine high-latitude cloud: benchmarking dark gas tracers	P974
Polzin, Sobey, Breton, Oslowski, Roberts, Johnston	Wide-band characterisation of the radio eclipses of black widows and redbacks	P976
Leahy, Carretti, Cavallaro, Crawford, Dai, Gaensler, Ingallinera, Kaczmarek, Mcclure-Griffiths, Norris, Riggi, Skipper, Thomson, Tothill, Umana	A wide-band survey of the Scorpio field in support of EMU/POSSUM	P977
Bailes, Johnston, Oslowski, Jameson, Shannon, van Straten	Commissioning a new real-time coherent de-disperser	P981
Zhang, Hobbs, Li, Lorimer, Dai, Cameron, Zhu	The first coherently de-dispersed search for new pulsars in southern globular clusters	P982
Zhang, Hobbs, Li, Kaczmarek, Dai, Cameron, Yuan, Zhu	Characterising the broad-band intermittency time scale, mode changing, periodicities and polarization variations of PSR J1926-06	P985
Kumamoto, Dai, Takahashi, Hobbs	Targeted search of steep spectrum sources with the Ultra-Wideband receiver	P986
Hollow, Hobbs, Green, Kaczmarek, Zhang, Dai, Toomey, Cameron, Oslowski, Sobey	Maximising the science and education output from PULSE@Parkes and OPTIMUS in the era of the wide-bandwidth receiver	P988
Wang, Li, Lorimer, Hobbs, Cordes, Chatterjee, Pan, Wang, Zhu, Lynch, Qian, Cameron	Confirming candidates from the Parkes multibeam pulsar survey	P989
Li, Hobbs, Green, Krco, Stanimirovic, Mcclure-Griffiths, Dai, Cameron, Kaczmarek, Weisberg, Zhang	A follow-up study of stimulated emission toward PSR B1641-45	P990
Dai, Zhang, Johnston, Hobbs, Zhang	A pulsar survey towards the Galactic Centre with the Ultra-Wideband Low receiver	P991
Cameron, Champion, Kramer, Hobbs, Freire, Wex	Exploratory observations of a relativistic binary pulsar with an ultra-wideband receiver.	P992
Ferdman, Archibald, Kaspi	A search for pulsed emission from PSR~B0540–69 after a state change	P995
Han, Manchester, van Straten, Hobbs	Magnetic field reversals in distant spiral arms	P996
Jacob, Menten, Wiesemeyer, Green, Dawson	A renaissance of CH observations	P997
Lorimer, Zhang, Hobbs, Li, Dai, Cameron, Zhu, Kania	Terzan 6 - the next Terzan 5?	P998
Kupfer, Ravi, Geier	A deep search for radio pulsars around hot subdwarf stars in compact binaries	P1000

CDSCC

OBSERVERS	PROGRAM	Nº
Orosz, Gomez, Horiuchi, Imai	Monitoring of H_2O masers in all known water fountains	T215

LBA

OBSERVERS	PROGRAM	Nº
Ojha, Kadler, Edwards, Carpenter et al.	Physics of Gamma Ray Emitting AGN	V252
Hyland, Ellingsen, Reid, Brunthaler, Menten, Honma, Rioja, Dodson, Chibueze, Green, Krishnan, Sakai, Zhang, Breen, Chen, Dawson, Fujisawa, Phillips, Sanna, Shen, Xu, Voronkov, Zheng, Goedhart	Astrometric Observation of Methanol Masers: Determining Galactic Structure and Investigating High-Mass star formation	V255
Loinard, Deller, Forbrich, Orizt-Leon	The distance to the Coronet Cluster in Corona Australis	V329
Atri, Miller-Jones, Jonker, Maccarone, Nelemans, Sivakoff, Tzioumis	Constraining black hole formation with LBA astrometry	V447
Chanapote, Green, Dodson, Rioja, Kramer, Asanok	Magnetic field properties at the highest resolution	V452
Sobolev, Alakoz, An, Baan, Ellingsen, Henkel, Imai, Kostenko, Moran, McCallum, MacLeod, Shakhvorostova, Voronkov	Investigation of the extragalactic H2O masers in the Large Magellanic Cloud and in the Circinus galaxy with extremely high resolution	V477
Savolainen, Edwards, Reynolds, Anderson, Asada, Bach, Bruni, Fromm, Giovannini, Giroletti, Gomez, Hada, Hodgson, Kino, Kovalev, Krichbaum, Lee, Lobanov, Lu, Nagai, Orienti, Ros, Sohn, Sokolovsky, Voitsik, Zensus	The nuclear structure in M87 with RadioAstron	V510
Gomez, Lobanov, Bruni, Kovalev, Anderson, Fuentes, Vega-Garcia, Casadio, Marscher, Bach, Jorstad, Savolainen, Ros. Lu, Krichbaum, Zensus, Edwards, Phillips, Stevens, McCallum, Molina, Agudo, Marti, Perucho, Hada, Lee	Probing the innermost regions of AGN jets and their magnetic fields: LBA	V513
Titov, Edwards, Reynolds, Jauncey, Tzioumis, Dickey, Shabala, McCallum, Natusch, de Witt, Horiuchi, Watson, Shu, Gulyaev, McCallum, Reynolds	Improving the terrestrial and celestial reference frame through Southern Hemisphere Geodetic VLBI Observations	V515
Orosz, Gomez, Tafoya, Imai, Suarez, Burns	Astrometric measurements of the first water fountain planetary nebula	V544
Reynolds, Kovalev, Edwards, Sokolovsky, Bignall, Kardashev, Macquart, Jauncey, Tzioumis, Horiuchi, Koay, Deller,	Monitoring of the Brightest AGN Cores with RadioAstron and the LBA	V549
Loinard, Belloche, Deller, Ortiz-Leon	Measuring the distance to the Chamaeleon star-forming region	V553
Yang, Deller, Reynolds, An, Paragi, Quick, Hobbs, Gurvits, Hong, Ding, Li, Xia, Yan, Guo, Hao, Chen, Xu	Toward a sub-parsec accuracy for VLBI distance measurement of PSR J0437–4715	V558
Kirichenko, Shternin, Shibanov, Voronkov, Zyuzin, Danilenko	Determining the distance to PSR B1727-47 by parallax measurements with the VLBI	V560
Marcote, Callingham, de Becker, Edwards, Stevens, Schulz	Resolving the enigmatic source 2XMM J160050.7-514245: An Extreme Radio Bright Colliding Wind Binary Candidate	V565
Gurvits, Frey, Bignall, Cimo, Edwards, Ghosh, Gomez, Gulyaev, Jauncey, Johnson, Kovalev, Kutkin, Lobanov, Murata, Reynolds, Salter, Sokolovsky, Voitsik	A twenty-fold zoom into the structure of the bright enigmatic blazar AO 0235+164	V571
Motta, Miller-Jones, Fender, Bright, Homan, Kajava, Nowak, Remillard, Ferrigno, Sanchez-Fernandez, Casella, Vincentelli, Ingram	Probing the disc-jet coupling in the neutron star binary Sco X-1	V573
Lisakov, Sokolovsky, Kutkin, Voitsik, Litovchenko, Johnson	Probing Interstellar Scattering Material using Dense RadioAstron Observations of Refractive Substructure in AGN	V575

E: Demographic data

These figures show staff from all of CSIRO Astronomy and Space Science as gender targets, being established as part of CSIRO's Science in Australia Gender Equity program, will be set by Business Unit.

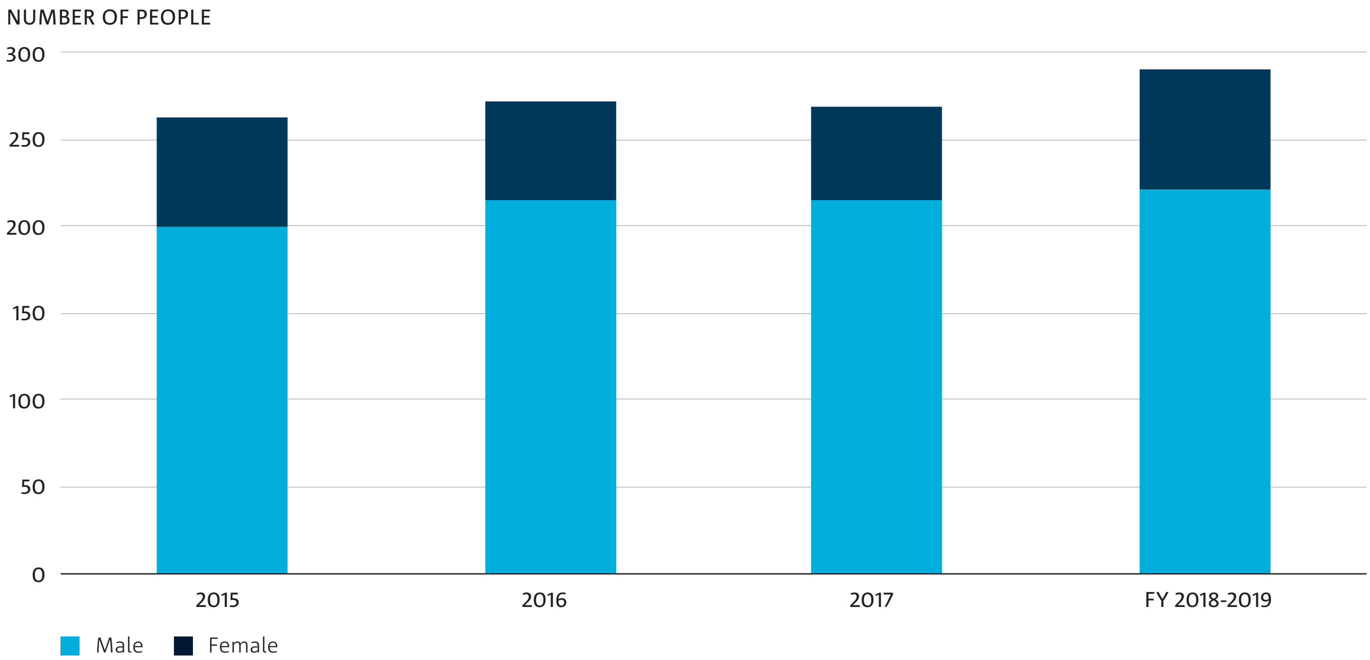


Figure 14: CASS gender breakdown over time.

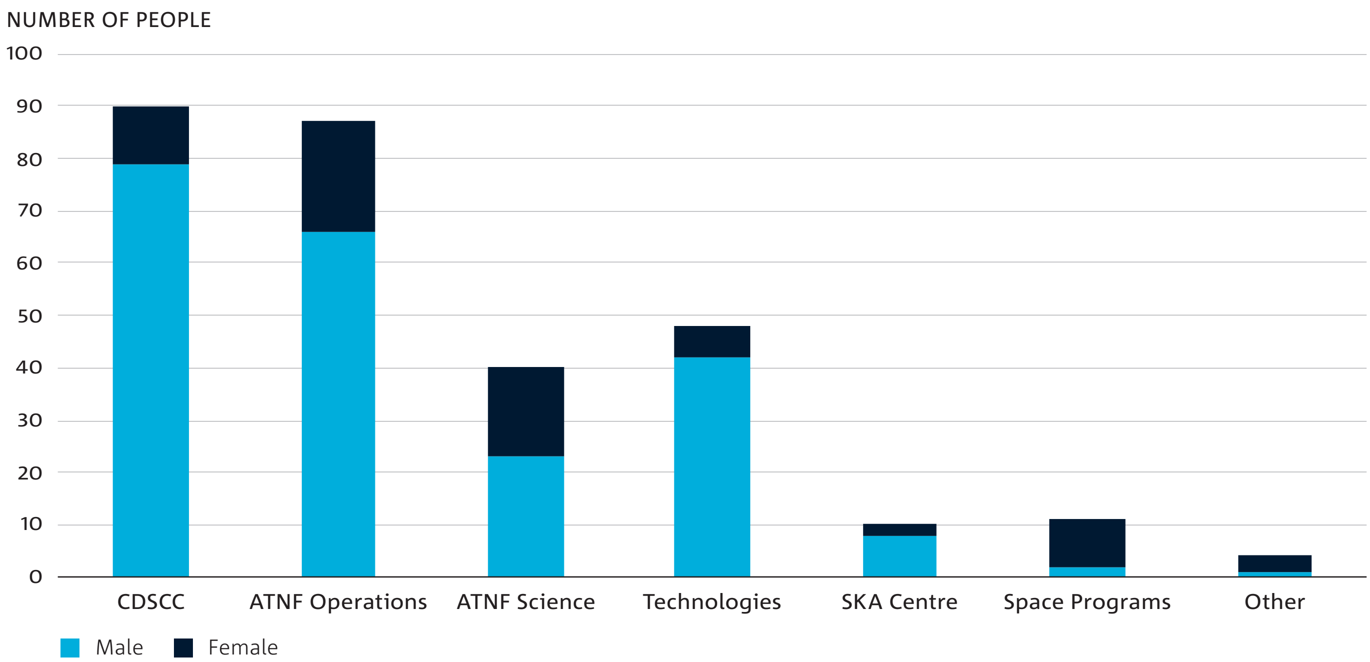


Figure 15: CASS gender breakdown across Programs. The ATNF comprises Operations, Science, Technologies and the SKA.

F: Postgraduate students

Postgraduate students co-supervised by ATNF staff as of 30 June 2019 (PhD, unless marked otherwise).

NAME	UNIVERSITY	PROJECT TITLE
Wayne Arcus	Curtin University	Fast radio bursts as cosmic probes
Cherie Day	Swinburne University of Technology	Pinpointing the origin of fast radio bursts
Dougal Dobie	University of Sydney	Radio transient detection using the Australian Square Kilometre Array Pathfinder
Ahmed Elagali	University of Western Australia	Studies of interacting galaxies and the environmental effects on their evolution
Yi Feng	National Astronomical Observatory, Chinese Academy of Science (CAS)	Jitter noise and GWs
Sarah Hegarty	Swinburne University of Technology	Accelerating and enhancing knowledge discovery for the Petascale Astronomy Era
Lucas Hyland	University of Tasmania	Structure of the Milky Way
Hiroki Kumamoto	Kumamoto University	Towards pulsar searching and pulsar timing with the SKA
Ali Lalbakhsh	Macquarie University	Additive manufacturing for next-generation radio telescopes
John Lopez	University of New South Wales	Molecular clouds in the Milky Way: peering into the galactic centre and unravelling the origins of Planck cold clumps
Marcus Lower	Swinburne University of Technology	Application of astrophysical inference to next generational pulsar timing datasets
Kieran Luken (MSc)	Western Sydney University	Applying machine learning techniques to estimate the redshift of galaxies
Peter MacGregor (MSc)	Western Sydney University	Using ASKAP to investigate the spatial structure of the Universe on megaparsec scales
Perica Manojlovic	Western Sydney University	Origin of the diffuse emission of galaxy clusters in the SPT field
Lachlan Marnoch (MSc)	Macquarie University	The host galaxies of Fast Radio Bursts
Tommy Marshman (MSc)	Macquarie University	Applying a GPU based pulsar searching pipeline on a new Parkes Galactic Plane survey
Tiege McCarthy	University of Tasmania	Class I methanol megamasers: a new probe of galactic starbursts
Noor Md Said	University of Tasmania	Intraday variability of active galaxies
Shannon Melrose	University of New South Wales	Analytical techniques for interpreting the results of large-scale, multi-molecular-line datasets of the ISM
Bradley Meyers	Curtin University	Investigating the links between radio pulsar populations that display intermittent emission phenomena at low frequencies
Karlie Noon (MSc)	Australian National University	3-D velocity vectors of high velocity clouds
Chikaedu Ogbodo	Macquarie University	MAGMO: mapping the galactic magnetic field with masers
Aditya Parthasarathy Madapusi	Swinburne University of Technology	High precision pulsar timing in the SKA era
Steve Prabu (MSc)	Curtin University	Space debris detection using the Murchison Widefield Array
Harry Qiu	University of Sydney	Exploring the dynamic radio sky with ASKAP
Tristan Reynolds	University of Western Australia	Studying the environmental dependence on HI in galaxy groups with WALLABY

NAME	UNIVERSITY	PROJECT TITLE
Jonathan Rogers	University of Tasmania	Unravelling the physics of galaxies and active galactic nuclei in the Square Kilometre Array era
Gary Segal	University of Queensland	Machine learning algorithms for detecting the interesting and the unexpected
Renzhi Su	Shanghai Astronomical Observatory, CAS	Tracing fuelling and feedback in powerful radio galaxies with 21 cm HI absorption
Stuart Weston	Auckland University of Technology	Data mining for statistical analysis of the faint radio sky: the pathway to EMU
Naoyuki Yonemaru	Kumamoto University	Simulation of gravitational wave signals from cosmic strings and the effects of the interstellar medium
Chao Zhang	National Astronomical Observatory, CAS	Pulsar search with interpretable machine learning
Lei Zhang	National Astronomical Observatory, CAS	Millisecond pulsars with FAST
Songbo Zhang	Purple Mountain Observatory, CAS	Searching for radio bursts in archival Parkes data
Andrew Zic	University of Sydney	Characterising the low frequency radio emission of dwarf stars and planets

G: PhD theses

Theses awarded to co-supervised PhD students.

NAME	UNIVERSITY	MONTH AWARDED	THESIS TITLE
Shaila Akhter	University of New South Wales	January 2019	A tale of high-mass star formation and its relationship to Galactic structure: a multimolecular line study from HOPS survey
Andrew Butler	University of Western Australia	March 2019	Measuring AGN feedback: black hole kinetic luminosity outputs from high and low excitation radio galaxies
Van Hiep Nguygen	Macquarie University	March 2019	Shining light on the dark Milky Way: probing our galaxy's hidden gas

H: Publications

Papers citing data from, or related to, ATNF telescopes, and other staff papers, from the calendar year 2018.

Journal publications

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Legend

*	Authors include ATNF staff
A	ASKAP
C	ATCA
M	Mopra
O	Other staff paper
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Legend

*	Authors include ATNF staff
A	ASKAP
C	ATCA
M	Mopra
O	Other staff paper
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I: Abbreviations

This list does not include units of measure or chemical symbols.

ABBREVIATION	DESCRIPTION
ACES	ASKAP Commissioning and Early Science
ACMA	Australian Communications and Media Authority
AO	Officer in the Order of Australia
ASA	Astronomical Society of Australia
ASKAP	Australian SKA Pathfinder
ATCA	Australia Telescope Compact Array
ATNF	Australia Telescope National Facility
ATOA	Australia Telescope Online Archive
ATSC	ATNF Steering Committee
ATUC	ATNF User Committee
AusSRC	Australian SKA Regional Centre
CABB	Compact Array Broaband Backend
CASDA	CSIRO ASKAP Science Data Archive
CASS	CSIRO Astronomy and Space Science
CDSCC	Canberra Deep Space Communication Complex
CPU	Central Processing Unit
CSIRO	Commonwealth Industrial and Scientific Research Organisation
DAP	Data Access Portal
DiFX	Distributed FX Correlator
DIIS	Department of Industry, Innovation and Science (Australian Government)
EDGES	Experiment to Detect the Global Epoch of reionisation Signature
EMU	Evolutionary Map of the Universe
ESA	European Space Agency
FAST	Five hundred meter Aperture Spherical Telescope (China)
FPGA	Field Programmable Gate Array
FRB	Fast Radio Burst
FTE	Full Time Equivalent
GPU	Graphics Processing Unit

ABBREVIATION	DESCRIPTION
ICRAR	International Centre for Radio Astronomy Research
ILUA	Indigenous Land Use Agreement
ITU-R	International Telecommunication Union – Radio sector
LBA	Long Baseline Array
LIGO	Laser Interferometry Gravitational Wave Observatory
LNA	Low Noise Amplifier
MMIC	Mircowave Monolithic Integrated Circuit
MRO	Murchison Radio-astronomy Observatory
MWA	Murchison Widefield Array
NAPA	Non A-Priori Assignable
NASA	National Aeronautics and Space Administration
NSW	New South Wales
NVSS	National Radio Astronomy Observatory Very Large Array Sky Survey
PAF	Phased Array Feed
PI	Principal Investigator
RACS	Rapid ASKAP Continuum Survey
RFI	Radio Frequency Interference
RFSoC	Radio Frequency System on a Chip
SKA	Square Kilometre Array
STEM	Science Technology Engineering and Mathematics
TAC	ATNF Time Assignment Committee
UWB	Ultra Wideband
VLA	Very Large Array
VLBI	Very Long Baseline Interferometry
WA	Western Australia
WALLABY	Widefield ASKAP L-band Legacy All-sky Blind survey
WRC	World Radiocommunication Conference

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