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CSIRO Australia Telescope National Facility

Annual Report
2017–18

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This is the report of the CSIRO Australia Telescope National Facility for the period 1 January 2017 to 30 June 2018 and is approved by its Steering Committee.

Editor: Nic Svenson
Science highlights: Helen Sim

Wajarri Yamatji Elder and Australian actor, Ernie Dingo, visits our Murchison Radio-astronomy Observatory with his niece, our Aboriginal Liaison Officer, Leonie Boddington. Image: Brett Hiscock.

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Cover: The Australian Square Kilometre Array Pathfinder radio telescope. Image: Red Empire.

Chair's report

In 2017, the ATNF Annual Report moved to financial year boundaries to align with CSIRO's Annual Report, so this Chair's report covers the 18 months from 1 January 2017 – 30 June 2018. The Australia Telescope National Facility Steering Committee (ATSC) met three times during this period, with the May 2017 meeting at Geraldton and the Murchison Radio-astronomy Observatory and the May 2018 meeting at Narrabri.

The ATSC is an advisory committee to the CSIRO Board. As such, we are pleased to advise the Board that the ATNF continues to impress with the number and quality of its achievements, as described in this Annual Report.

We congratulate the ATNF staff on these achievements and commend the Director and Deputy Director for their excellent leadership of a management team that has been in its current configuration for less than two years. Given the multimillion dollar investment and long-term commitment Australia has made to the international Square Kilometre Array (SKA) project, the ATSC strongly recommends that stable leadership within the ATNF is maintained as the Business Unit transitions to SKA operations over the next few years.

The ATSC also appoints the ATNF Users' Committee (ATUC) and the Time Assignment Committee (TAC) and I thank members of these committees for the valuable contribution they have made to the ATNF and, by extension, to the international astronomy community.

One side benefit of this 18-month report is being able to see advice the Committee gave in 2017 acted on and proving successful. As one example, it is gratifying to see the ATNF's partnership with the International Centre for Radio Astronomy Research (ICRAR) over the SKA Regional Centre now flourishing.

In 2017, we encouraged the ATNF to keep the Parkes radio telescope and Australia Telescope Compact Array (ATCA) online while devoting all available resources to realising the long-held ambition for an operational Australian Square Kilometre Array Pathfinder (ASKAP) telescope. With some tough decisions in recent years, and innovative approaches to securing funding, the whole ATNF remains open for business and ASKAP is now tantalisingly close to full operation: 24 of the 36 antennas are available as two sub-arrays – and both are kept busy by the Survey Science Teams.

The Committee endorsed the actions recommended in the CASS Culture Project report, which members saw at their first meeting in 2017. Over the course of this reporting period, we have been pleased to note progress here, which has gone well beyond responding to the issues raised in 2016. Staff at all levels, including in corporate functions such as Human Resources, are working together to ensure the ATNF – and the broader CSIRO Astronomy and Space Science – provide a supportive and respectful work environment.

I was also a member of the international panel appointed by CSIRO to review the ATNF in late November 2017. The panel's report was presented to the ATSC in 2018. The review report was very positive and we congratulate all ATNF staff on the outcome. The ATSC endorsed the ATNF's response to the panel's recommendations, including those on workplace culture.

As the review panel found, and this Annual Report showcases, the ATNF's engineers develop some of the best receivers, digital signal processing equipment and software packages in the world. The ATSC notes that many of these have application beyond astronomy. We recognise the resource constraints, commend the efforts being made, and strongly encourage the ATNF to pursue commercialisation of its world-leading technologies.

Professor Elaine Sadler
Chair, ATNF Steering Committee
Image: Australian Academy of Science

The review panel also recommended that the ATNF pursue close strategic relationships with universities, particularly through joint appointments and co-supervision of students. It is pleasing to see in this Report that levels of co-supervised postgraduate students have regained historical levels.

I look forward to progressing plans to further relationships with the university sector in my new role as ATNF Chief Scientist. I accepted this position in March 2018 and stood down from the ATSC at that point. I would like to thank Dr David Skellern for stepping in as Chair and the rest of the ATNF Steering Committee for their contributions throughout my time as ATSC Chair.

The ATSC met at the MRO in May 2017. Image: Nic Svenson.

Director's report

In this reporting period ASKAP commenced sky surveys for the SKA era with its Early Science program and it now has phased array feeds on every antenna. Meanwhile the Parkes radio telescope and ATCA have undergone substantial transitions to support financially sustainable science excellence. With our Vision and Mission agreed by the ATSC, our user community and CSIRO, we have set our sights firmly on the future.

A major external review of our work, the Business Unit Review, took place in late 2017. Across all areas, the panel rated our science quality, impact and innovation capacity as benchmark or strong. Our radio astronomy research was ranked third in a global list led by larger institutions in Germany and the USA. The panel also rated our Technologies for Radio Astronomy program as among the best in the world, noting that we have led, or jointly led, global innovation in antenna design, digital beamforming and adaptive mitigation of radio frequency interference. A case in point is the installation this year of our 19-beam receiver on the Five Hundred Metre Aperture Spherical Telescope (FAST) in China.

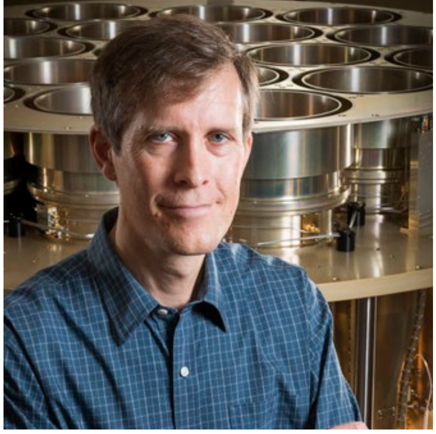
The Breakthrough Listen team, which purchased 25% of observing time on the Parkes radio telescope, commenced its Galactic plane survey. Backend systems, developed in a collaboration led by Swinburne University of Technology, continued to support discovery of fast radio bursts (FRBs) and our new ultra-wideband receiver was installed. These developments promise to maintain Parkes' reputation as one of the world's most productive telescopes. More than 50% of Parkes time is still available for merit-based access, even as externally funded projects now cover most day-to-day operating costs. This is the culmination of a decade-long transition at Parkes.

At ATCA Legacy Projects began to use around 35% of telescope time and we introduced a new rapid response mode to react to new transient discoveries. A program to study near Earth objects continues in partnership with the Canberra Deep Space Communication Complex.

ATNF telescopes also responded to target of opportunity requests – such as triggers from the gravitational wave instrument, LIGO. Within 24 hours of an alert in August 2017, ASKAP, Parkes and ATCA were searching for radio emissions from this merger of two neutron stars. ATCA was successful in detecting a brightening afterglow and has monitored its evolution ever since.

As construction of the SKA draws closer, we have devoted significant resources to SKA preconstruction (design) and on preparing our Murchison Radio-astronomy Observatory (MRO) and Boolardy Station. A major milestone was in-principle agreement with the Wajarri Yamatji traditional owners on key terms of the agreement to use the land.

We hosted many VIP visits to the MRO in 2017-18 including by the then Minister for Industry, Innovation and Science, the Hon Arthur Sinodinos, and his counterpart in the Western Australian government, the Hon Dave Kelly MLA; Senator the Hon Zed Seselja, Assistant Minister for Science, Jobs and Innovation; and SKA Director General Prof Phil Diamond and SKA Board Chair Dr Catherine Cesarsky.

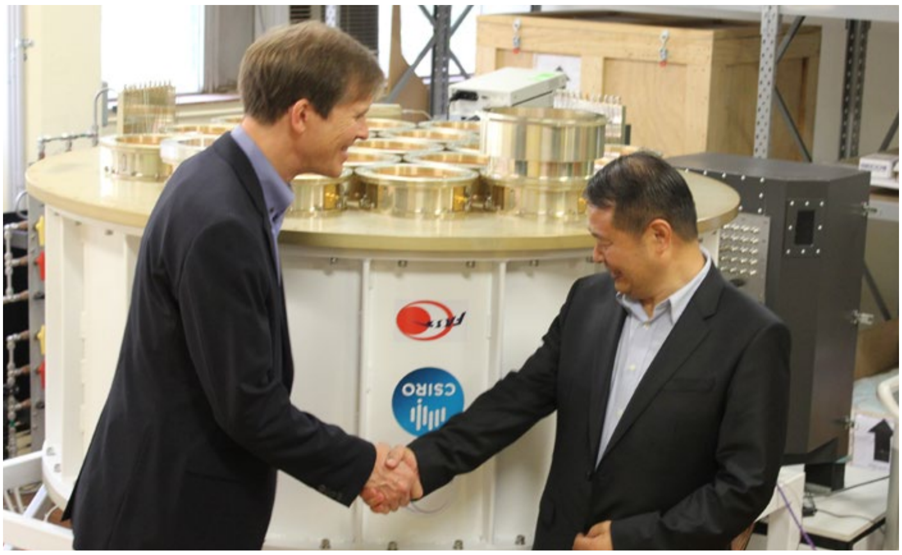


Dr Douglas Bock
Director, ATNF
Image: Wheeler Studios

These visits are major undertakings and I thank our colleagues at Curtin University (operators of the Murchison Widefield Array) for their support.

The critical role the MRO will play in the success of SKA1-Low was highlighted by results published in Nature in March 2018 from the Experiment to Detect the Epoch of Reionisation Signature (EDGES). While other telescopes will probably have confirmed (or otherwise!) EDGES' detection of the earliest stars in the Universe by the time SKA1-Low comes on line, when it does, the MRO's radio quiet environment will remain crucial to allowing the telescope to flesh out the detail of this period in the Universe's history. There are many other science highlights described in this report.

I thank the ATSC, ATUC and TAC for their advice and guidance. Nevertheless my greatest recognition must be of the ATNF staff. They have continued to deliver and I am proud of their achievements and impact.



Douglas Bock presents the 19-beam receiver for the FAST telescope to Dr Jun Yan, Director of the National Astronomical Observatories of China. Image: Nic Svenson.

Management team

ATNF DIRECTOR AND DIRECTOR CSIRO ASTRONOMY AND SPACE SCIENCE

Douglas Bock

DEPUTY DIRECTOR

Sarah Pearce

MAJOR PROJECT DIRECTOR

Antony Schinckel

PROGRAM DIRECTOR, ATNF OPERATIONS

John Reynolds

PROGRAM DIRECTOR, TECHNOLOGIES FOR RADIO ASTRONOMY

Tasso Tzioumis

PROGRAM DIRECTOR, ATNF SCIENCE

Phil Edwards

STRATEGIC PLANNING AND MAJOR PROJECT SPECIALIST

Phil Crosby

RESEARCH OPERATIONS MANAGER

Warren Bax

In March 2017, most Operations staff responsible for science operation merged with the Astrophysics group to form ATNF Science. Ian Heywood acted as Program Director, Astrophysics, then of ATNF Science, until May 2017. Dave McConnell took over the Acting role until Phil Edwards was appointed interim Program Director in September 2017.

About us

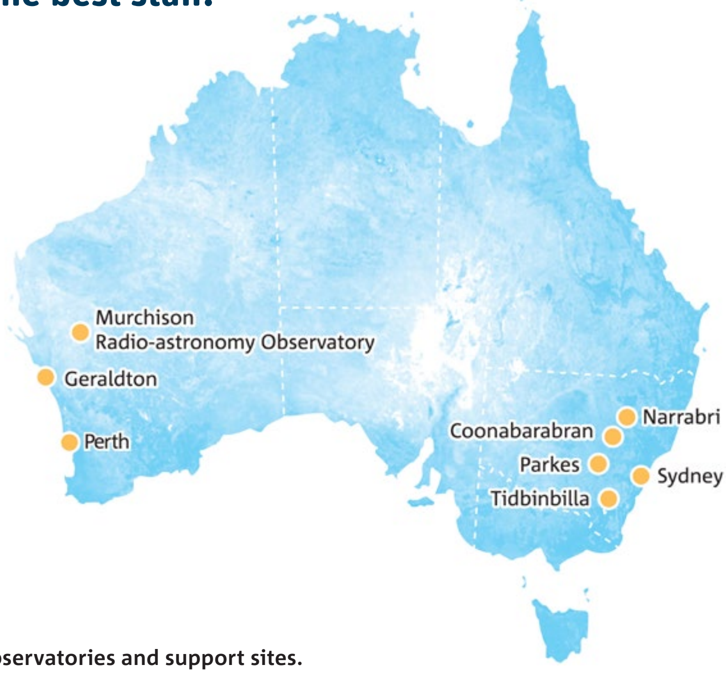
The Australia Telescope Compact Array.
Image: Max Voronkov.

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 which forms 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 Digital, National Facilities and Collections. CASS also operates the Canberra Deep Space Communication Complex (CDSCC) at Tidbinbilla on behalf of NASA and manages Australian astronomers' access to CDSCC antennas. CASS has recently taken carriage of CSIRO's Earth observation capability, which will include managing Australian scientists' access to the NovaSAR Earth observation satellite.



ATNF observatories and support sites.

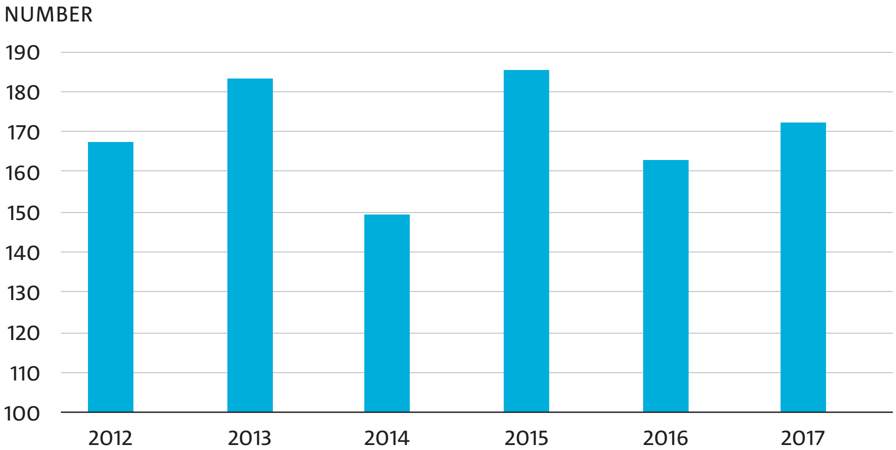


Figure 1: Total publications by ATNF staff over time.

ASKAP
Collecting area 36 x 12 m
Frequency range 0.7-1.8 GHz
Bandwidth 300 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 CDSCC's Deep Space Station 36 (34-m) is the latest addition to its suite of antennas. Image: CDSCC.

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 provides astronomers at Australian and overseas institutions with the opportunity to use its telescopes free of charge. Access is based on the scientific merit of the proposed observing project. This 'open skies' policy is the general practice of the international radio astronomy community and Australian astronomers access overseas facilities on the same principle.

Telescope access can also be purchased. For example, we have an agreement with the Breakthrough Prize Foundation for the use of the Parkes radio telescope to search for extraterrestrial intelligence. The search will use 25% of the telescope's observing time for five years from October 2016. It will return the cost of operating the telescope during the observations and contribute to an upgrade of the data systems used for this and other science.

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 2017, 113 papers using data from ATNF telescopes were published in refereed journals. Overall, ATNF staff published 172 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) to assist it to fulfil its governance responsibilities through the provision of high-level advice 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 receives around $36.3m in funding from CSIRO: $2.4m for capital expenditure and $33.9m for operating (not including funding for depreciation of assets). This is supplemented with $14.9m 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 183 staff on activities related to radio astronomy around Australia (Fig. 3). The list of staff is at Appendix C.

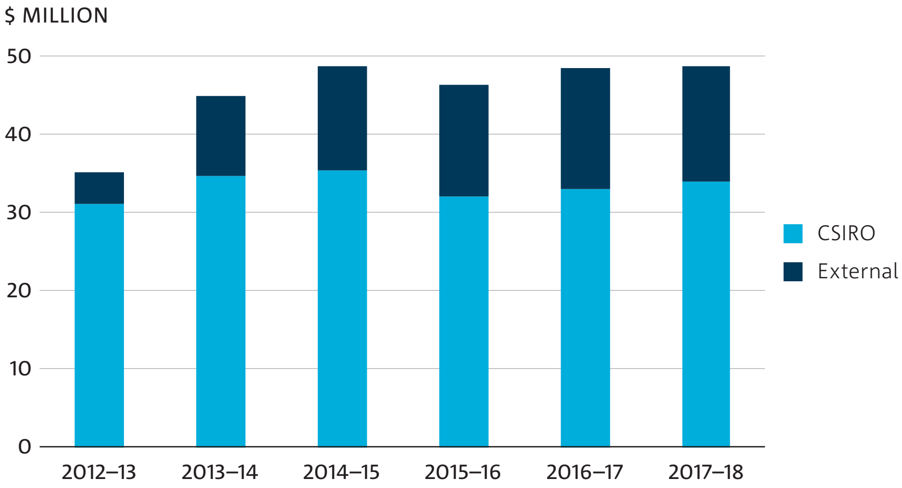


Figure 2: ATNF funding by source over time (excludes depreciation).

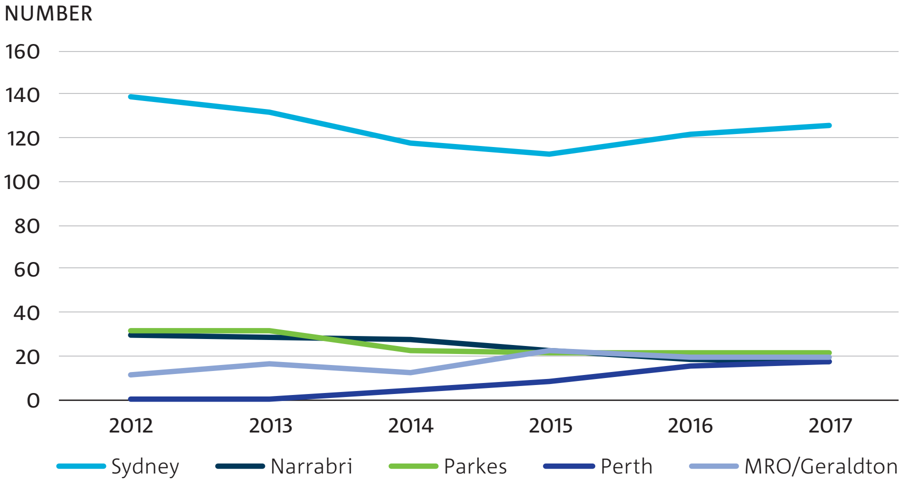


Figure 3: ATNF staff by site over time.

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 Eora 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

We have a particularly close relationship with the traditional owners of the MRO, the Wajarri Yamatji. As part of the MRO Indigenous Land Use Agreement, students from the Pia Wadjarri Remote Community School get to visit the observatory. Image: Rob Hollow.

Performance indicators

Jane Kaczmarek, George Hobbs and Shi Dai observing at the Parkes Radio Telescope. Image: Red Empire.

Telescope usage

Over the three observing semesters covered by this Report some 330 observing proposals were received: 120 for the October 2016-March 2017 semester, 118 for April 2017-September 2017 and 92 for October 2017-March 2018. The oversubscription rate (the factor by which proposals exceed available telescope time) was 1.9 for both the Parkes radio telescope and ATCA (after excluding allocations for ATCA Legacy Projects). The LBA continued to be in demand, with proposals exceeding available time by a factor of two.

In this reporting period, observing proposals were received from 980 individual researchers from 35 countries. ATNF staff led 15% of these proposals, 36% were led by staff of other Australian institutions and 49% by overseas researchers.

On both ATCA and Parkes, up to ten per cent 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, make-up 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 74% as less time was spent using the instrument as a test-bed for new receivers (Fig. 4). ATCA remained stable at 76%. Time lost through equipment failure at

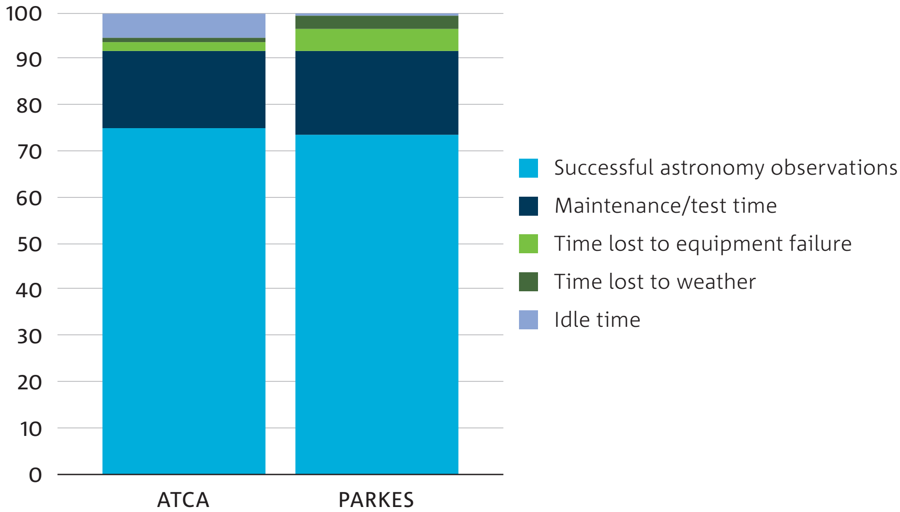
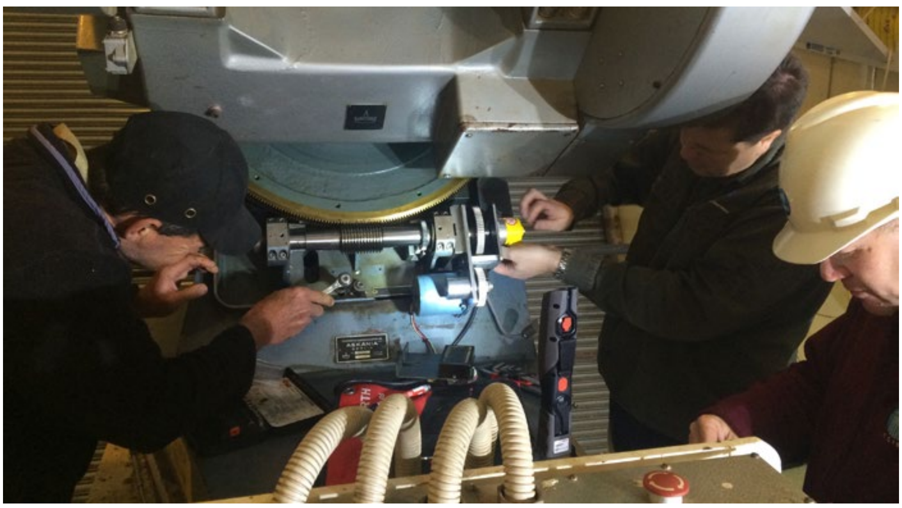


Figure 4: Use of ATCA and Parkes in this reporting period.

ATCA was again stable (2%), however Parkes unscheduled downtime more than doubled to 5% due in part to some extended down-time caused by an issue with the Master Equatorial. Bad weather (mostly high winds) had more of an impact at Parkes (3%) than ATCA (1%).

Early Science with ASKAP commenced in October 2016. Five Survey Science Teams have spent over 1000 hours observing with an array typically consisting of 12 antennas. A separate array has been used in parallel to search for transient events such as fast radio bursts.

In addition, the ATNF handles proposals requesting service 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, 226 hours were used for observing under these arrangements: 85.5 hours for 'single dish' observing, and 140.5 hours as part of the LBA. CDSCC antennas are most in demand for LBA observing, where it can be difficult to synchronise the required blocks of time around the CDSCC antennas' primary activity: spacecraft tracking.



Repairing the Parkes radio telescope Master Equatorial. Image: Tim Wilson.

Time allocation

For the period from 1 October 2016 – 31 March 2018, 120 proposals were allocated time on ATCA or the Parkes radio telescope (counting each proposal only once each even though some are submitted every semester): 80 proposals were given time on ATCA and 40 on Parkes. These numbers are lower than in recent years due to the introduction of the four large Legacy Projects on ATCA (which together take up ~35% of the available observing time) and the Breakthrough Listen project at Parkes (which is allocated 25% of available observing time). Also in this period, 30 proposals were allocated time on the LBA and 2 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 over-represented as primary investigators (PIs) on Parkes proposals and also that the most recent 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 contain large teams with strong Australian representation and which are allocated large amounts of time.

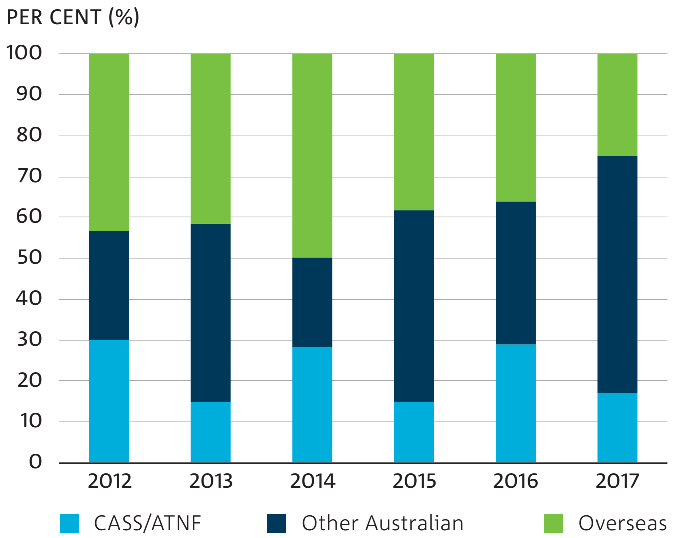


Figure 5: ATCA time allocation by PI.

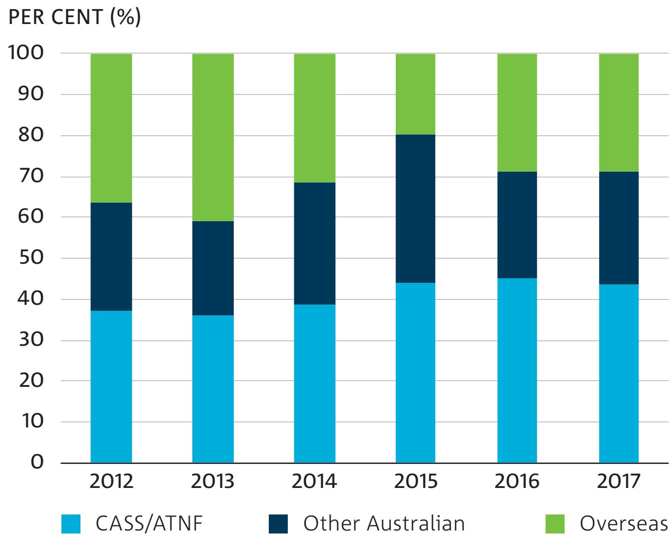


Figure 6: Parkes time allocation by PI.

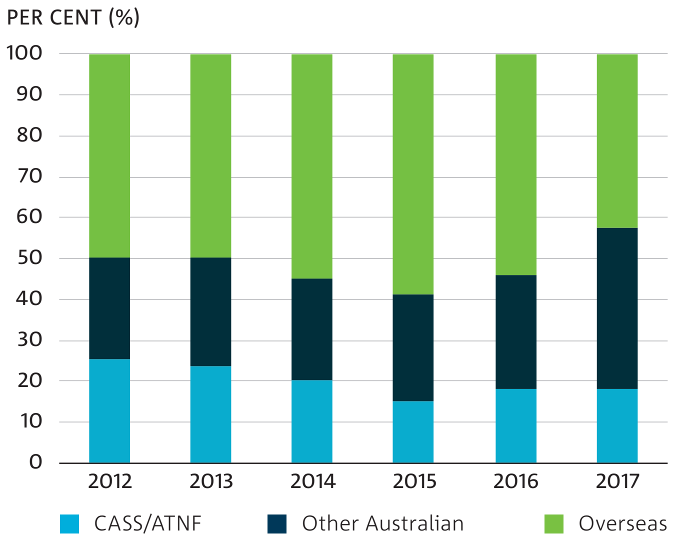


Figure 7: ATCA time allocation by all investigators. Time allocated to each proposal has been divided evenly between all authors on the proposal.

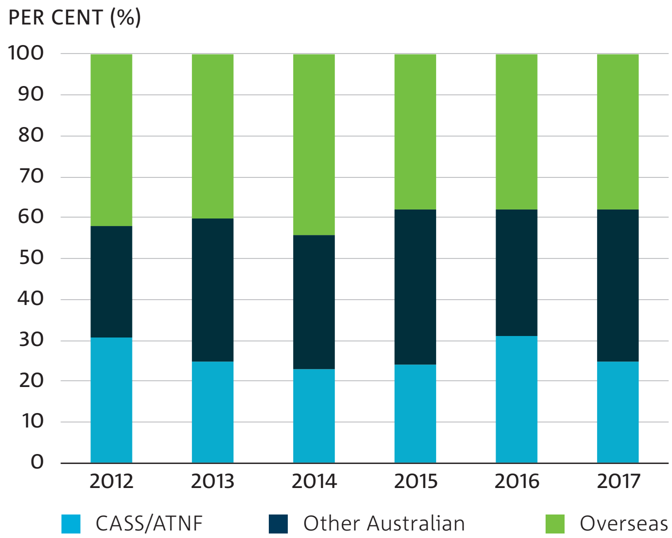


Figure. 8: Parkes time allocation by all investigators. Time allocated to each proposal has been divided evenly between all authors on the proposal.

Publications and citations

In 2017, 113 papers using data from ATNF telescopes were published in refereed journals. Of these, 62% included a CSIRO author or authors.

In 2017 there were 172 refereed publications by ATNF staff, including scientific papers with data from other facilities. In total, 212 refereed journal papers and 30 conference papers – both those using National Facility data and other papers by our staff – were published during the year. They are listed in Appendix G. The National Facility publication counts are a little lower than those of the previous year, contributing factors being a decline in the number of ATNF postdoctoral researchers, the impact of ATCA Legacy Projects and the use of Parkes by Breakthrough Listen.

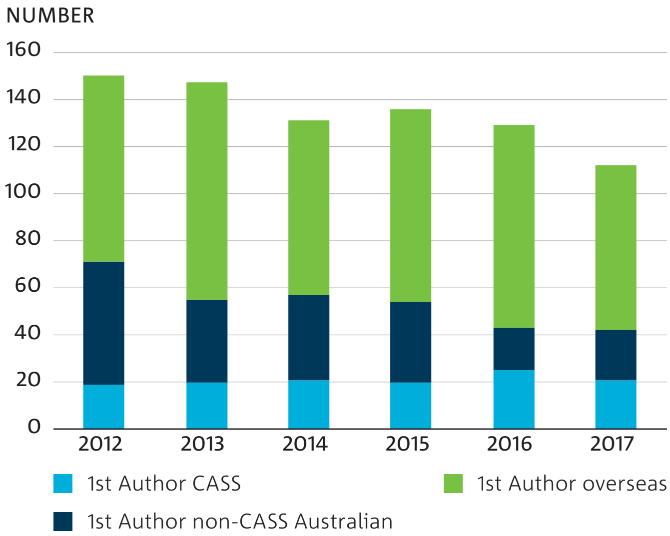


Figure 9: Publications that use data from ATNF telescopes by year.

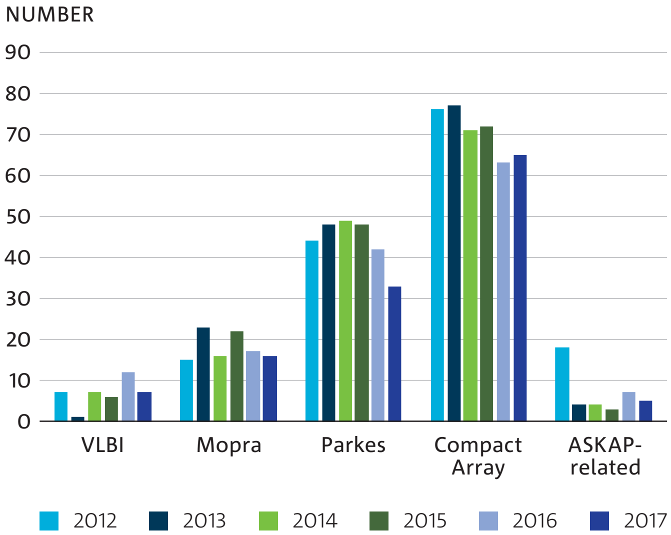


Figure 10: Publications in refereed journals that include data from ATNF telescopes grouped by telescope. A few papers with data from more than one instrument are counted more than once.

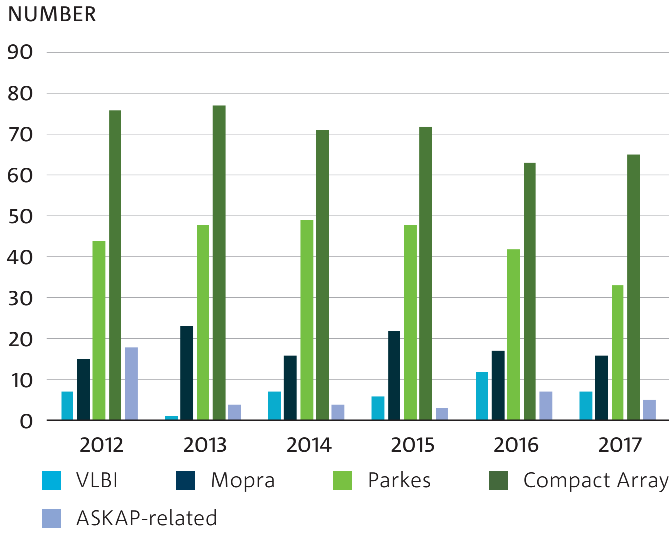
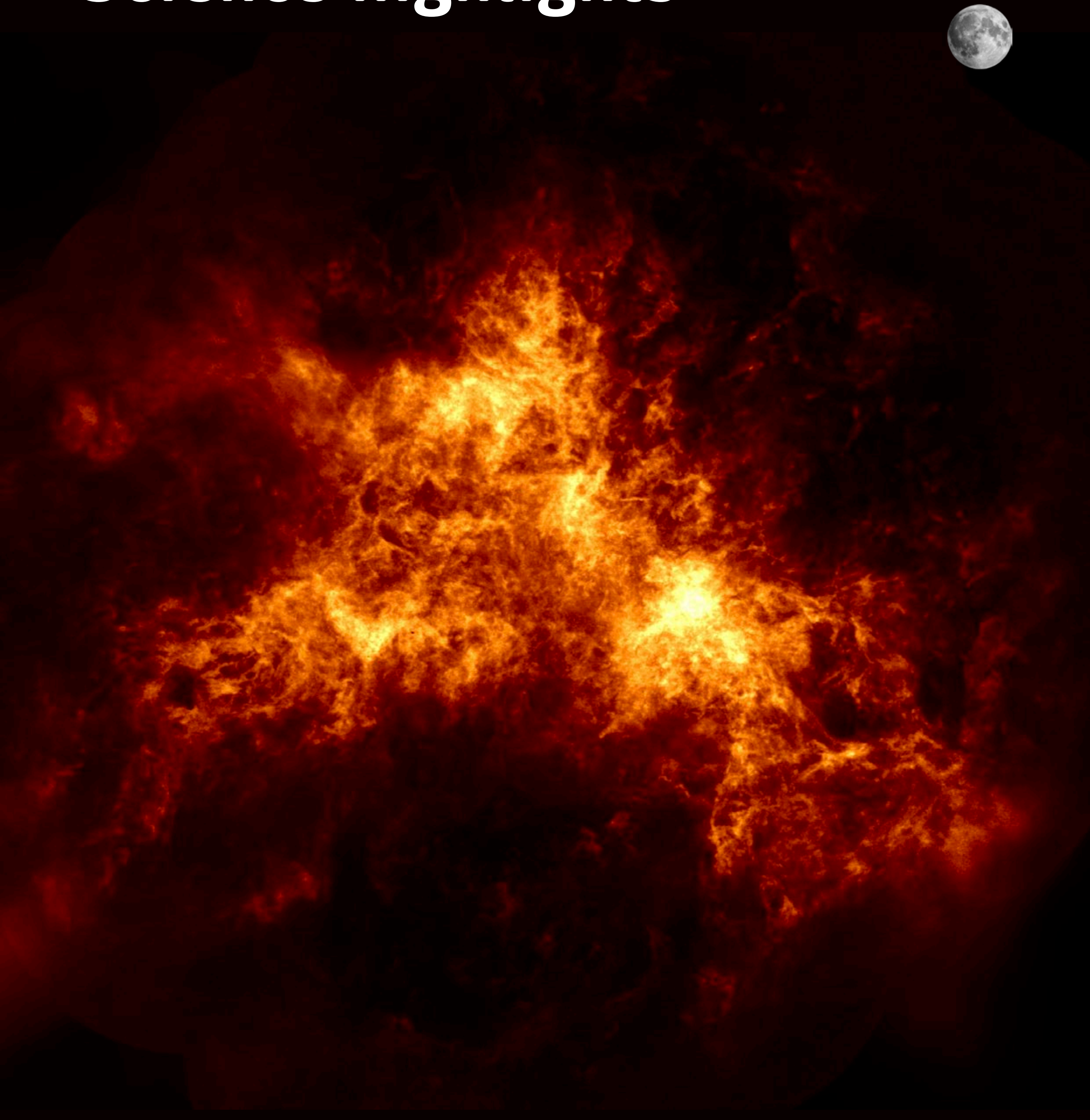


Figure 11: Publications in refereed journals that include data from ATNF telescopes grouped by year. A few papers with data from more than one instrument are counted more than once.

In January 2018, all operational antennas were being driven to observe a calibration field and check that everything is working. Image: Brett Hiscock.

Science highlights



This radio image of nearby galaxy, the Small Magellanic Cloud (SMC), was made in one pointing repeated over three nights, using 16 ASKAP antennas and capturing a much larger area of the sky than previously achieved (the full Moon is shown for scale). Further data from Parkes was added to pick up faint details. The last time the SMC was imaged, by five ATCA antennas, it took 320 pointings over eight nights. This work is part of the GASKAP Survey Science Project. Image: Australian National University and CSIRO.

Thin-skinned galaxy may explain 'twisted' light

Jane Kaczmarek
CSIRO

The radio emitting lobes seen in giant galaxies may have a thin surface layer of low energy electrons, ATCA observations suggest. This layer is probably what 'twists' the polarised radio emission that the lobes generate.

In about 1% of large galaxies, we see signs of a central supermassive black hole at work. The black hole pushes out 'lobes' of radio emitting material, so large that they can billow millions of light years into space. The radio emission comes from high energy electrons.

The lobes transfer huge amounts of energy to the gas in the main part of the galaxy, forming cavities and creating regions of shocked gas that affect – and probably quench – star formation.

Most of the particles in the lobes are high energy, radio emitting ones. To better understand how much energy the lobes carry, we want to know about other particles they may contain – the lower-energy 'thermal' electrons'. We don't yet know what fraction of the lobes' particles is thermal electrons, but there is a way to find out.

The non-thermal radio emission from the high energy electrons is polarised: its waves 'vibrate' in a particular direction. Magnetic fields can 'twist' the plane of polarisation, and we can measure the amount of twist or rotation. How much the polarisation is rotated depends on both the strength of the magnetic field doing the twisting and the density of thermal electrons in space.

The problem is to know where the rotation is taking place. Is it happening inside the radio lobes themselves, or outside, somewhere along the line of sight between the galaxy and us? The total amount of polarisation rotation we observe is the sum of the 'twisting' taking place at every point between us and the galaxy's radio emitting particles. The strength of the magnetic field and the density of the thermal electrons will vary along that line of sight. Unpicking this integrated effect is challenging.

Jane Kaczmarek (CSIRO) and her collaborators have tackled the problem by observing the galaxy NGC 612. This galaxy is relatively close to us, just 390 million light years (120 Mpc) away, and so appears relatively large on the sky.

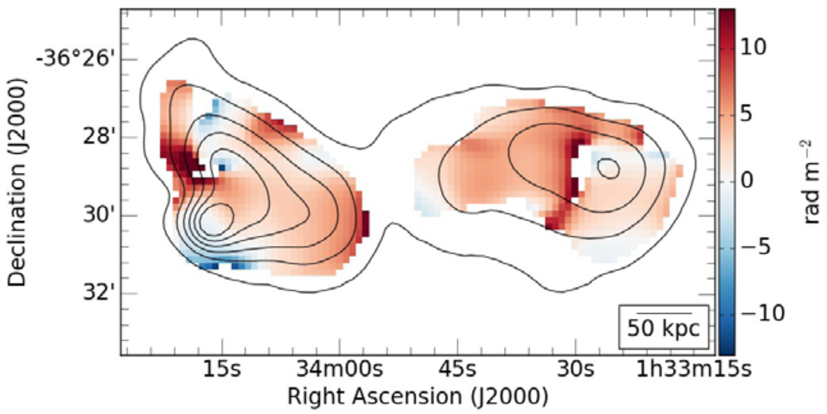
The researchers used ATCA to map the strength and direction of the linearly polarised radio emission over the whole of NGC 612, at three wavelengths. The resulting maps show that the polarisation varies significantly across the lobes. A 'hotspot' in the eastern lobe particularly stands out.

To explain their findings, the researchers modelled different physical situations: the polarisation rotation occurring primarily within the lobes or outside them, and the magnetic field being turbulent or essentially smooth. All the models accounted about equally well for the observations.

In their analysis, the team argued that the polarised emission was not being rotated primarily by material in our own Galaxy, or by hot gas in the environs of NGC 612, but instead by a thin skin of thermal electrons covering the galaxy's radio lobes. This skin would be formed as the expanding radio lobes swept up and compressed thin gas in the space immediately around them. The researchers calculated a value for its electron density (~8 x 10^{-5} cm^{-3}) and found it be not much greater than that of the surrounding gas. They also argue that variations seen in the polarisation are eddies that arise as the radio lobes interact with their surrounds.

NGC 612 is one of sample of large angular size radio galaxies that were selected to show a range of intrinsic properties and environments. Kaczmarek and her collaborators plan to study the rest of the sample to investigate if there is any relationship between the properties of these galaxies and the properties of their polarised emission.

Kaczmarek, J.F.; Purcell, C.R.; Gaensler, B.M.; Sun, X.; O'Sullivan, S.P.; McClure-Griffiths, N.M. "Revealing the Faraday depth structure of radio galaxy NGC 612 with broad-band radio polarimetric observations". MNRAS, 476, 1596–1613 (2018).



Modelled Faraday depth (a measure of how much the polarised radio emission has been 'twisted') across the radio emitting lobes of NGC 612. The black contours outline total intensity levels of the radio emission, spanning 25–400 mJy beam^{-1} in increments of 75 mJy beam^{-1}. (From Kaczmarek et al. 2018)

Monitoring the first neutron star merger

Dougal Dobie
University of Sydney

ATCA observations are helping unravel the physics of one of the most exciting astronomical events this decade, the first confirmed merger of two neutron stars.

Neutron stars are city-sized balls of matter with more mass than the Sun. On 17 August 2017 the consortia operating the LIGO and Virgo gravitational wave detectors announced that they had detected two of these dense stars merging. The merger, which took place 130 million light years away, generated a massive explosion and worldwide excitement among astronomers.

GW170817 was the first astronomical event to be detected through gravitational waves and then observed across the electromagnetic spectrum, in light, radio waves, X-rays and other wavelengths. Some 3000 astronomers were involved in the observations.

In Australia, a team led by Tara Murphy (University of Sydney) quickly obtained permission to make 'target of opportunity' observations with ATCA. They confirmed an initial detection of radio emission made with the Very Large Array (VLA) in the USA, and observed the source repeatedly over the following months.

The radio emission was expected to rise in strength, peak and then fall, with the height and timing of the peak telling us about the physics of the explosion. Theorists had argued that the merger of two neutron stars would create a 'short gamma-ray burst', a burst of gamma rays lasting less than two seconds. We detect these all over the sky, one every few weeks. They were discovered decades ago but their cause had never been pinned down. Astronomers thought GW170817 might confirm they arise from neutron star mergers.

The key evidence would be an ultrarelativistic (fast moving) jet of radio emitting particles – something required by the models of short gamma-ray bursts. But months of monitoring by ATCA and the VLA have not found conclusive signs of a jet. The radio emission peaked 149 days after the explosion and then began to decline. The height and timing of the radio peak suggest that the merger explosion threw out a 'cocoon' of matter. The cocoon may have within it a jet that is contributing to the radio emission we detect.

Continued radio monitoring will give us more information. If we are seeing the afterglow of a relativistic jet, the radio emission will drop off rapidly. If there is a slow moving jet, or no jet at all, the emission will decline more slowly. The full record of how the radio emission rises and falls can be used to calculate the total energy emitted by the explosion, and determine the angle at which we are viewing that emission.

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Hallinan, G.; Corsi, A.; Mooley, K.P.; Hotokezaka, K.; Nakar, E.; Kasliwal, M. M.; Kaplan, D. L.; Frail, D.A.; Myers, S.T.; Murphy, T.; and 23 coauthors. "A radio counterpart to a neutron star merger". Sci, 358, 1579-1583 (2017).

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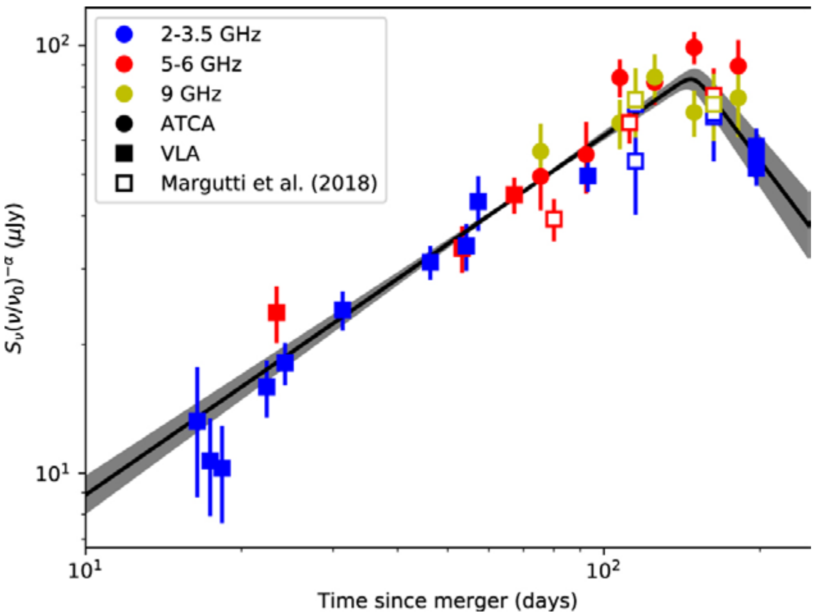


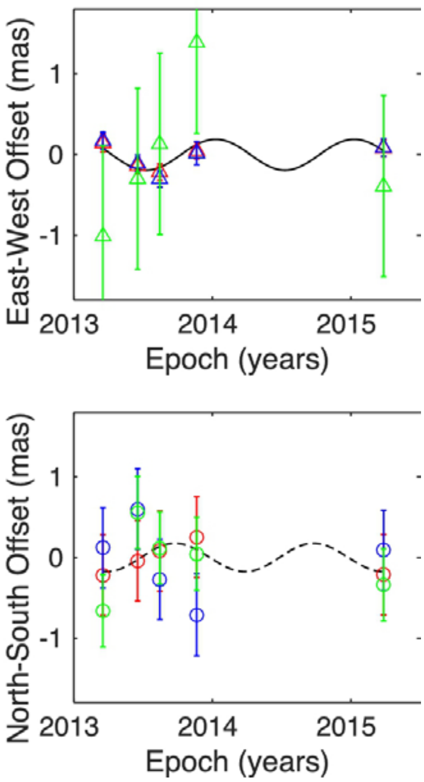
Radio light curve of GW170817 from observations made with ATCA (circles) and VLA (squares). Observations are grouped by frequency band. The flux densities have been adjusted to 5.5 GHz. Open squares denote observations from Margutti et al. (2018), while filled symbols denote observations from the present work or earlier observations with these telescopes (Hallinan et al. 2017; Mooley et al. 2018). The best-fit smoothed, broken power-law is shown in black, with uncertainties shaded: the temporal index on the rise is 0.84 ± 0.05, the temporal index on the decay is 1.6 ± 0.2, and the peak time is 149 ± 2 days. (From Dobie et al. 2018)

Masers measure our backyard better

Vasaant Krishnan
University of Tasmania

Using ATNF telescopes, astronomers have improved the map of our Galaxy by measuring precise distances to cosmic radio sources called masers.

Our Galaxy, the Milky Way, is all around us, and that makes it hard to study its structure. After 60 years of work, we've learned that it's a 'barred spiral' galaxy, with a thick central mass of stars (a bar) and curved 'spiral arms' of gas, dust and stars. New stars form in the arms. The Milky Way seems to have four major arms and a number of minor ones. We live in a minor arm, about a third of the way out from the Galaxy's centre.



Parallax motion of the –33.1 km s^{-1} reference feature in G 305.200+0.019, shown with respect to three quasars: J 1254–6111 (red), J 1312–6035 (blue) and J 1256–6449 (green). The maser's proper motion (actual motion through space) has been removed. (From Krishnan et al. 2017).

Astronomers have mapped the Galaxy using markers such as gas clouds or young stars, but it can be hard to measure accurate distances to these objects. For his PhD thesis, Vasaant Krishnan (University of Tasmania) measured better distances to a group of bright, point-like radio sources called masers.

Masers work like lasers but emit microwaves rather than visible light. They can occur naturally in gas clouds in space where conditions are just right. Water, hydroxide, methanol and other molecules can all make masers. One type of maser (methanol, emitting at a frequency of 6.7 GHz) is found only at places in a galaxy's spiral arms where high-mass stars are forming.

Krishnan and his collaborators studied three of these 6.7-GHz masers that lie in a group called G 305.2. The distance to this complex has been measured at anything from 9000 to 20,000 light years (2.8 to 6.2 kpc). The researchers aimed to measure it more precisely. To do so, they used parallax, the shift of a foreground object relative to a background when seen from a different point of view.

The researchers measured where the masers were on the sky relative to very distant background sources (three quasars). They repeated these measurements over the following months as the Earth moved around its orbit: as our vantage point changed, so did the masers' positions relative to the quasars. They then used these shifts in relative position, and the known size of the Earth's orbit, to work out the distance to the masers.

To measure the tiny changes in the masers' apparent positions, Krishnan and his collaborators used a high precision technique, very long baseline interferometry (VLBI). This requires radio telescopes spread over large distances. In this case the set of telescopes was the southern hemisphere Long Baseline Array: three CSIRO telescopes (the Parkes radio telescope, ATCA and Mopra), University of Tasmania antennas in Tasmania and South Australia, the Hartebeesthoek telescope in South Africa and the Warkworth antenna in New Zealand.

Masers can have real motion in space, so the researchers re-observed the masers exactly two years after their first observation. This gave them the masers' actual motion over two years, which they used to correct the apparent (parallax) motion.

Because the masers are all in the one gas cloud, the researchers calculated a weighted average value for the parallax. From this, they derived a distance of 13,400 light-years (4.1 (+1.2, -0.7) kpc). This is now the best distance measured to this maser complex. Knowing the distance let the researchers work out in which spiral arm the maser complex probably lies: the Carina–Sagittarius arm. They updated the pitch angle of this spiral arm (a measure of how tightly wound the spiral is) from $19^\circ.8 \pm 3^\circ.1$ to $19^\circ.0 \pm 2^\circ.6$.

This work has redrawn a piece of our Galaxy's map. The southern and northern hemispheres see different parts of the Galaxy: less mapping has been done from the south, and every step made here is valuable.

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ASKAP finds striking sample of fast radio bursts

Ryan Shannon
CSIRO

A team using ASKAP has netted a huge number of the mysterious fast radio bursts (FRBs) – millisecond-long radio pulses that seem to come from the distant Universe – almost doubling the number known at the start of the project.

FRBs were discovered in 2007 in data taken with the Parkes radio telescope. By early 2017 astronomers had recorded 29 of them, most with Parkes. They are smeared out in frequency, suggesting that the radio waves have travelled millions of light years through space, interacting with thin intergalactic matter along the way. If they do come from these distances, they must be produced by extraordinarily energetic events.

Yet after a decade of work we still know very little about the bursts. We don't know what causes them. We don't know in what sort of environments they originate: just one FRB has been connected with a host galaxy, and that is an atypical object, the only FRB that repeats. And we've lacked a good, uniform sample that would clearly show how FRBs are distributed in space – but ASKAP has now filled that need.

ASKAP's search for FRBs has been conducted as part of research project called CRAFT (Commensal Real-time ASKAP Fast Transients survey), jointly led by Keith Bannister (CSIRO), Jean-Pierre Macquart (Curtin University/ICRAR) and Ryan Shannon (now with Swinburne University of Technology). The CRAFT team used eight of ASKAP's fully outfitted dishes, getting the most from them through an innovative strategy. Usually ASKAP's dishes all point at the same part of sky. But they can be made to look in slightly different directions, as the segments of a fly's eye do. This multiplies the amount of sky the telescope can see. In this observing mode, eight ASKAP dishes can see 240 square degrees of sky, an area about a thousand times the size of the full Moon.

This larger field of view came at the cost of reduced sensitivity, meaning that only bright FRBs could be detected. But it was a trade-off that paid off. ASKAP began hunting for FRBs in January 2017 and found its first one less than four days after starting to search. By mid-2018 it had discovered 26 FRBs, almost equal the total from all previous searches.

The ASKAP sample provides quality as well as quantity. The FRBs have been collected in a uniform way, and ASKAP's phased array feeds allow their brightnesses to be determined much more precisely than those of the FRBs found with Parkes. Although the 'fly's eye' technique finds only bright FRBs, these are the ones most valuable for determining how FRBs are distributed throughout the Universe and are the easiest to follow up with other telescopes.

ASKAP regularly revisited the fields of bursts it had detected, doing 12,000 hours of follow up. No bursts were seen to repeat, suggesting that the only known 'repeater' (FRB 121102), found with the Arecibo telescope, is a different class of object to all other FRBs.

Some of the new ASKAP bursts are so bright that a sensitive telescope such as the Square Kilometre Array could see them coming from right across the Universe, more than 12 billion light years away. These would be FRBs that had originated in the early Universe and spent 12 billion years travelling through space at the speed of light. All FRBs could help study the matter that lies in intergalactic space, which is a third of the Universe's ordinary (non-dark) matter. This thin material alters a radio burst travelling through it (that is, leave a mark that we could decipher) and FRBs are one of the few tools we have for learning about it.

The 'fly's eye' observing mode has proved its worth. The CRAFT team's next steps will be to use ASKAP as an interferometer, to both detect and localise FRBs, and to increase the system's sensitivity to weak bursts.

Bannister, K.W.; Shannon, R.M.; Macquart, J.-P.; Flynn, C.; Edwards, P.G.; O'Neill, M.; Oslowski, S.; Bailes, M.; Zackay, B.; Clarke, N.; and 46 coauthors. "The detection of an extremely bright fast radio burst in a Phased Array Feed survey". ApJ, 841, 12 (2017)

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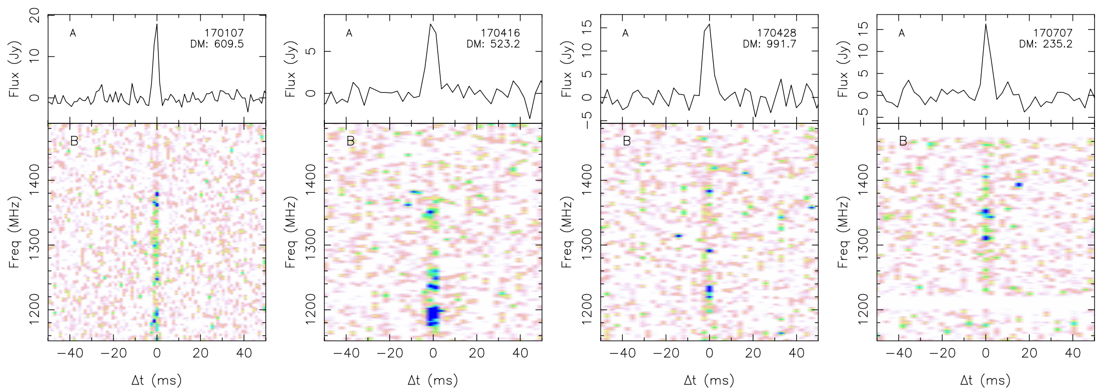

Profiles (top panel) and dynamic spectra of a selection of ASKAP-detected FRBs. The spectra have been dedispersed to the maximum-likelihood dispersion measure. Flux densities reported in the pulse profile have not been corrected for off-axis attenuation. (From Shannon et al. (in press))

Pilot ASKAP survey probes the transient Universe

Shivani Bhandari
CSIRO

A pilot survey with ASKAP has found a number of variable radio sources and put limits on the rate of short-term transient ones. It paves the way for a much larger ASKAP survey.

Explosions and flares, pulses and twinkles, come and go in the Universe. Individual cases can tell us about the physics involved (as the neutron star merger of 2017 showed: see earlier in this section). But we also want to know how frequently various kinds of event occur, to understand the role they play in shaping their host galaxies – how much energy they transfer, for instance.

Optical and gamma-ray telescopes have been doing large surveys for transients for a decade; radio telescopes are now starting to catch up. Radio observations show where charged particles are moving in magnetic fields. They complement observations at higher wavelengths, giving us different information (for instance, the total energy released by an explosion). Until now, few radio surveys have been able to regularly monitor large areas of sky with great sensitivity. But because of its large field of view, ASKAP is well placed to do this.

ASKAP will carry out two large surveys for transients and variables: CRAFT (Commensal Real-time ASKAP Fast Transients) and VAST (Variables and Slow Transients). CRAFT is designed to find phenomena that change on short timescales (up to the correlator integration time of five seconds) while VAST will pick up changes over longer periods. VAST comprises three sub-surveys. One, VAST-Wide, is designed to detect rare, bright events such as gamma-ray bursts and supernovae, and to monitor black holes that show varying activity.

Shivani Bhandari (CSIRO) and her collaborators have carried out a pilot survey for VAST-Wide, observing at 1.4 GHz. Using data taken with 12 ASKAP dishes as part of the ASKAP Early Science program, they searched a 30 square degree area centred on the galaxy group NGC 7232. The field was observed 12 times in the Early Science program, for a total of 135 hours, but the researchers drew on just eight of those observations. An automated pipeline developed for VAST searched the data for variables and transients: this was its first use with ASKAP data.

In all eight observing epochs 1653 radio sources appeared with a flux density greater than 1.5 mJy. The VAST pipeline identified 52 as potential variables. Closer inspection cut the number to nine. Bhandari and her collaborators observed these nine sources with ATCA, to study their spectral properties and sizes. All seemed to be galaxies or quasars with active black holes (active galactic nuclei (AGN)), ‘twinkling’ – fluctuating rapidly in brightness – as their radio waves are refracted by interstellar gas. One such source, J220833–453600, also showed long-term change: it had strengthened dramatically since 2003, when it was recorded in the Sydney University Molonglo Sky Survey (SUMSS) catalogue of radio sources. This change appears to be intrinsic to the AGN.

The eight epochs of ASKAP observations were also combed for transient sources. None were found on timescales of days. A comparison with the SUMSS catalogue showed no sources that had appeared or vanished since 2003.

This pilot survey demonstrated the quality of ASKAP data and put limits on the occurrence of radio transients. As the Figure shows, those limits are competitive with ones determined by previous surveys. The pilot survey used 12 ASKAP dishes and covered 30 square degrees of sky. By contrast, VAST-Wide will use the full ASKAP array of 36 dishes and cover 10,000 square degrees of sky per day. Of all the surveys currently planned, it is expected to set the best limits on radio transients.

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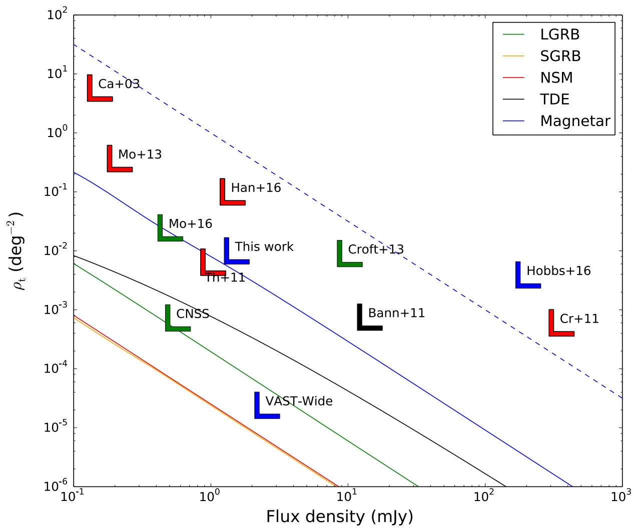

Limits on the surface density of transient radio sources, from current and planned surveys. Surveys performed at 1.4 GHz (red), 3 GHz (green) and 843 MHz (black). Blue symbols indicate ASKAP surveys: the pilot survey discussed in the text; a survey by Hobbs et al. 2016 at 863.5 MHz; and VAST-Wide. The dashed blue line shows the relation for a Euclidean source population. Other lines show the upper limits for models of neutron star mergers, magnetars, long and short gamma-ray bursts and tidal disruption events. The lines for neutron star mergers and short gamma-ray bursts coincide (Metzger et al. 2015). (Figure from Bhandari et al. 2018)

Nanodiamonds may cause mystery microwaves

Jane Greaves
University of Cardiff

Cosmic microwaves that have baffled astronomers may be caused by spinning nanodiamonds, ATCA observations have helped show.

In the 1990s astronomers began to observe the cosmic microwave background in detail. To do this, they had to carefully measure and excise from their data any foreground emission – that is, microwave emission from our Galaxy. In the course of removing this foreground, they discovered microwave emission that they couldn't attribute to any known process. What's more, this 'anomalous microwave emission' (AME) stood out from other kinds of emission (free-free, synchrotron or thermal) because it peaked in the microwave region of the radio spectrum.

The AME comes from regions that have a lot of cosmic dust. In particular, it coincides with polycyclic aromatic hydrocarbons – small, multiringed carbon molecules that are widespread in space. So it seemed likely that the radiation was caused by fast-spinning dust grains. But recent work has cast doubt on this idea.

Now Jane Greaves (University of Cardiff) and her collaborators have suggested a different origin: diamond particles about a nanometre across. These 'nanodiamonds' have been found in meteorites, and tell-tale infrared emission shows they are present in interstellar space. They are also known to exist in some proto-planetary discs – the discs of gases and dust grains, found around young stars, from which planets are born.

Greaves' team studied discs around two types of young stars (Herbig A-type emission line objects and classical T Tauri stars), looking for anomalous microwave emission. They used ATCA and the Green Bank Telescope in the USA to make new observations of stellar discs (9 and 30 respectively); they also made an observation with the Arcminute Microkelvin Imager in the UK and drew on a range of published data.

Greaves and her collaborators found anomalous microwave emission in three objects: V892 Tau, HD97048 and MWC297. These are the only systems known to contain hydrogenated nanodiamonds (nanodiamonds with attached hydrogen atoms). The researchers were able to reproduce the observed spectra by modelling the emission from nanodiamonds 0.75–1.1 nm in size, which would represent groups of 200–700 carbon atoms. They calculate that the nanodiamonds would represent up to 1–2% of the total carbon in the young stellar systems.

The stars the emission was found around were three of the four hottest stars in the sample. The researchers suggest that nanodiamonds may be widespread in stellar systems, but the stars are not always hot enough to excite them sufficiently to produce detectable emission.

In our Solar System, nanodiamonds may have formed in the Sun's protoplanetary disc and/or been inherited from previous generations of stars. In stellar systems generally, winds from stars and the evaporation of their proto-planetary discs could expel nanodiamonds into the interstellar medium. A next step might be to study dense interstellar clouds in our Galaxy to look for an association between nanodiamonds, detected in the infrared, and anomalous microwave emission.

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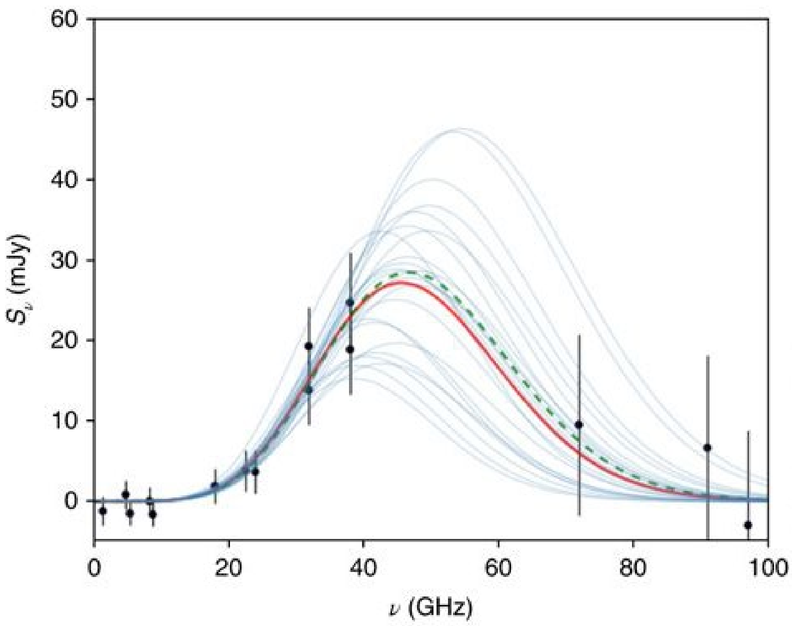

Anomalous microwave emission from the MWC 297 system, with the modelled effects of dust and stellar wind subtracted. One data point was obtained with the GBT, the remainder with ATCA. The dashed line is the maximum likelihood fit and the solid line is the model. Thin lines are 24 samples drawn randomly from the posterior distribution. (From Greaves et al. 2018)

Parkes finds extreme pulsar for testing general relativity

Andrew Cameron
Max Planck Institute for Radio Astronomy

Researchers using the Parkes radio telescope have found one of the most extreme pulsar systems known, and are using it to test Einstein's general theory of relativity, our standard theory of gravity.

Developed a century ago, general relativity is an outstandingly successful theory: it has stood up to every test we have thrown at it. But it doesn't seem to be the final description of gravity. Nature's other fundamental forces (electromagnetism, and the strong and weak nuclear forces) can be described by quantum physics, but we don't yet have an accepted quantum theory of gravity. So astronomers subject general relativity to harder and harder tests, searching for the point at which its predictions no longer match reality.

Gravitational waves were directly detected in 2016, and ground-based gravitational-wave detectors can test general relativity. But nature itself offers systems for making strong tests of general relativity. One binary pulsar, for example, offers a test about 1000 times stronger than that we can make with the Laser Interferometer Gravitational Wave Observatory (LIGO).

Binary pulsars comprise a pulsar and some kind of companion star. The pulsar is a neutron star, a ball of 'neutron matter' that spins while it emits radio waves: the result is a clock-like train of radio pulses entering our radio telescopes. In about 5% of binaries the companion star is also a neutron star (although not necessarily a pulsar). A neutron star has a strong gravitational field, and so a pulsar orbiting a neutron star is essentially a clock moving in a strong gravitational field. This is perfect for testing general relativity, as we can measure how various effects arising from the strong gravitational field change the regularity of the pulsar's pulses as they arrive on Earth.

Institutions in Australia, the UK, Italy and Germany have collaborated for many years on the international High Time Resolution Universe Pulsar Survey (HTRU). Germany's Max Planck Institute for Radio Astronomy led a component of HTRU, the HTRU South Low Latitude survey, which was carried out with the Parkes radio telescope. Observations covered the inner Galactic plane (–80° < l < 30° and $|b|$ < 3.5°), the region predicted to have the greatest number of extremely relativistic binaries.

The survey used a new technique to search for pulsars in binary orbits. Each observation was divided into time segments and each segment scanned for evidence of an accelerating object: if none was found, the segments were divided further and searched again. This process was repeated several times. The technique needed considerable computing resources. At least 1.46 million Fourier transform operations had to be computed for each pixel of sky observed, and the complete survey comprises more than 16,000 of these, representing more than 260 TB of data.

Among the hundreds of thousands of pulsar candidates that were examined, one stood out by virtue of its extreme acceleration: PSR J1757–1854. Follow-up observations made with Parkes and other telescopes in the UK, USA and Germany confirmed that this pulsar was in a highly eccentric orbit (ε = 0.61) around another neutron star. The two bodies orbit each other in just 4.4 hours and at their point of closest approach would fit inside the Sun. The pulsar's maximum acceleration is the most extreme known for any pulsar: ~684 m s^{-2}, almost 70 times than the acceleration due to Earth's gravity. The discovery and characteristics of PSR J1757–1854 have been reported in a paper led by a member of the HTRU team, Andrew Cameron (Max Planck Institute of Radio Astronomy; now with CSIRO).

PSR J1757–1854's extreme characteristics mean it can be used for powerful tests of general relativity and alternative theories of gravity. The HTRU team has already measured five relativistic parameters in the pulsar's orbit. These allow for three tests of general relativity (which the theory has passed). Ongoing observations are looking for three more effects: the precession of the pulsar's spin axis, the precession of its orbit, and the deformation of its orbit. Finding more of the extreme pulsar systems, and systems that are extreme in different ways, will let us make ever more stringent tests.

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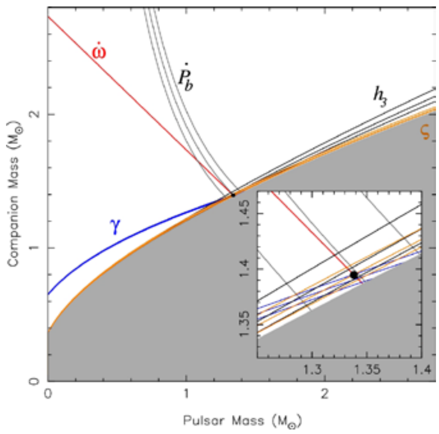

Mass–mass diagram for PSR J1757–1854. The figure shows the mass constraints that measured parameters impose on the binary system, along with their 1-σ error bars. The inset shows a zoomed view of the region of intersection; the black dot marks the masses of the pulsar and its companion. The grey region is excluded by orbital geometry. (From Cameron et al. 2018)

Gassy galaxies may be too stable to make stars

Katharina Lutz
Swinburne University of Technology

Galaxies with excess gas may just lack the knack of turning it into stars, new work with ATCA and other telescopes suggests. The culprit seems to be high angular momentum, which makes a galaxy too stable to form stars.

Stars arise from hydrogen gas. Neutral hydrogen (HI) in galaxies condenses to form clouds of molecular hydrogen; these clouds compact further and form stars. Making stars uses up a galaxy's reservoir of HI, so to keep star-formation going a galaxy has to be 'refuelled'. The new HI can be gained in dollops, when one galaxy merges with another, or drip-fed in from the galaxy's outskirts or space beyond.

In a pair of papers, PhD student Katharina Lutz (Swinburne University of Technology) and her collaborators have investigated galaxies carrying large amounts of HI – 'extreme HI' (HIX) galaxies – drawn from HIPASS (the HI Parkes All Sky Survey). Lutz's HIX galaxies had at least 2.5 times more HI than expected from the brightness of their stars. Have they simply acquired a lot of gas, or have they been poor at turning it into stars?

To find out, the researchers compared their HIX galaxies with a control sample drawn from HIPASS. Galaxies in the two samples differed significantly in the amount of HI they contained but were otherwise similar.

In their first paper, Lutz et al. (2017) looked in detail at a single galaxy, ESO075–G006. With $10^{10.8}$ solar masses of HI, this was the most HI-massive galaxy in their sample. The researchers used ATCA to study the HI and the Australian National University's 2.3-m telescope to take optical spectra of the galaxy. Neither these observations nor any published data showed that the galaxy had recently accreted more HI than average galaxies. The galaxy's disc appeared symmetric and well-settled, with a slight warp.

The researchers calculated the disc's stability and found it to be high. Stability comes from angular momentum. Studies made in the last few years have suggested that a galaxy can form stars only when its angular momentum is low and its disc unstable, which allows gas clumps to form. Being very stable, ESO075–G006 hasn't been able to make enough stars to use up its excess HI.

In their second paper (Lutz et al. 2018), the researchers examined the other HIX galaxies in their sample. These too turned out to have higher angular momentum, and hence be more stable, than the control galaxies.

A computer simulation, DARK SAGE, suggests that most galaxies overweight in HI could have been born with high angular momentum, being formed in dark matter haloes that themselves had high spin. This would have made it hard for these galaxies to turn HI into stars. But some galaxies may have accreted their excess HI. Investigations continue.

Lutz et al.'s studies of HIX galaxies complement previous work led by Helga Dénes (CSIRO) on HI-deficient galaxies (Dénes et al. 2016), and draw on a sample of 1796 HIPASS galaxies Dénes compiled to obtain scaling relations between the stellar and the HI content of galaxies (Dénes et al. 2014).

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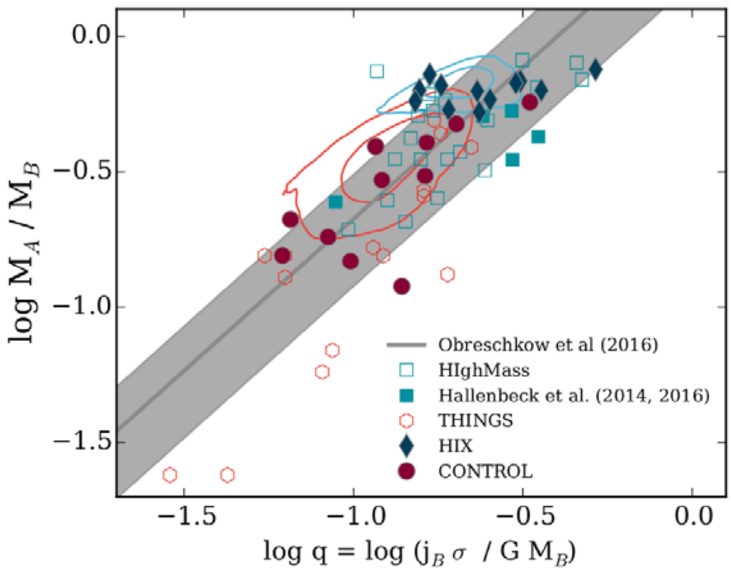
Obreschkow, D.; Glazebrook, K.; Kilborn, V.; Lutz, K. "Angular momentum regulates atomic gas fractions of galactic disks". ApJ, 824, L26 (2016).



The ratio of galaxies' atomic gas (HI) to baryonic matter, as a function of the global stability parameter, q. Blue diamonds represent HIX galaxies; red circles, the control sample. Data from other surveys are included for comparison. The orange and blue contours encompass 68 and 95% respectively of the 'control-like' and 'HIX-like' galaxies simulated with DARK SAGE. Both observed and simulated data agree with the analytical model of Obreschkow et al. (2016), shown as a solid line. (From Lutz et al. 2018)

Super-size galaxies sip from the cosmic web

Dane Kleiner
Monash University

Massive galaxies can suck in gas from 'cosmic filaments', work using archival Parkes radio telescope data suggests. This finding supports a recent model that explains why some galaxies form stars for longer than others.

Galaxies aren't sprinkled evenly throughout the Universe. Instead, they lie in a structure: the cosmic web. This is defined by filaments (long strings of galaxies) and voids (big 'deserts' with no galaxies). These features show up only in very large galaxy surveys.

Filaments hold dark matter and gas as well as galaxies; in fact, they carry about 40% of the Universe's mass. The gas is mostly hydrogen. Much of it exists as unionised atomic hydrogen (HI), but at concentrations too low to be detected by today's radio telescopes.

HI in a galaxy can form molecular hydrogen (H_2) and ultimately stars. But in making stars, a galaxy uses up its stock of HI. Can it get more from the filaments?

It has recently been suggested that galaxies attached to the cosmic web do indeed accrete cold gas this way. Then, as the galaxies jostle with each other, some get cut off from their gas supply, like apples falling from a tree. Starved of fresh gas, their star formation dwindles. This is the 'cosmic web detachment' model.

The model explains important aspects of galaxy evolution, but until now there was no observational evidence to support it. PhD candidate Dane Kleiner (Monash University) and his collaborators set out to find some.

The researchers first identified filaments using a large Australian optical survey, the Six-degree Field Galaxy Survey (6dFGS). They then compared galaxies found close to the filaments with a matched control sample of galaxies much further away. Both samples were drawn from HIPASS (the HI Parkes All Sky Survey).

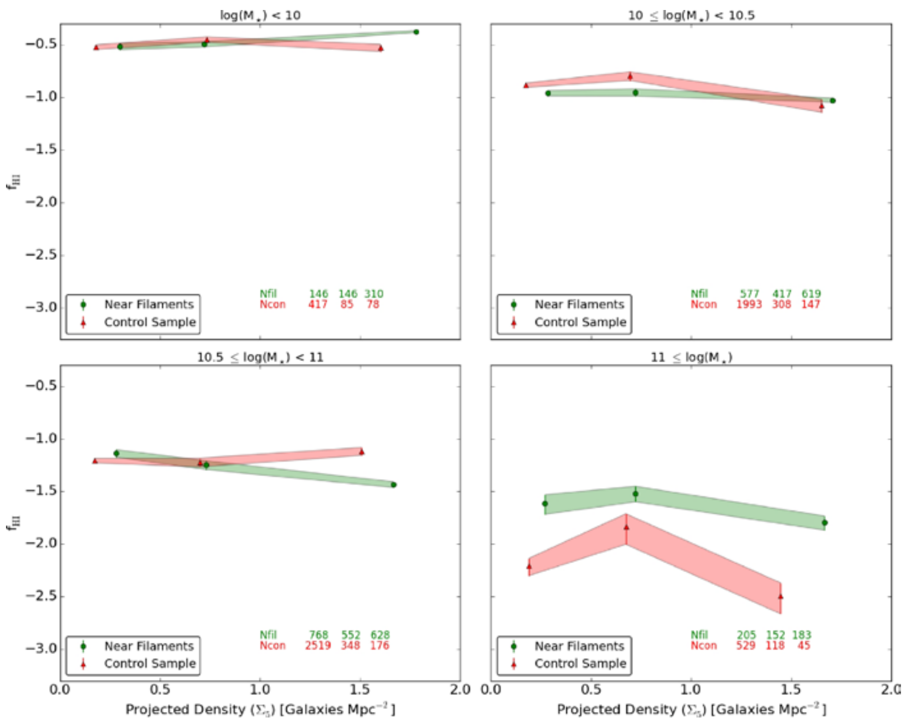
The researchers looked in particular at each galaxy's HI fraction – the ratio between the mass of its HI and the mass of its stars. To determine the HI content, they used a technique called spectral stacking, which measures the average HI content of an ensemble of galaxies. Stacking 'counts in' the HI signal from a galaxy even if that signal is too weak to detect directly.

For smaller galaxies, ones with stellar masses less than 10^{11} times the mass of the Sun, the near-filament and control galaxies had the same HI fraction. This implies that the filaments had no influence on the HI in the smaller galaxies.

For larger galaxies it was a different story. The ones near the filaments had a significantly higher HI fraction than those in the control sample. The researchers had already taken into account other effects that might influence the HI fraction, so this finding suggests that massive galaxies accrete cold HI from filaments. It looks like only massive galaxies have a gravitational pull strong enough to suck in significant amounts of gas. But observations with a more sensitive telescope, such as ASKAP, are needed to confirm this.

This work is a pilot study for future galaxy surveys. The Australian optical survey TAIPAN, which will start observations in 2018, will reveal the cosmic web in more detail than 6dFGS, while the ASKAP surveys, WALLABY and DINGO, will improve our understanding of the HI content of galaxies.

Kleiner, D.; Pimbblet, K.A.; Heath Jones, D.; Koribalski, B.S.; Serra, P. "Evidence for H I replenishment in massive galaxies through gas accretion from the cosmic web". MNRAS, 466, 4692-4710 (2017).



The HI fraction in the near-filament sample (green circles) and control sample (red triangles) for four stellar mass ranges. The coloured text gives the number of galaxies stacked to obtain the HI fraction. Shaded regions are the 1-σ uncertainties. For stellar masses above 10^{11} $M_{\odot}$ the near filament HI fraction is higher than that of the control sample, with a 5.5-σ significance. (From Kleiner et al. 2017)

Observatory reports

On 21 November 2017 the very last receiver was installed on ASKAP – meaning each of the 36 antennas now bears a second generation phased array feed. Image: Brett Hiscock.

Australia Telescope Compact Array

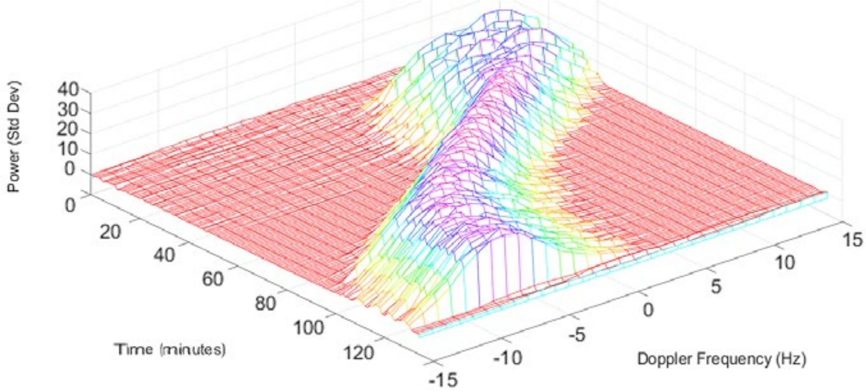
The major science highlight for ATCA in this reporting period was our involvement in follow-up of a gravitational wave detection. Within 24 hours of the email alert, A/Prof Tara Murphy of the University of Sydney was leading a small Australian team using ATCA to – successfully – detect the radio afterglow of this event, which we have monitored ever since (see Science highlights).

We have so far dedicated an entire semester to Legacy Projects (large single investigations, not reproducible by any combination of smaller projects, that generate data of lasting importance), albeit spread over three semesters. Two Legacy Projects commenced in the October 2016 semester: GAMA Legacy ATCA Southern Survey (GLASS) and Imaging Galaxies Intergalactic and Nearby Environment (IMAGINE). The following semester, Dense Gas Across the Milky Way: the 'full-strength' MALT45, and A Comprehensive ATCA Census of High-Mass Cores commenced. Over the three semesters covered in this report, these four Legacy Projects have used 3433 hours of observing time – equivalent to virtually all of the schedulable time in a typical semester. All four teams presented encouraging preliminary results at a Science Day symposium in May 2018.

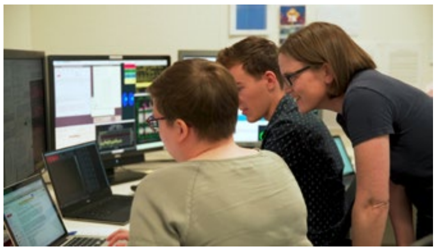
A new observing mode was introduced in the 2017 April semester, allowing a rapid automated response to transient event triggers. Two Non-A Priori Assignable (NAPA) projects (C3200 and C3204) were involved in development and testing of this new rapid response mode as they are interested in the very prompt emission created by superflares from dwarf stars and short gamma-ray bursts. ATCA is now capable of starting the slew to the transient target within three seconds of a trigger from gamma-ray and X-ray space telescopes.

Some rule changes were required to allow NAPA over-rides of scheduled projects. Before the 2017 October semester, the TAC score of a NAPA was required to be higher than that of the scheduled project it sought to displace. After discussion with the community, the rules were changed to allow any NAPA to proceed if it had a score greater than the lowest TAC score where most projects were allocated most of their requested time.

There were two significant hardware upgrades for the telescope systems in this reporting period: a new primary monitor (PMON) and better cooling for the seeing monitor. The new PMON was installed in September 2017, replacing the old system with a modern, more maintainable machine. Similar to the Parkes Telescope Protection System, it can be viewed and controlled remotely over a network. The array no longer needs to be manually taken out of a PMON wind-stow (which occurs when the wind speed exceeds 50 km/h for 7 seconds) and correctly handles being wind-stowed at the same time as a heat-stow (when an antenna's scroll compressor discharge temperature exceeds 110 C).



ATCA and DSS 34 at the CDSCC track asteroid 2012 TC4 as it passes within 22,000 km of Earth's surface on 12 October 2017. Image: Zohair Abushaban and Jamie Stevens.



A/Prof Tara Murphy, postdoc Christene Lynch and CASS co-supervised PhD student Dougal Dobie using ATCA in their successful follow-up of a LIGO detection from the ATNF's Science Operations Centre in Sydney. Image: University of Sydney.

The cooling system for the seeing monitor cabinets was redesigned and installed in early 2018 to help ensure that the system will remain cool even on the hottest of summer days.

Although there was no development work on the Compact Array's Broadband Backend, in October 2017 a software feature was discovered lurking in the existing code. Called tvmedian, this feature allows use of the median statistic while calculating the amplitudes and delays in the correlator. This has helped observers cope in the RFI-affected 16-cm band.

ATCA has also been involved in efforts to use radar to monitor potentially hazardous near-Earth objects. In collaboration with the CDSCC and its sister station in Goldstone, California, ATCA tracked the asteroids Florence (at 4.4 km diameter, one of the largest near-Earth asteroids), which passed within 7 million km of Earth, and 2012 TC4 (10 m diameter), which passed within 22,000 km of Earth). CDSCC antennas, trained in the general direction of the asteroids, transmitted at 7-8 GHz (the same frequencies used for spacecraft uplink communications) and ATCA detected the reflected signal. ATCA is the only southern hemisphere telescope able to routinely observe at these frequencies and thus stands to play a crucial role in this field. So called bi-static radar is a powerful technique for studying the sizes, shapes, rotation, surface features and roughness of near-Earth objects and it allows for more precise determination of their orbit around the Sun.

Parkes radio telescope

Science highlights included:

- Detection of four FRBs through use of the Berkeley-Parkes-Swinburne Recorder, developed in collaboration with Swinburne University of Technology and the University of California at Berkeley. This system was successfully run in parallel with other observing projects, the Parkes Pulsar Timing Array (pulsars), and the Breakthrough Listen project (search for extraterrestrial intelligence) and enabled simultaneous detections.
- The implications of FRBs for Galactic rotation measures were presented (Petroff et al. 2017, MNRAS, 469, 4465).
- Parkes pulsar data informed an updated model of the neutral electron content in the Milky Way (Yao, Manchester & Wang 2017, MNRAS, 468, 3289).

For the instrument itself, 2017 commenced with the return of the fully serviced 13-beam receiver, after the PAF made for the Max Planck Institute for Radio Astronomy was freighted to Germany.

A maintenance shutdown in May allowed replacement of the power switchboard and investigations into a novel, but aging, aspect of Parkes' operation: the Master Equatorial. This allows accurate pointing by placing the equatorial unit at the intersection of the two axes of rotation (elevation and azimuth) and tying it to the dish – placing it at the heart of the telescope structure...

After on-dish testing in August 2017, our new low frequency Ultra-Wideband receiver (UWB-L) was installed in May 2018. The UWB-L is instrumental to Parkes maintaining its position as one of the world's most productive telescopes. It offers continuous frequency coverage from 700-4030 MHz (thus covering the HI, CH and OH lines) and replaces four receivers which had gaps between their coverage. The very wide bandwidth and excellent polarisation performance of the receiver gives high sensitivity for observations of pulsars, galactic synchrotron emission and active galactic nuclei. It will improve observation of frequency-dependent phenomena, such as Faraday rotation and interstellar scattering, provide enhanced capability for very long baseline interferometry and complement images made with ASKAP and the SKA by filling in the low spatial frequency components.

The UWB-L is the first of three similar receivers that will eventually cover the full frequency range of The Dish. Able to share the focus cabin with the multibeam, the new receiver package will increase efficiency as we will no longer need to swap receivers several times a year.

Parkes' new GPU-based backend system, dubbed MEDUSA for its ability to handle multiple strands of backend processes, has greatly expanded software capabilities to support the UWB-L and additional processing hardware to produce archive-ready data products.

New user interfaces feature updated versions of our FROG monitoring software and the observer-staff communication channel, PORTAL. A new web-based control software interface is under development for the UWB-L.

The Ultra-Wideband Low receiver is hoisted into position on 15 May 2018. Image: John Sarkissian.

The backend system for the Breakthrough Listen project was installed, allowing the team's comprehensive Galactic plane survey with the multibeam receiver system to get underway. At the same time, the Breakthrough project enabled an FRB searching capability for their observations with the multibeam, successfully detecting an FRB in March 2018.

Sale of telescope time provides crucial support to Parkes. To our relationship with Breakthrough Listen, we have added China's FAST radio telescope, principally for follow-up observations of pulsar candidates.

The 12-m Parkes Test Facility dish continued to be used for science observations, including pulsar monitoring. We are investigating upgrading the Test Facility with an uncooled wideband receiver, to complement the 64-m telescope and expand the science capability.

Parkes – and our Breakthrough Listen partners – featured prominently in ABC TV's Stargazing Live extravaganza, including by being one of the hosts of a world-record breaking star party. Image: John Sarkissian.

Australian Square Kilometre Array Pathfinder

In November 2017, the final second generation (Mk II) phased array feed (PAF) receiver was installed on the last of ASKAP's 36 antennas. This marks the completion of full deployment of ASKAP's front-end hardware, including the upgrade of our first set of six first generation (Mk I) PAFs to the current design specifications. 24 antennas are connected to their digital processing systems and available in two science sub-arrays. (Installation and testing of remaining digital hardware is scheduled for completion by November 2018.)

Development of the Science Data Processing software has been a major focus of activity in the last year, driven by the availability of a large amount of early science data for testing and verification. ASKAP's real-time supercomputer, Galaxy, at the Pawsey Supercomputing Centre in Perth, has been at capacity as the science teams analysed early science observations with the prototype ASKAPsoft imaging pipeline. Although there are differences between the optimal processing strategies for a subset of antennas and the full array, experience with real data is an essential component of the development and testing process. A series of 'data challenges' has seen the science teams engaged in optimisation of the many imaging parameters producing the highest quality output and feeding experience back into the development process.

We have also been increasing ASKAP's operational readiness. This includes:

- Automation of system configuration tasks, such as optimisation of antenna signal levels.
- Integration of the on-dish calibration system to help stabilise beam patterns.
- A new timing and reference system.
- Improvements to the reliability of antenna drives and of PAF power and cooling subsystems.
- A major upgrade of the phase tracking system.

An improved version of the Observation Management Portal has been developed and deployed to allow web-based visualisation and management of ASKAP observations from preparation to execution and processing. The ATNF's in-house telescope monitoring software, MoniCA, has been enhanced with modern open-source software to handle an instrument of ASKAP's scale (with 1.5 million monitoring and control points, ASKAP is some 30 times more complex than ATCA) and to give it a user-friendly web interface. The Pawsey Supercomputing Centre has also adopted these tools and allows ASKAP operations to monitor its performance, such as data ingest. All these efforts will allow a larger fraction of uptime and increase the efficiency of fault-finding and maintenance efforts.

James Hannah tests a PAF regulator on an ASKAP antenna. Image: Brett Hiscock.

The ASKAP early science program commenced with the 12-antenna array in October 2016 and its original scope is almost completed. That is, two survey streams: a wide, shallow survey over a broad bandwidth and a deeper survey covering a smaller frequency range and less sky area. The science goals of the first survey were oriented towards continuum and polarisation studies, while the deeper survey was aimed more at detection of neutral Hydrogen emission, though both survey streams were expected to accommodate several survey science projects. We have archived several petabytes of 18.5 kHz spectral resolution, 10-second averaged visibilities, allowing a wide range of science goals to be pursued on both data sets. Several results have already been published.

The structure of the early science program evolved to be more flexible than initially intended. The need to share time with ongoing construction and commissioning activities has made it difficult to execute large-scale science observations and we have instead observed a sequence of test fields broadly aligned with the final survey goals.

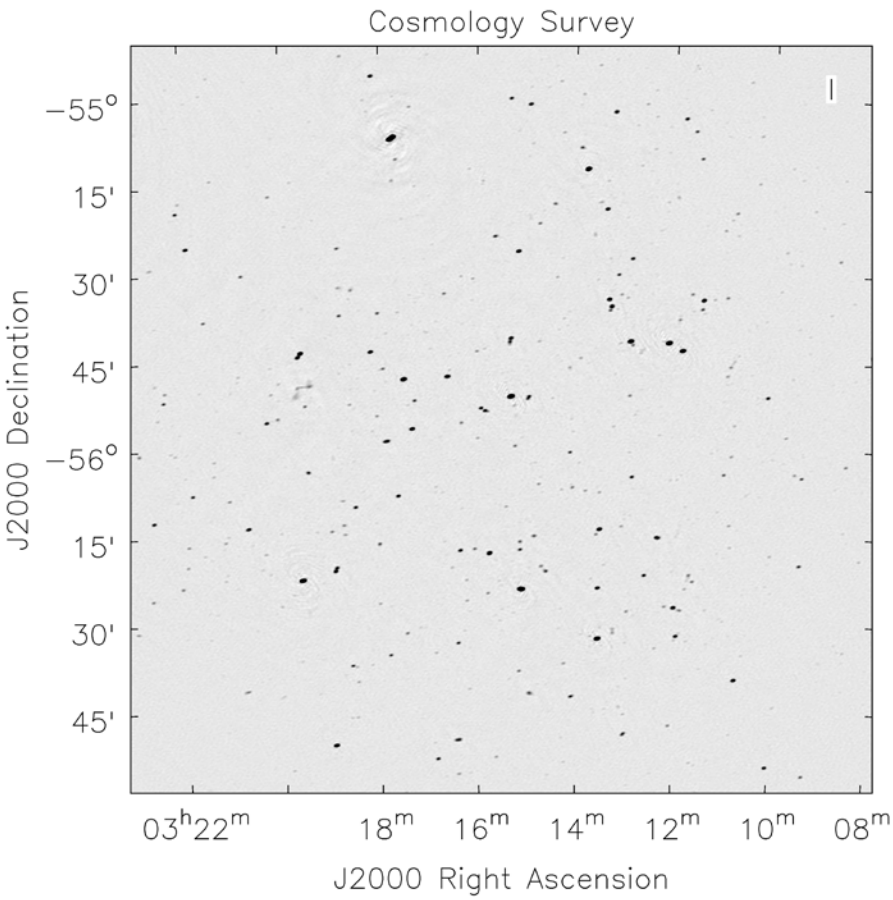
Regular communication with the science teams via representatives in the ASKAP Commissioning and Early Science (ACES) group, and the early science forum, has ensured rapid response to changing priorities and to observe science targets of highest relevance. Goals included testing aspects of the ASKAP system and its performance as well as capitalising on emerging research opportunities, such as the search for fast radio bursts (FRBs, see below).

ASKAP in fly's eye mode. Image: Kim Steele, Curtin University.

Under the wide-shallow survey we observed nine fields covering regions surveyed by other telescopes or at other wavelengths, including the Chandra Deep Field South, the Galaxy And Mass Assembly (GAMA) 23 field, and the Small Magellanic Cloud (featured on the cover of the Science Highlights section of this report). Observations of well-studied fields provides important multi-wavelength information and an opportunity to verify ASKAP's performance against other world-leading telescopes. These regions were observed for between 20 and 100 hours each, for a total of roughly 500 hours and the majority of ASKAP's survey science teams (that is: EMU, VAST, DINGO, GASKAP and POSSUM) obtained useful data. Most of these observations consisted of one, or at most a few, tiled regions covered by ASKAP's 30 square degree field of view. Recently, we have embarked on a more extensive pilot survey of roughly 2000 square degrees, requiring 68 ASKAP fields; around a quarter of this observing has been completed. These data will be used by several science teams, including EMU, which will study the cosmological implications of the resulting continuum source catalogues, and FLASH, which will search for new HI absorption sources over the full area.

Under the deep survey we observed four regions (NGC 7232, M83, Fornax and Dorado) each with ASKAP's full 30 square degree field of view. These form the core of the WALLABY survey science team's early science observations. Each field was observed for roughly 150 hours and, after combining multiple nights, the WALLABY team was able to reach the same sensitivity as expected for the full-scale survey with all 36 antennas, making the early science observations a valuable pilot project that will assist in the development of future processing pipelines.

In parallel, a subset of ASKAP's antennas (those not yet connected to the correlator) have been used to search for FRBs (see Science Highlights). By combining the field of view of several ASKAP antennas pointed in different directions (fly's eye mode) and searching raw beamformer outputs from each antenna individually, the CRAFT survey science team has discovered more than 20 FRBs, nearly equalling the number of previously known events. There is a good chance that ASKAP will be one of the first telescopes to localise an FRB using interferometry, which may lead to a better understanding of their origins.



Single beam image from one of the first observations from the largest survey to date (2000 square degrees). This image shows hundreds of radio sources, some with complex extended structure. (16 antennas, 240 MHz bandwidth, centre frequency of 912 MHz, 200 minutes per pointing). Image: Aidan Hotan.

Murchison Radio-astronomy Observatory

The Murchison Radio-astronomy Observatory (MRO) in Western Australia is 315 km from the coastal town of Geraldton on the former pastoral property, Boolardy Station, and on Wajarri Yamatji country.

As well as being home to ASKAP, the MRO hosts the Murchison Widefield Array (MWA) and the Experiment to Detect the Global Epoch-of-Reionisaton Signature (EDGES), and two test arrays for the SKA (see SKA).

- The MWA is a low-frequency instrument of 4096 dipole antennas arranged in 256 tiles, with 56 of these providing baselines up to 5 km. MWA observes in five bands from 80-300 MHz and is operated by Curtin University on behalf of an international consortium of some 120 organisations, including CSIRO.
- EDGES is a radio spectrometer operated by Arizona State University and the Massachusetts Institute of Technology's Haystack Observatory. Using sky-averaged spectra below 200 MHz, the instrument aims to detect neutral hydrogen gas produced by the formation of the first stars in the Universe and subsequent reionisation of the intergalactic medium.
- The SKA test arrays are 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 MRO is the largest observatory in the world operating on solar power. Image: Red Empire.

Power station

In early December 2017 the solar component of the MRO power station came online. The power station is designed to run for a large part of the day without recourse to diesel, making MRO the largest observatory in the world running on renewable power.

The hybrid power station now comprises: 1.85 MW solar photovoltaic power, 2.5 MWh of lithium-ion battery storage (one of the largest in Australia), and 4 diesel generators (2 x 250 kW and 2 x 1005 kW).

Preserving the MRO's radio quiet environment is paramount and requires RFI shielding of all critical components of this system, including the 6 km underground power cable connecting the power station to the MRO distribution network.

Premier radio quiet site

The Murchison region is ideal for radio astronomy due to its low population density: the Murchison Shire spans some 49 500 square kilometres and is home to around 100 people. This means fewer of the trappings of modern life that cause RFI (such as engines, mobile phone towers and electricity lines) which 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, radioastronomy is the primary user of spectrum (see Spectrum management). CSIRO also has strict on-site standards and procedures to keep interference to a minimum. RFI is continuously monitored and any sources tracked down.

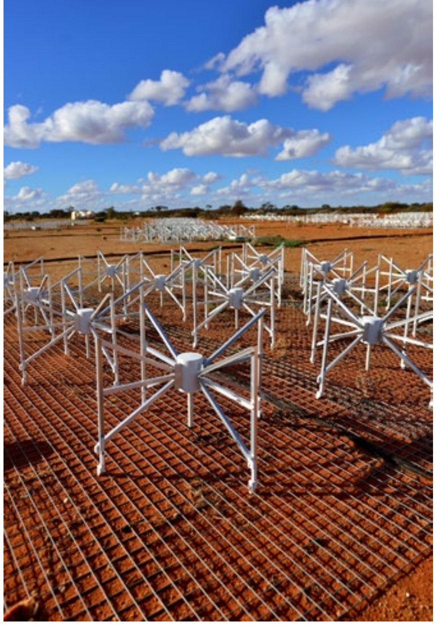
Long Baseline Array

The ATNF's Long Baseline Array (LBA) is a set 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 radio telescope, ATCA and Mopra telescope in New South Wales; the University of Tasmania's 26-m antenna in Hobart, Tasmania and 30-m antenna in Ceduna, South Australia; the Hartebeesthoek 26-m antenna in South Africa; and Auckland University of Technology's 12- and 30-m antennas in Warkworth, New Zealand. These are augmented by the 70- and 34-m antennas at the CDSCC near Canberra (when available), and the University of Tasmania's 12-m AuScope antennas in Yarragadee, Western Australia, and Katherine in the Northern Territory. The LBA is also occasionally used as part of an ad-hoc global VLBI array with telescopes from Asia and Europe, and regularly observes as part of the ground array supporting the Russian 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 October 2016-March 2018 there were 30 LBA experiments (comprising 69 individual imaging observations and 131 one-hour RadioAstron survey and monitoring observations), involving four unique Australian primary investigators (PIs) and 20 unique overseas PIs and using a total of 878 hours of observing time. Thirteen of the 20 experiments with overseas PIs included Australian collaborators. Seven of the experiments utilised the LBA as part of global VLBI experiments, the majority of these being for RadioAstron imaging experiments. This period included many successful co-observations with the EVN (European), KVN (Korean) and CVN (Chinese) VLBI networks.

LBA experiments (other than RadioAstron and global experiments) are correlated by CSIRO staff using the DiFX software correlator running on the Magnus supercomputer at the Pawsey Supercomputing Centre in Perth. A total of 49 user projects were correlated representing ~650 hours of observations. This system has been running smoothly, with a median time of 42 days between observation and release of data. The processing time is dominated by the time taken to transfer data (median 28 days), largely because some stations do not have high-speed data networks and must ship disk modules. A total of 225,000 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, largely driven by the RadioAstron observations. The relatively large number of PIs demonstrates the continued need for Southern Hemisphere VLBI capability, which will become increasingly important for following up results from ASKAP.

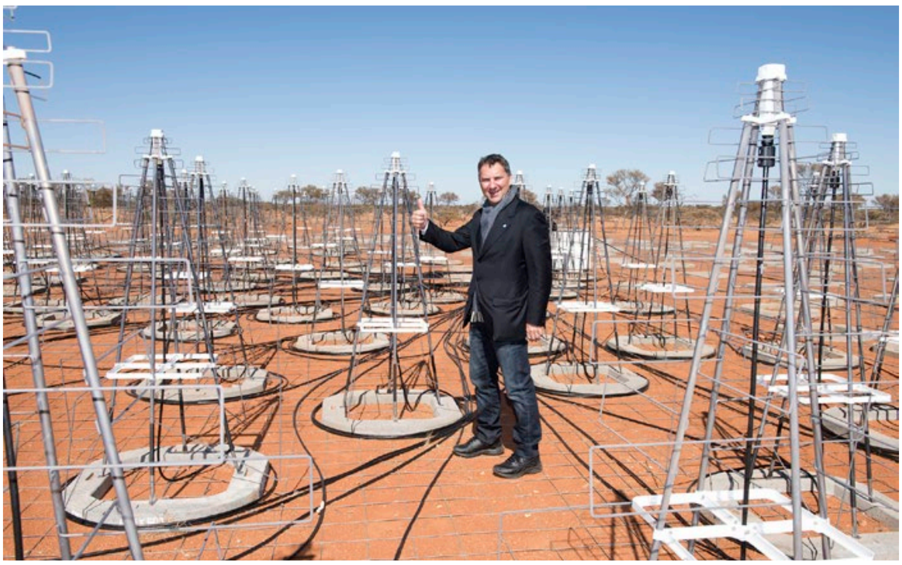


The core of MWA. Image: Red Empire.

Mopra

The Mopra radio telescope continues to be operated by CSIRO under contract to a consortium of universities, although leadership of this consortium transferred from the University of New South Wales to the University of Adelaide in April 2018. Under the new agreement CSIRO continues to recover all the routine operating costs of the telescope and Mopra continues to participate in LBA observing, typically for two five-day sessions in each Semester.

CSIRO Chief Executive, Larry Marshall, is one of many VIPs to visit the MRO this year. Pictured amidst antennas of the AAVS. Image: Kurt Warhurst.



Data archives

Our data archives grew in size and impact and now include:

- Australia Telescope Online Archive (ATOA)
- Parkes Pulsar Data Archive, a principal component of CSIRO's Data Access Portal (DAP)
- CSIRO ASKAP Science Data Archive (CASDA).

A science highlight is the use of DAP archival data to investigate and describe the polarimetry of 600 pulsars (Johnston and Kerr 2018 MNRAS, 474, 4, 4629).

The ATOA is well established and continues to have impact through serving and storing data from existing ATNF facilities: ATCA, Parkes (non-pulsar data) and the LBA, as well as Mopra legacy data. The ATOA dataset is ~237 TB and growing at about 32 TB per year. There were more than 300 downloads per month from the ATOA and, in the past year, about 40% were outside of the 18-month proprietary period, indicating that ATOA archival data is of high value to the astronomy community.

The Parkes Pulsar Data Archive, served via the DAP, is the most comprehensive pulsar data archive in the world. The DAP as a whole recently passed 1 PB, with pulsars making up 900 TB of those data. It is growing at about 400 TB per year, which is likely to increase with UWB-L coming online. Downloads from the Parkes Pulsar Data Archive totalled a few thousand per month.

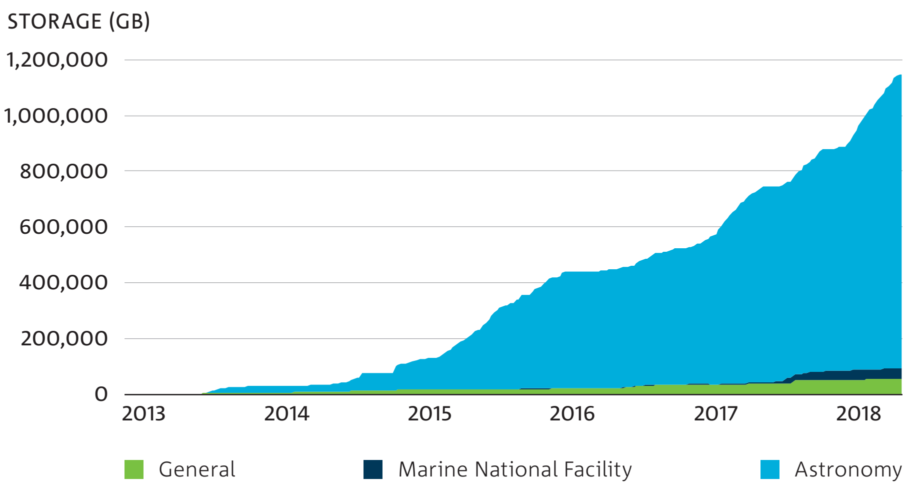
The first public release of ASKAP Early Science data occurred in July 2017 via CASDA, a collaboration between the ATNF, CSIRO Information Management and Technology (IM&T) and the Pawsey Supercomputing Centre. The release consisted of observations of NGC7232 which were taken as part of WALLABY observations in October 2016 (12 antennas, 48 MHz bandwidth). This data release consisted of continuum images (all 36 PAF beams), calibrated visibilities (frequency averaged to 1 MHz), and source catalogues.

CASDA supported calibrated continuum visibilities, ASKAPsoft pipeline image products, user-derived image products, metadata and quality assessment metrics. A revamp of CASDA in February 2018 saw the inclusion of additional features such as:

- handling of spectral and moment map data types
- the ability for users to upload their value-added data products (Level 7 images/cubes and catalogues)
- evaluation files made available and quality metrics shown, for continuum data, to allow for data quality assessment
- enhancements to virtual observatory services
- Skymap interface to search for data using an image of the sky.

A legacy dataset of much interest and value to the community is the HI Parkes All Sky Survey (HIPASS). HIPASS covers the whole southern sky, and northern declinations to +25 degrees. To facilitate the use of this HIPASS data, its combination with ASKAP data, and to test the CASDA functionality, HIPASS cubes are now available in CASDA. The CASDA data release comprises all 538 HIPASS cubes.

CSIRO is a world leader in virtual observatory services. In mid-2017 CASDA became an official node of the All-Sky Virtual Observatory (ASVO), the network of data archives comprising Australia's VO effort. The team at the International Centre for Radio Astronomy Research (ICRAR) has implemented CASDA VO tools in the MWA Data Archive and CASDA and DAP technologies are being explored for use with the new FAST telescope for the Shanghai Astronomical Observatory archives and for the future Australian SKA Regional Centre.



In March 2018, the CSIRO Data Access Portal passed 1 PB. >900 TB is data from Parkes and ASKAP. Storage growth has jumped from an average of 16 GB a week in 2012/13 to 8 TB now. Image: Research Data Support, IM&T.

Technology development

Engineer Mia Baquiran debugs ASKAP digital signal processing equipment. Image: Wheeler Studios.

Receiver success

The two receivers built recently for external clients are now operational on their respective telescopes: the 19-beam receiver on China's Five-hundred-meter Aperture Spherical radio Telescope (FAST) and the PAF made for the Max Planck Institute for Radio Astronomy (MPIfR) on the 100 m Effelsberg Radio telescope. The customised digital system was also installed, along with ASKAP-based software integrated with the Effelsberg telescope control system.

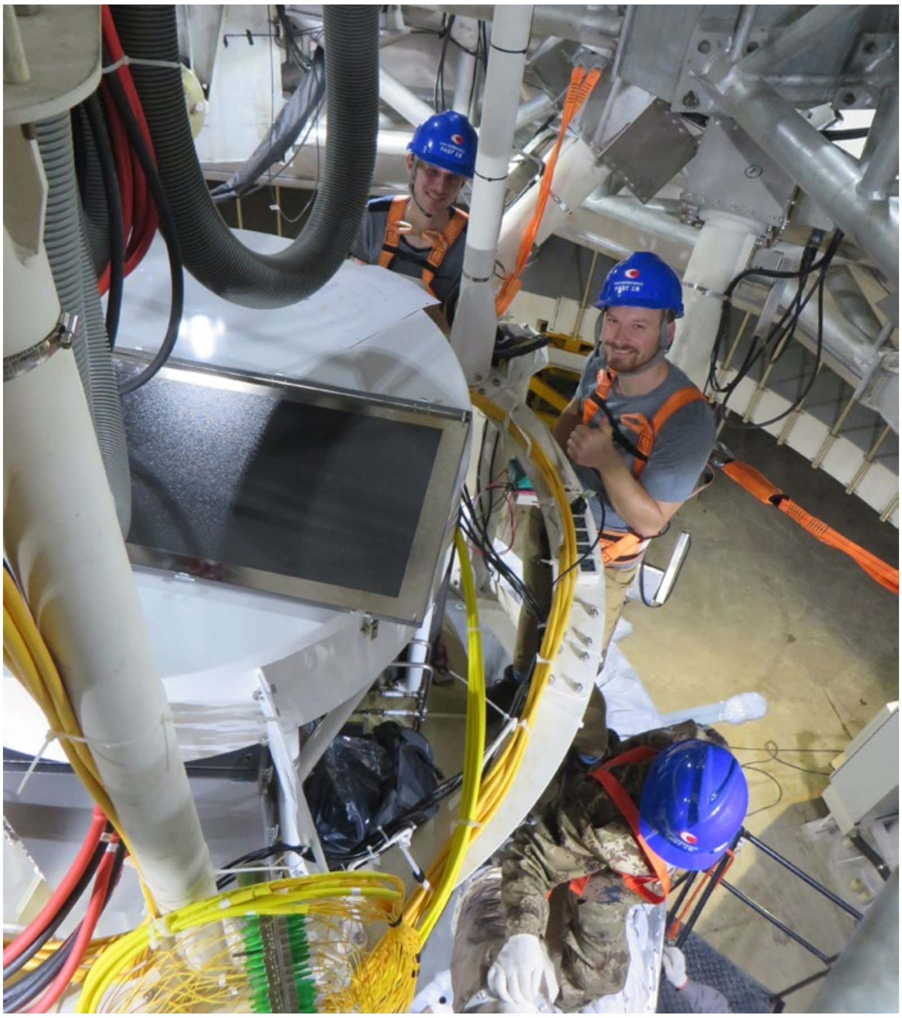
Ultra-wideband receiver

The low frequency Ultra-wideband (UWB-L) receiver, newly installed on the Parkes radio telescope, was a major focus for the engineering teams and the software group over this reporting period.

The UWB-L required a novel design to achieve science and operational goals without compromising performance. It features a dual polarised, quad-ridged feed horn with an outer corrugated skirt and a central insert made of three concentric layers with different dielectric constants: quartz, Teflon and an artificial dielectric made by cutting slots in Teflon. The materials were chosen for their low loss (minimal contribution to noise in the system) and ability to maintain performance when cooled to cryogenic temperatures.

The cryogenic design and construction also required novel approaches. The radio transparent vacuum window, for example, needed to be a relatively large dome shape to accommodate the dielectric and is the first we are aware of to use a composite fibreglass and foam sandwich structure. To verify the strength and stiffness properties of the window, a destructive test was performed in the hyperbaric chamber at the Prince of Wales Hospital in Sydney. This reinforced room, usually used for treating divers, was pressurised up to 4 atmospheres before the vacuum window imploded, giving us confidence that the structure can withstand the required loads.

The PAF installed on the Effelsberg radio telescope in Germany. Image: MPIfR.



Alex Dunning and Peter Roush installing the multibeam receiver on FAST in China. Image: Doug Hayman.

Unusually, a switch mode power supply was employed. This technology is typically rejected because of the inherent RFI; however, extreme care in filtering and shielding allowed this very efficient power supply to pass RFI qualification.

A powerful digitisation and signal processing system completes the receiver hardware. Engineering commissioning results confirm that, with careful design, it is possible to place analog to digital converters and their associated support electronics next to the sensitive feed elements and low noise amplifiers (LNAs) without contaminating the weak signals the telescope aims to detect. This is a significant departure from conventional receiver design where radio noisy electronics are kept as far as possible from sensitive receiver components. Digitising the signal at its source, as opposed to sending it some distance over fibre or cable to be digitised elsewhere, delivers higher performance in environments where RFI is a problem and offers more flexibility at the instrument design stage. This new arrangement has far reaching implications for future single-element and multi-channel receiver designs.

Software for the control of UWB-L is based on frameworks developed for ASKAP. While the observation management portal was customised for a single dish telescope, all remaining layers (control and monitoring of hardware and software) re-used tools developed for ASKAP.

Several international groups supported the development of this receiver. Several more, having seen early performance results and now extremely encouraging early science commissioning observations, have expressed interest in purchasing one.

UWB-L in the testing facility confirming the design characteristics of high aperture efficiency, minimal ground noise pickup and no detectable resonances (which might otherwise be confused with spectral lines). Image: Santiago Castillo.

Cryogenic PAF

Following successful on-dish tests of the prototype Rocket PAF (named for its distinctive Vivaldi-style receiver elements), the third generation of CSIRO's multi-award winning PAF receivers is now going cryogenic.

The complex feed assembly consists of 188 PAF elements and LNAs, 94 for each of the two polarisations, to deliver a minimum of 36 beams on the sky. This number of LNAs means internal power dominates over the thermal load from infrared radiation so new designs and novel materials are being analysed to ensure the LNAs stay cold.

The cooled PAF promises a four-fold improvement in sensitivity over ASKAP's Mk II PAFs and will have active RFI mitigation features built in. An enhanced backend system is being designed to process the expected data rate of 3 Tb per second. This development is strategically important for future radio astronomy receivers on large telescopes in Australia and China, and potentially for ASKAP and Phase 2 of the SKA.

Radio transparent receiver supports

We are investigating improving ASKAP's sensitivity by replacing the metal supports that hold a PAF above the antenna dish with a material that radio frequencies can pass through. The idea is that the new legs will be sufficiently 'radio transparent' that the blocking and scattering typical of metal supports is much reduced, leading to an improvement in sensitivity.

The new legs are made of a fibreglass and foam sandwich structure, reinforced at the top with extra fibreglass and some metal (this section is effectively blocked by the PAF itself so does not need to be transparent).

Lightweight composite structures require careful analysis and testing and the manufacturer, builder of high tech racing yachts, McConaghy Boats, provided valuable expertise along the way. Factory acceptance testing included one representing the wind and gravity loads on an antenna tipped to the horizon with approximately twice the normal load on the legs. Having passed these tests, the transparent feed legs were installed on ASKAP antenna 32 in late June 2018 and their performance is now being assessed.

Spectrum management

CSIRO strives to protect spectrum for radio astronomy and space research and works to gain specific protection for our facilities. Beyond the protections for the MRO (see MRO), there are Radio Notification Zones around our other facilities. Under the Radio Assignment and Licensing Instruction (RALI) MS 31, CSIRO must be notified of any proposed radio licences in given bands at given distances – different for each site.

This requires that CSIRO maintains a good working relationship with international and domestic bodies and major users of the spectrum. At the international level, the radio spectrum is regulated by the Radio sector of the International Telecommunication Union (ITU-R); the international Radio Regulations treaty is updated every four years via the World Radiocommunication Conference (WRC). In Australia, spectrum regulation is handled by the Australian Communications and Media Authority (ACMA).

We are currently:

- Working on studies for the next ITU-R WRC in 2019. CSIRO is actively involved in ACMA processes to develop Australia's position for WRC agenda items.
- Leading studies in ITU-R Working Party 7D (Radio Astronomy) and ITU-R Study Group 3 (Radiowave Propagation). ATNF scientists chair both of these bodies, Tasso Tzioumis the Working Party and Carol Wilson the Study Group.
- Representing radio astronomy and space research interests in the Department of Communications' review of the spectrum-management framework.

Prototype transparent feed legs being installed on an ASKAP antenna. Image: Nick Carter.

Square Kilometre Array

Antony Schinckel (second from left) and senior staff from the SKA Organisation at the proposed location of the core of SKA1-Low. Image: Brett Hiscock.

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 some 131,072 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 currently scheduled to commence in 2021.

In this reporting period, Australia's Science Directorship on the SKA Board transitioned from Sarah Pearce to Douglas Bock. Phil Edwards was made Chair of Australia's SKA Science Advisory Committee, Warren Bax and Shi Dai undertook short-term secondments to the SKA Organisation and Antony Schinckel accepted a part-time secondment as Head of SKA Construction Planning in Australia. Senior Engineer, Mark Bowen, continued in his two-year secondment.

Preconstruction

Underway since 2013 is design and development work known as preconstruction. The SKA telescopes are being designed by 11 international preconstruction consortia. In this reporting period, CSIRO was involved in eight and led two of these. In November 2017 we stepped down from leadership of the Dish Consortium. By March 2017 the PAF Consortium (part of the SKA's Advanced Instrumentation Program) was underway.

Highlights of our preconstruction work include development of the correlator and beamformer for SKA1-Low within the Central Signal Processor consortium. The correlator-beamformer transforms the outputs from the 512 antenna stations of SKA1-Low into visibility data for imaging and beams for pulsar timing. CSIRO leads an international team including ASTRON and Auckland University of Technology which has designed a liquid-cooled, optically-connected, FPGA-based compute farm for the correlator and beamformer. The system must handle data rates of around 7 Tb per second (input/output) on a very low power budget – and FPGAs are ideal for both. This work leverages ASKAP digital signal processing but is an advance on it in processing power, physical size (it is one sixth the volume) and power consumption, yet at a similar cost.

In the Science Data Processor consortium (a large collaboration designing software for data ingest, calibration, imaging processing and archiving), we co-authored the imaging pipeline and the High Performance Computing architecture as well as contributing to the research effort into the calibration challenges of SKA1-Low and prototyping. This work also builds on experience developing ASKAP software and its supercomputing platform.

Another consortium leveraging significant experience with ASKAP and establishment of the MRO is Infrastructure Australia. This consortium is tasked with designing all SKA1-Low site infrastructure, such as roads and tracks, power distribution, communications, site monitoring and buildings, with a strong emphasis on achieving the MRO's stringent radio quiet requirements while keeping costs down. A large component of the work was design of the central processor facility (double the size of the current MRO control building). An interesting development was the potential for small solar power stations to be used at clusters of antennas far from the core of the telescope.

Preconstruction is close to completion: several consortia have passed critical design review (the remaining reviews will occur in the second half of 2018 and early 2019.

Indigenous heritage surveying of the likely location of the core of SKA1-Low. Photo: Wilfredo Pena.

Site establishment

Work continued with colleagues in the Australian SKA Office of the Department of Industry Innovation and Science (DIIS) on site establishment: those activities in relation to the MRO that are needed to allow SKA1-Low to be built and operated here. For example, because SKA1-Low will extend beyond the borders of the current MRO into Boolardy Station, a new lease from the Western Australian Government is required.

The Wajarri Yamatji traditional owners must also agree to the construction of SKA1-Low. This consent will be documented in an Indigenous Land Use Agreement, along with the benefits to be made to the traditional owners. Antony Schinckel is CSIRO's lead in this negotiation. In principle agreement over the monetary benefits in November 2017 led to the Wajarri Yamatji allowing surveying of the proposed location of the core of SKA1-Low for cultural artefacts or sites of significance. These heritage surveys are the first in a long line of surveys that must be undertaken before the layout of SKA1-Low can be confirmed.

Regional data processing

CSIRO commenced work with colleagues at the International Centre for Radio Astronomy Research (ICRAR) on shaping an SKA Regional Centre (SRC) in Australia. The SRC will provide, for example, data products, computing resources for data processing and an archive and will work with similar centres in the Asia-Pacific region. We held a joint workshop in November 2017, from which a white paper on SRC requirements is being developed, and the Australia-China SKA Big Data Workshop in April 2018 deployed an SRC end-to-end prototype using ASKAP and MWA software.

International sphere

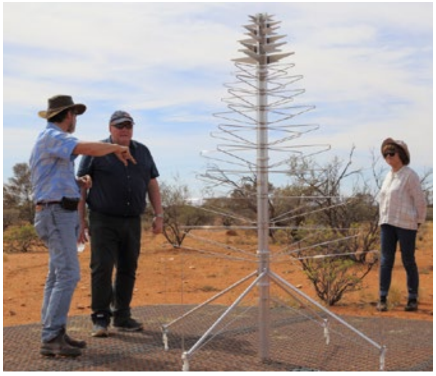
The SKA Organisation will transition from a UK company to an Intergovernmental Organisation (the SKA Observatory), governed by a multilateral treaty (Convention). Negotiations recently concluded and the Convention was initialled by Australia's Ambassador in Rome. The aim is for the Convention to be signed by the end of 2018 and ratified in 2019. A Convention Preparatory Taskforce (CPTF) will lead the transition from the current SKA Organisation to the new SKA Observatory. Sarah Pearce was part of Australia's negotiating team for the Convention, and will support the CPTF.

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, have largely agreed the terms of the Hosting Agreement which will be signed once the Convention is ratified.

Towards operation

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.

Australia's Ambassador to Rome, Greg French, initials the SKA Convention. Image: Twitter.



Antony Schinckel shows a new SKA1-Low prototype antenna installed in early 2018 to SKA Director General Phil Diamond and SKA Board Chair Catherine Cesarsky. Image: Brett Hiscock.

Senior data scientist, Minh Huynh, at the first Australia-China SKA Big Data Workshop in April 2017. Image: Peter Quinn, ICRAR/UWA.

Earliest stars seen from our MRO

The MRO is an ideal location for an instrument such as SKA1-Low, as the team behind the EDGES instrument (see MRO) has revealed. Writing in *Nature* in March 2018, Bowman et al. (Nature, 555, 67) detail what they interpret as evidence of the first stars in the Universe. The groundbreaking detection of this subtle feature required exquisite measurements with a very well understood antenna. The signal is so faint that the MRO, with its low levels of radio interference, is one of the few places on Earth from which it could have been found.

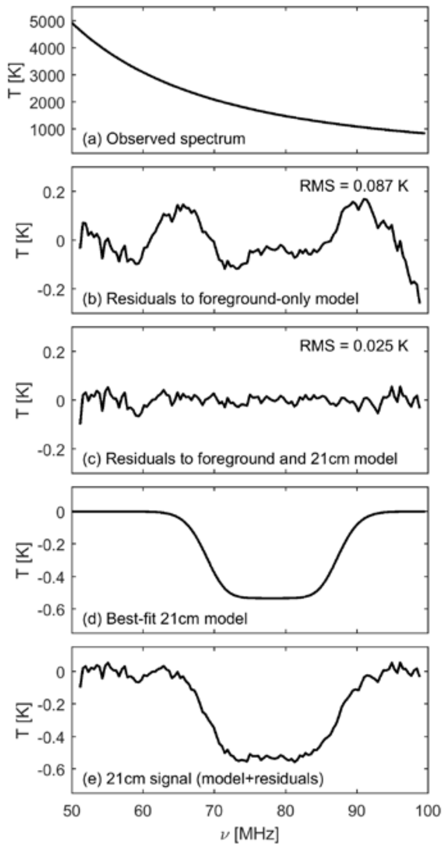
After the Big Bang the Universe consisted simply of cold neutral hydrogen gas, which emits a radio line at a wavelength of 21 cm. This is theoretically detectable from the Earth at the current time at a radio frequency of less than 200 MHz (frequency mapping to redshift and therefore cosmic time). Over time, gravity caused the hydrogen to condense and eventually collapse to form the first stars, which in turn ionised the surrounding hydrogen gas and altered the apparent strength of the 21 cm line. Knowing how the hydrogen line varies across frequency provides valuable information about the evolution of the Universe. Not only are signals from this far back in time extremely faint by the time they reach Earth, they also fall in a crowded part of the spectrum – FM radio stations are commonly found at the most astronomically interesting frequencies, for example. This is where the MRO's radio quiet nature comes to the fore.

Bowman's team observed for three months, collecting the average radio spectrum across vast swathes of the southern sky and searching the data for minute fluctuations in frequency. They saw a dip centred at 78 MHz, corresponding to an age of around 180 million years after the Big Bang.

The team then spent two years validating the detection. They installed a duplicate EDGES antenna at the MRO and repeated the experiment to verify the initial result. They also made other alterations to the hardware and the data analysis and calibration techniques, trying to determine if the detection was real or a systematic error. Finally, they were sufficiently convinced to publish.

This is the first time that astronomers have observed a signal from such an early time in the Universe; Nature called it 'the first reputable claim' of a long-sought detection of gas from a very interesting period in the history of the Universe. Naturally, the paper presenting this result is attracting a certain level of attention. If the detection is ultimately verified, its importance will be magnified by the fact that theorists are struggling to find a plausible model explaining the stronger-than-expected signal.

While other instruments, such as PAPER, HERA and MWA, hope to confirm the detection, SKA1-Low will go even further and map the distribution of the gas affected by the first stars in the Universe – highlighting the importance of the MRO for this kind of research.



Summary of the EDGES detection. While the central frequency is in line with theoretical predictions, the peak amplitude is much greater and the absorption profile is unusually flat-bottomed. Image: Judd Bowman, Arizona State University.

One of the EDGES antennas at the MRO. At ~2 m long and 1 m high it is smaller than a ping pong table. The plastic bottle protects a capacitive tuning plate from condensation and rain as excess moisture can change the tuning of the antenna, adversely affecting the sensitive cosmology measurements. Image: Brett Hiscock.

People and community

ATNF staff proudly support diversity and inclusion so everyone feels comfortable bringing their whole selves to work. Image: Rob Hollow.

Staff

There are currently 194 people working for the ATNF (Appendix C). Staff numbers overall have fallen by 22 since December 2016, although WA grew by 4 people. Across this reporting period 18 people joined the ATNF and 36 people ceased employment as a result of resignation (9), retirement (2), term employment ending (18) or redundancy (7). We have exceeded CSIRO's target of 3% indigenous employment, including 4 indigenous trainees and 3 cadets. There have been 11 joint appointments or secondments in this reporting period.

Culture, diversity and inclusion

The CASS Diversity Committee continued to work to ensure that CASS, and CSIRO as a whole, promoted diversity and inclusion in the workplace. There is now broad representation within the Committee across CASS sites, and raised awareness of the help and support that Diversity Committee members can provide to staff.

Highlights of the Committee's work include engagement in CSIRO's application to the Science in Australia Gender Equity initiative and in LGBTI support activities such as Wear it Purple Day. The Committee was proud to receive the 2017 CSIRO Digital, National Facilities and Collections Award for Inclusion and Diversity in recognition of its efforts. Shortly after receiving the award on behalf of the Committee, its Chair, Ryan Shannon, took up an appointment at Swinburne University of Technology. Jimi Green and Michelle Storey are now Co-Chairs of the Committee.

A prominent initiative in this reporting period was the CASS Culture project, which was established in December 2016 to address workplace culture in CASS and suggest actions to ensure a safe and welcoming place for all to work, study and visit. Three principal issues were: reality and perceptions of culture in CASS, stress in the workplace and training and policy. The project team consulted with CASS staff, the broader astronomy community and industry stakeholders over the reality and the perceptions of bullying and harassment within CASS, and to investigate best-practice in similar institutions. Relevant CSIRO policy documents were reviewed and compared with corresponding policies in Australian universities and industry.

All the recommendations in the team's report were accepted and substantial progress has been made in implementation. For example: there have been significant improvements in the quality and accessibility of information available to staff, affiliates and students on matters such as acceptable standards of behaviour and where to go for help and support. A buddy scheme for new starters has been introduced and a mentoring scheme will be rolled out during 2018. More importantly, there is an increased awareness at all levels of the need for everyone to promote a supportive and inclusive culture, supported by a requirement on senior managers to intervene immediately to stop unacceptable behaviour whenever it occurs. The remaining recommendations will be implemented during 2018, with assistance from the Diversity Committee as appropriate, and a staff survey is planned to help assess the impact of the project's outcomes.

Jolene Merry, general hand at the MRO, holds freshly picked gagurla (bush pear). ASKAP antenna 5 is named after this local delicacy. Image: Kurt Warhurst.

ATNF staff stand by their LGBTI colleagues. Image: Vicki Drazenovic.

Awards

Our award-winners include:

- Keith Bannister, who won the 2017 Astronomical Society of Australia's Louise Webster Prize for early career scientists for his work on extreme scattering events with ATCA.
- Karen Lee-Waddell, who won the 2017 International Union of Radio Science award for Young Scientists
- Adrian Rispler, who was named the 2018 Project Professional of the Year by the Project Management Institute of Australia.
- Founding ATNF Director, Ron Ekers, who was elected a Fellow of the US National Academy of Science.

Indigenous engagement

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

- contracting, employment and training opportunities
- educational support, such as mentoring and visits to the MRO
- acknowledgement of traditional owners in science publications using data from the MRO
- naming rights for MRO infrastructure (for example, each ASKAP antenna has a Wajarri name)
- provision of a satellite network link at the nearby Pia Wadjarri Remote Community
- an indigenous heritage induction for all who work on or visit the MRO
- the opportunity to provide a formal Welcome to Country for VIP guests.

We are investigating opportunities for further engagement with indigenous groups at our other sites.

As part of NAIDOC ((National Aboriginal and Islanders Day Observance Committee) week in 2017, our Wajarri Yamatji Aboriginal

James Hanna and students from the Pia Wadjarri Remote Community School in the workshop at the MRO control building. Image: Rob Hollow.

Liaison Officer, Leonie Boddington, and her fellow language worker, Godfrey Simpson, presented the *Our Languages Matter* workshop at the ATNF in Sydney and at the Australian SKA Office in the Department of Industry, Innovation and Science.

Our indigenous Cadetships offer 12 week's paid work experience for those undertaking a degree as well as covering the cost of completed university subjects and providing a stipend during the academic year. The Traineeship program is for those starting out or looking for a career change. It provides a structured training program that can be applied into the workplace. CSIRO covers the training costs and provides a wage.

ASKAP Project Manager Adrian Rispler is the Project Professional of the Year. Image: Project Management Institute, Australia.

Health, safety and environment

In this reporting period, ATNF staff reported no medical treatment injuries (MTI), 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 (shown below). The LTI was due to a manual handling incident. Beyond the longer reporting period, one reason for the increase in health and safety incidents is CSIRO's introduction in May 2017 of a much simpler online reporting tool.

ATNF health, safety and environment incidents over time.

PERIOD	E INCIDENTS	H&S INCIDENTS	LTI	MTI
Jan–Dec 2012	0	16	4	3
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

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

Education

Postgraduate students

In this reporting period, 35 PhD students and two Masters students were co-supervised by ATNF staff, regaining historical levels (Fig. 9). Macquarie University, Swinburne University of Technology and Western Sydney University remain among the top four sources of students, however the University of Tasmania now leads the list (Fig.10). 11 students were awarded PhDs in this reporting period. Student affiliations and thesis titles are listed in Appendix E and Appendix F.

Undergraduate vacation scholars

The 2017-18 Undergraduate Vacation Scholarship Program had 8 students based in Sydney and 5 in Perth. This was the second year of our collaboration with SKA South Africa and two students joined us. We also had two students from New Zealand.

Each student undertook a research project under the supervision of a member of staff and all visited ATCA in January 2018 where they worked on observing, data reduction and imaging. The program concluded with a symposium in February 2018 where each scholar presented the results of their summer's work.

Summer vacation scholars visit ATCA. Image: Jamie Stevens.

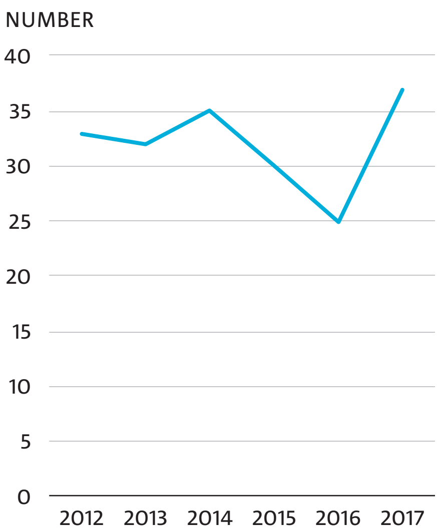


Figure 12: Number of postgraduate students co-supervised by ATNF staff over time.

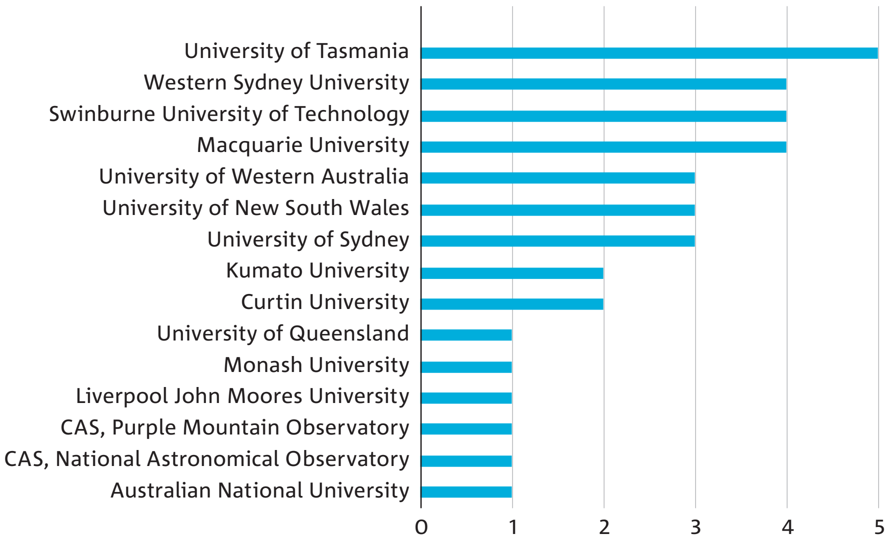


Figure 13: Affiliation of ATNF co-supervised postgraduate students in this reporting period.

Radio school

The 2017 Radio Astronomy School was at ATCA in September and focused on radio interferometry. 50 undergraduate students and 27 local and international experts participated in the hands-on activities, including observing and analysing data. A group of 23 undergraduate students from the University of Sydney's Talented Student Program in Physics joined in for a day on their way to Parkes where they met up with 13 students from Macquarie University.

At the 2017 Radio Astronomy School, undergraduate students gathered at ATCA. This image was taken using a 30 second exposure and participants wielding chemical torches. Image: Aditya Parthasarathi.

Teacher workshops

Our three-day Astronomy from the Ground Up workshop at the Parkes Radio Telescope in April 2017 brought 13 teachers from near and not so far to hear about the latest astronomical research, get involved in hands-on activities and learn how to run a stargazing event at their schools. Some sessions from this workshop were also held at various science teacher conferences and events across Australia and our Lisa Harvey-Smith gave the keynote address at the Astronomy Education Conference in Canberra.

We also partner with ICRAR in Edith Cowan University's Australian Teacher Astronomy Research Program (ATARP). This program teams high school science teachers with professional astronomers to work on a real radio astronomy research project.

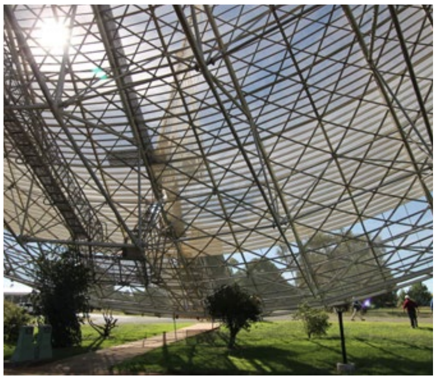
PULSE@Parkes

Our educational program, PULSE@Parkes, continues to keep the team (combinations of Shi Dai, Jimi Green, George Hobbs, Rob Hollow, Charlotte Sobey, Andrew Cameron and John Sarkissian) very busy. During this reporting period, some 220 high school students and 140 teachers, other professionals and members of the public got involved. Highlights of our school sessions included one run in conjunction with the Pawsey Supercomputing Centre in Perth in February 2017 and another at the Victorian Space Science Education Centre in February 2018.

Again PULSE@Parkes went international, this time spending a week in South Africa in August 2017, hosted by SKA South Africa. The team ran very successful observing sessions for 40 undergraduate students at the University of Cape Town, for 26 high school students from Manzomthombo High School and for about 30 staff and graduate students at the SKA offices. While there, the team performed the first simultaneous observation by the Parkes Radio Telescope and South Africa's SKA precursor telescope, MeerKAT.

For teachers attending the STEMX Academy in January 2017, we ran a session at CSIRO Discovery in Canberra. Another dedicated session for teachers was run in July in conjunction with the International Astronautical Congress in Adelaide. In Japan we ran a session as part of the International Astronomical Union (IAU) Communicating Astronomy with the Public conference. We also held demonstration sessions at the Asia-Pacific Region IAU Meeting (APRIM) and at the C3DIS computing conferences in Melbourne.

In mid-2017, PULSE@Parkes was involved in CSIRO's entrepreneurial development scheme ON Prime. The team is now extending the existing program to an undergraduate level training package which will include a 3D virtual model and augmented reality app.


Maree Timms, eLearning Coordinator at Galen Catholic College in Victoria, caught The Dish at an unusual angle during the Astronomy from the Ground Up workshop. Image: Maree Timms.

Astronomy community

The users of ATNF instruments contribute to decision-making through the Australia Telescope User Committee (ATUC, Appendix A). ATUC is a twice-yearly forum for users to discuss current operations, priorities for future developments, and other matters raised by the user community. ATUC makes recommendations to the ATNF Director, most of which are accepted and implemented. Over this reporting period, ATUC met in June and November 2017 and in May 2018. ATUC's reports, and the Director's replies, are at: www.atnf.csiro.au/management/atuc/index.html.

RFI expert Balthasar Indermuehle and partner Aly made science into art at Vivid Sydney in June 2017. Their interactive display *Connections* visualises the RFI from the mobile phones of passer's by. Image: Balthasar Indermuehle.

Meetings, workshops, conferences and colloquia

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

ACES Busy Weeks. The ASKAP Commissioning and Early Science (ACES) team holds week-long workshops, typically twice per year (although this may now increase), where members get together to focus on a particular aspect of ASKAP commissioning, such as data processing or image production.

Astronomical Society of Australia (ASA). We host a Town Hall meeting as part of the annual ASA meetings to give the broader astronomy community an opportunity to provide valuable input. The 2018 meeting featured four special sessions dedicated to science from SKA precursor telescopes and included the largest showcase of ASKAP Early Science to date.

Bolton and Student Symposium. This annual event showcases the science of young astronomers and promotes discussion and collaboration among researchers with different levels of seniority. The December 2017 event ended with the launch of a biography of John Bolton by Australian author Peter Robertson.

C3DIS. Within the May 2018 Collaborative Conference on Computational and Data Intensive Science, co-hosted by CSIRO, was a half day workshop on computing challenges for ASKAP and the SKA.

GPU Hackathon. Organised by the Pawsey Supercomputing Centre, this week-long programming workshop in April 2018 was the first of its kind in Australia. CSIRO's team focused on a GPU-based replacement for the ATCA backend and a corrector suitable for VLBI.

International Astronomical Union, Symposium 337. ATNF pulsar experts were prominent among attendees at this special symposium at Jodrell Bank Observatory in September 2017 which celebrated 50 years of pulsars.

PAF workshop. In November 2017, 60 delegates from 24 institutions gathered in Sydney for the ATNF's annual workshop to showcase the latest development in PAFs for astronomy and their broader application.

SPARCS. July 2017 saw the 7th SKA Pathfinder Radio Continuum Science meeting in Perth. Entitled The Precursors Awaken, it was co-hosted by CSIRO and the International Centre for Radio Astronomy Research (ICRAR) and brought together 50 researchers from around the world who are using the SKA precursors and pathfinders for radio continuum and polarisation science.

SKA big data. April 2017 and 2018 saw the first two Australia-China SKA Big Data Workshops. Co-sponsored by CSIRO and ICRAR, the workshops cover not just software and algorithms, but also advanced global networking and data sharing technologies and methods as we move towards developing the prototype of an integrated SKA regional centre.

Outreach and media

Our communications team achieved great impact for the ATNF throughout this reporting period, commencing in January 2017 with the then Minister for Industry, Innovation and Science announcing commencement of ASKAP Early Science. The next month, ASKAP and the MWA were front page news in the *Australian Financial Review* and the subject of a major feature in *Cosmos* magazine.

We are increasingly taking a joint approach to our media activities. That is, contributing to the media efforts of our university or industry partners: contributing video and stills, providing spokespeople and cross-promoting their efforts through our channels. The stand-out example of the success of this approach domestically was around follow up of the gravitational wave detection. Internationally, it was EDGES' potential discovery of the first stars (see SKA).

We have been extensively involved in two of ABC television's *Stargazing Live* extravaganzas – in April 2017 and May 2018. Beyond providing locations (such as the Parkes radio telescope), Lisa Harvey-Smith was a roving reporter, our staff helped out at public events and many more were members of the 'couch army' answering viewer questions on twitter. With a TV and social media reach into the many millions and ~44 000 people showing up to break the world record for simultaneous observing, this is one of our most successful outreach activities.

Astrofests are key outreach events. The Perth events, in particular, are extremely popular (attracting around 5000 visitors each year), Parkes is growing and events in Sydney are just taking off. We are also part of other science outreach events, such as Perth Science Festival, National Science Week and Pint of Science, and initiatives such as Scientists in Schools and Science Meets Parliament.

Another important aspect of our outreach work is our visitors' centres at the Parkes radio telescope and ATCA (see table). The self-guided facility at ATCA continues to attract a steady stream of visitors, but Parkes attracted the largest number of visitors in quite some time. While tourism within Australia does seem to be up over previous years, the increase may also relate to the rising profile of events such as the Parkes Elvis Festival – which always features activities at The Dish.

Number of visitors to ATCA and the Parkes Radio Telescope.

	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18
Parkes	92 876	84 698	68 427	95 212	83 851	105 085
ATCA	10 500	12 500	10 971	11 511	10 965	12 081

Stargazing Live hosts Brian Cox and Julia Zemiro give us a shout-out. Image: ABC TV.


George Heald, Minh Huynh and Jane Kaczmarek at Science Meets Parliament in 2018. Image: Jane Kaczmarek.

Elvis at the Dish is a popular part of the annual Parkes Elvis Festival. Image: John Sarkissian.

Appendices

ASKAP at dusk.
Image: Kurt Warhurst.

A: Committee membership

The following people served on our three key committees between January 2017 and June 2018.

ATNF Steering Committee

CHAIR

Prof Elaine Sadler, University of Sydney*

AUSTRALIAN ASTRONOMY COMMUNITY

Prof Elaine Sadler, University of Sydney

Prof Matthew Bailes, Swinburne University of Technology

A/Prof Cathryn Trott, Curtin University

INTERNATIONAL ASTRONOMY COMMUNITY

Prof Na Wang, Xinjiang Astronomical Observatory, China (2017)

Prof Xiang-Ping Wu, National Astronomical Observatories of China (2018)

Prof Grazia Umana, Catania Astrophysical Observatory, Italy

Prof John Carlstrom, University of Chicago, USA

AUSTRALIAN STAKEHOLDER COMMUNITIES

Prof Robyn Owens, University of Western Australia

Dr David Skellern, CMCRC Ltd

EX-OFFICIO

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

Mr Brendan Dalton, Chief Information Officer, CSIRO

Prof Warrick Couch, Director, Australian Astronomical Observatory (2017)

Prof Andrew Hopkins, Head of Research & Outreach, Australian Astronomical Observatory (2018)

SECRETARIAT

Nic Svenson, CSIRO

*Prof Elaine Sadler stood down from the ATSC in March 2018 when she accepted a position with CSIRO. The May 2018 meeting was chaired by Dr Skellern.

ATNF User Committee

CHAIR

Dr James Miller-Jones, Curtin University

MEMBERS

Dr Stuart Ryder, Australian Astronomical Observatory

Dr Shari Breen, University of Sydney

Dr Stefan Oslowski, Swinburne University of Technology

Dr Joanne Dawson, Macquarie University/CSIRO

Dr Maria Roja, CSIRO

Dr Stanislav Shabala, University of Tasmania

Dr Vanessa Moss, University of Sydney

Dr Julie Banfield, Australian National University

Dr Willem van Straten, Swinburne University of Technology

Dr Paolo Serra, CSIRO

STUDENT MEMBERS

Ms Shivani Bhandari, Swinburne University of Technology

Mr Tiege McCarthy, University of Tasmania

Mr Daniel Reardon, Monash University

Ms Katherine Lutz, Swinburne University of Technology

SECRETARY

Dr Joane Dawson, CSIRO

Dr Cormac Reynolds, CSIRO

ATNF Time Assignment Committee

CHAIR

Dr Martin Meyer, University of Western Australia (2018)

Prof Sarah Maddison, Swinburne University of Technology (2017)

VOTING MEMBERS

Dr Julia Bryant, Australian Astronomical University/University of Sydney

Dr Ivy Wong, Curtin University

Dr James Allison, University of Sydney

Dr Ryan Shannon, Swinburne University of Technology

Dr Roberto Soria, Curtin University

A/Prof Chris Power, University of Western Australia

Dr Stanislav Shabala, University of Tasmania

Dr Christene Lynch, University of Sydney

Dr Joanne Dawson, Macquarie University/CSIRO

EX-OFFICIO

Dr Douglas Bock, CSIRO

Dr Lisa Harvey-Smith, CSIRO

Dr Phil Edwards, CSIRO

Dr Hayley Bignall, CSIRO (Executive Officer)

ADMINISTRATION

Ms Amanda Gray, CSIRO

B: Financial summary

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

	YEAR TO 30 JUNE 2013	YEAR TO 30 JUNE 2014	YEAR TO 30 JUNE 2015[6]	YEAR TO 30 JUNE 2016	YEAR TO 30 JUNE 2017	YEAR TO 30 JUNE 2018
Revenue						
External	4,213	10,179	13,209	14,377	15,418	14,889
CSIRO[1,2]	35,668	41,803	40,473	42,094	44,631	46,269
Total	**39,881**	**51,982**	**53,682**	**56,471**	**60,049**	**61,158**
Expenditure						
Salaries[3]	16,688	17,723	19,545	21,179	22,784	20,959
Travel	1,432	1,325	1,429	1,981	1,866	1,713
Other operating[4]	5,143	7,157	9,334	8,837	11,708	13,250
Overheads[5]	12,725	14,709	14,506	13,711	13,492	13,316
Depreciation and amortisation	4,628	7,095	7,513	10,101	11,607	12,321
Total	**40,616**	**48,009**	**52,327**	**55,809**	**61,457**	**61,559**
Operating result	**-735**	**3,973**	**1,355**	**662**	**-1,408**	**-401**

1. From the year to June 2015 CSIRO funding has been adjusted to match actual depreciation costs incurred.

2. Covers overheads, depreciation and a proportion of direct (operating) costs – shown below.

	YEAR TO 30 JUNE 2014	YEAR TO 30 JUNE 2015[6]	YEAR TO 30 JUNE 2016	YEAR TO 30 JUNE 2017	YEAR TO 30 JUNE 2018
Direct CSIRO funding	22,323	18,454	18,282	19,533	20,632

3. Increase in 2017 is primarily to cover redundancy provisions.

4. Increase in 2018 is due to CSIRO's $2m contribution to the SKA Regional Centre.

5. Includes support services such as Human Resources, Health, Safety and Environment and Property Services.

6. Figures for 2015 were incorrect in the 2016 Annual Report and have been corrected here.

C: Staff list

ATNF staff by Program as at 30 June 2018. This list includes casual staff, joint appointments and honorary fellows, but not students or contractors.

SYDNEY (NSW)		
Ahmed	Azeem	Project specialist
Allen	Graham	Project specialist
Amy	Shaun	Operations
Bannister	Keith	Technologies
Baquiran	Mia	Technologies
Barker	Steve	Technologies
Bax	Warren	Management
Bekiaris	Georgios	Science
Beresford	Ron	Technologies
Bhandari	Shivani	Technologies
Bock	Douglas	Management
Bourne	Michael	Technologies
Bowen	Mark	Technologies
Broadhurst	Steve	Technologies
Brothers	Michael	Technologies
Brown	Andrew	Technologies
Bunton	John	Technologies
Cameron	Andrew	Science
Carter	Nick	Technologies
Castillo	Santiago	Technologies
Chapman	Jessica	Fellow
Chekkala	Raja	Technologies
Chen	Yuqing	Technologies
Cheng	Wan	Technologies
Chippendale	Aaron	Technologies
Chow	Kate	Project specialist
Chung	Yoon	Technologies
Cooper	Paul	Technologies
Cooper	Adam	Technologies
Cosma	Morgan	Technologies
Craig	Daniel	Operations
Crosby	Philip	Management
Dai	Shi	Science
Dawson	Joanne	Science
D'Costa	Howard	Project specialist
Death	Michael	Technologies
Doherty	Paul	Technologies
Drazenovic	Vicki	Operations
Dunning	Alex	Technologies
Edwards	Philip	Science
Edwards	Leanne	Operations
Ekers	Ron	Fellow
Fedeli	Jordan	Technologies
Ferris	Richard	Fellow
George	Daniel	Technologies
Gough	Russell	Fellow
Gray	Amanda	Operations
Green	Jimi	Science
Guntek	Edward	Operations
Hampson	Grant	Technologies
Hartmann	Carmel	Project specialist
Harvey-Smith	Lisa	Science
Hay	Stuart	Technologies
Hayes	Michael	Project specialist
Hayman	Douglas	Technologies
Hobbs	George	Science
Hollow	Robert	Education
Huynh	Minh	Technologies
Indermuehle	Balthasar	Science
Jeganathan	Kanapathippillai	Technologies
Johnston	Simon	Science
Kachwalla	Elsa	Operations
Kaczmarek	Jane	Science
Kesteven	Michael	Fellow
Kiraly	Dezso	Technologies
Kleiner	Dane	Science
Koribalski	Baerbel	Science
Kosmynin	Arkadi	Operations
Leach	Mark	Fellow
Lee-Waddell	Karen	Science
Lenc	Emil	Science
Lennon	Brett	Operations
Li	Li	Technologies

Lim	Boon	Technologies
Lourenco	Liroy	Technologies
Mackay	Simon	Technologies
Macleod	Adam	Project specialist
Madrid	Juan	Science
Maher	Tony	Operations
Mahony	Elizabeth	Science
Manchester	Richard	Fellow
Marquarding	Malte	Operations
McConnell	David	Science
McIntyre	Vincent	Operations
Mitchell	Daniel	Operations
Ng	Andrew	Project specialist
Norris	Ray	Fellow
Ord	Stephen	Operations
Pearce	Sarah	Management
Phillips	Chris	Science
Pilawa	Mike	Technologies
Pope	Nathan	Operations
Raja	Wasim	Operations
Reilly	Les	Technologies
Reynolds	John	Operations
Rioja	Maria	Science
Rispler	Adrian	Project specialist
Roberts	Paul	Technologies
Roush	Peter	Technologies
Schinckel	Antony	Project specialist
Severs	Sean	Technologies
Shaw	Robert	Technologies
Shields	Matt	Project specialist
Silva	Chaden	Operations
Smart	Ken	Technologies
Smith	Stephanie	Technologies
Storey	Michelle	Management
Svenson	Nic	Management
Tam	Kam	Operations
Tesoriero	Julie	Technologies
Toomey	Lawrence	Science
Troup	Euan	Operations
Tuthill	John	Technologies
Tuthill	Luke	Operations
Tzioumis	Tasso	Technologies
Voronkov	Maxim	Operations
Wark	Robin	Science
Whiting	Matthew	Science
Wieringa	Mark	Operations
Wilson	Carol	Technologies
Wu	Xinyu	Operations
Yorth	Hanna	Management
Young	Annabelle	Project specialist
NARRABRI (NSW)		
Bateman	John	Operations
Cole	James	Operations
Forbes	Kylee	Operations
George	Mike	Operations
Hill	Mike	Operations
Kelly	Pam	Operations
Lee	Kun	Operations
McFee	Jock	Operations
McFee	Margaret	Operations
Mirtschin	Peter	Operations
Rex	Jordan	Operations
Stevens	Jamie	Science
Sunderland	Graeme	Operations
Trindall	Jane	Operations
Wilson	Tim	Operations
Wilson	John	Operations
Wilson	Chris	Operations
PARKES (NSW)		
Abbey	Alex	Operations
Hoyle	Simon	Operations
Hunt	Andrew	Fellow
Kaletsch	Robert	Operations
Lees	Tom	Operations

Lensson	Erik	Fellow
Mader	Stacy	Science
Mason	Hanneke	Operations
Milgate	Lynette	Operations
Palmer	Kyasha	Operations
Preisig	Brett	Operations
Reeves	Ken	Operations
Ruckley	Tim	Operations
Sarkissian	John	Science
Sarkissian	Maggie	Operations
Smith	Mal	Operations
Trim	Tricia	Operations
Unger	Karin	Operations
Wade	Jessica	Operations
PERTH (WA)		
Anderson	Craig	Science
Bastholm	Eric	Operations
Bignall	Hayley	Science
Devereux	Drew	Operations
Ferguson	Kevin	Operations
Galvin	Tim	Science
Gurkan Uygun	Gulay	Science
Guzman	Juan Carlos	Operations
Haskins	Craig	Operations
Heald	George	Science
Hotan	Aidan	Science
Huynh	Minh	Science
Kitaeff	Slava	Operations
Reynolds	Cormac	Science
Riseley	Chris	Science
Sobey	Charlotte	Science
Taylor	Zoe	Operations

GERALDTON & MRO (WA)		
Boddington	Leonie	Operations
Cox	Tom	Operations
Desmond	Rochelle	Operations
Hannah	James	Operations
Harding	Alex	Operations
Hathway	Steve	Operations
Hiscock	Brett	Operations
Jackson	Suzy	Operations
Merry	Clarence	Operations
Merry	Jolene	Operations
McConigley	Ryan	Operations
McIntosh	Savannah	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 from October 2016–March 2018. A small number of target of opportunity observations are not listed. Proposal cover sheets are available through the ATNF proposal application system, OPAL: http://opal.atnf.csiro.au

ATCA

OBSERVERS	PROGRAM	Nº
Stevens, Edwards, Wark, Wieringa	ATCA Calibrators	C007
Staveley-Smith, Cendes, Gaensler, Indebetouw, Matsuura, Ng, Tzioumis, Zanardo	Supernova Remnant 1987A	C015
Corbel, Tzioumis, Kaaret, Tomsick, Orosz, Loh, Fender	Large scale radio/X-ray jets in microquasars	C1199
Lundqvist, Perez-Torres, Kundu, Ryder, Bjornsson, Fransson	NAPA: Probing Type Ia Supernova progenitors with ATCA	C1303
Ryder, Kool, Anderson, Stockdale, Kotak, Amy, Romero-Canizales, Renaud	NAPA Observations of Core-Collapse Supernovae	C1473
Edwards, Stevens, Ojha, Kadler, Lovell, Mueller, Wilms	ATCA monitoring of gamma-ray loud AGN	C1730
Purser, Lumsden, Hoare, Obonoyo	Searching for variability and proper motions towards massive ionised jets	C1862
Voronkov, Goedhart, Maswanganye, Ellingsen, Sobolev, Green, Breen, van der Walt, Parfenov	Understanding periodic flares of the methanol masers	C1929
Agliozzo, Buemi, Leto, Phillips, Pignata, Trigilio, Umana	Diving into the ejecta of the Luminous Blue Variable RMC127	C1973
Dzudzar, Kilborn, Sweet, Meurer, Drinkwater, Bekki	The evolution of gas-rich galaxies in the group environment	C2440
Possenti, Wieringa, Esposito, Burgay, Israel, Rea	NAPA: Continuum radio emission from magnetars in outburst	C2456
Soria, Russell, Blair, Long, Winkler	Thermal and non-thermal radio sources in the spiral galaxy M83	C2494
Miller-Jones, Maria, Migliari	NAPA: The disc wind-jet connection in black hole transients	C2514
Cavallaro, Bufano, Umana, Ingallinera, Trigilio, Buemi, Leto, Norris, Franzen, Marvil, Riggi	Stellar radio emission in the SKA era: the SCORPIO project	C2515
Miller-Jones, Atri, Jonker, Maccarone, Nelemans, Sivakoff, Tzioumis	NAPA: Constraining black hole formation with LBA astrometry	C2538
Russell, Miller-Jones, Sivakoff, Altamirano, Krimm, Soria	NAPA: Jet-disc coupling in black hole X-ray binary outbursts	C2601
Aravena, Apostolowski, Spilker, Aguirre, de Breuck, Bethermin, Bothwell, Carlstrom, Chapman, Crawford, Fassnacht, Gonzalez, Greve, Gullberg, Hezaveh, Litke, Ma, Marrone, Malkan, Murphy, Stark, Strandet, Tothill, Vieira, Weiss	A CO survey of the brightest dusty star-forming galaxies at z=2-6 discovered by the SPT	C2818
Bannister, Walker, Stevens, Johnston, Bignall, Reynolds, Tuntsov, Murphy, Ravi	ATESE: An ATCA survey for Extreme Scattering Events	C2914
Loinard, Menten, Kaminski, Serra, Zapata, Rodriguez	Giant factory caught contaminating the environment	C2930
Kanekar, Nayana, Menten, Carilli	Confirming detections of molecular absorption from a "blind" ATCA absorption survey	C2951
Dickey, Bania, Dawson, Jordan, McClure-Griffiths, Anderson, Armentrout, Balser, Wenger	Southern HII Region Discovery Survey (SHRDS)	C2963
Bannister, Walker, Johnston, Stevens, Bignall, Reynolds, Tuntsov	NAPA: Daily monitoring of ATCA Extreme Scattering Events	C2965
Norris, Manojlovic, Tothill, O'Brien, Basu, Clerc, Collier, Crawford, Delhaize, Filipovic, Galvin, de Horta, Holzapfel, Huynh, Johnston-Hollitt, Marrone, Marvil, McIntyre, Murphy, Reiprich, Salvato, Seymour, Smolcic, Sommer, Spilker, Stark, Vernstrom, Venturi, Vieira, Walsh, Wong	ATLAS-SPT: Extended Cluster Emission in the SPT Deep Field	C2992
Piro, Ricci, Troja, Gendre, Fiore, Piranomonte, Bannister, Wieringa	NAPA: ATCA observations of the new class of ultralong GRBs: a local proxy of popIII explosions?	C3001

OBSERVERS	PROGRAM	Nº
Miller-Jones, Diaz trigo, Migliari, Russell, Rahoui	NAPA: The evolving multi-wavelength spectrum of a transient neutron star X-ray binary	C3010
Emonts, Dannerbauer, Lehnert, Huynh, Allison, Kimball, Seymour, Kodama, Hatch, Mao, Valtchanov, Koyama, Norris, Rottgering, Altieri, Villar-Martin	The Cold Molecular Medium around a high-z massive galaxy: ATCA's new window on the molecular Universe	C3003
Moss, Tingay, Sadler, Allison, Maccagni, Stevens, Edwards, Macquart, Morganti, Oosterloo, Glowacki, Musaeva, Shabala, Callingham, Ekers, Beuchert, Wilms, Kadler	Rocking the cradle: a continuing ATCA/XMM-Newton case study of continuum variability in young radio AGN	C3019
Bhandari, Keane, Bailes, Petroff, Flynn, van Straten, Caleb, Green, Johnston	NAPA: Localisation of Fast Radio Bursts	C3044
Russell, Altamirano, Ceccobello, Markoff, Miller-Jones, Russell, Tetarenko, Sivakoff, Soria	NAPA: The evolving jet properties of transient black hole X-ray binaries	C3057
McClure-Griffiths, Dickey, Liu, Staveley-Smith, Li, Jameson, Stanimirovic, Wong, Bolatto, Mao, Denes, Wolfire, Gaensler, Dawson, Nguyen	Gas Temperature Demography in the Magellanic Clouds	C3086
Uscanga, Gomez, Suarez, Qiao, Walsh, Miranda, Trinidad, Anglada, Boumis	Physics of the ionized gas in extremely young planetary nebulae	C3095
Stanway, Brown, Levan	NAPA: Characterising the Little Known Population of Tidal Disruption Events	C3098
Maddison, Wright, van der Marel, Casassus, van der Plas, van Dishoeck, Pinilla, Walsh, Agnew, Ansdell, Menard, Perez, Marino	Dust traps in transition disks	C3119
Zahorecz, Toth, Denes, Cunningham, Jones, Bagoly, Balazs, Horvath, Doi	Exploring the pattern of the Galactic HI foreground of GRBs with ATCA	C3121
Cazzoli, Emonts, Pereira-Santaella, Koribalski, Arribas, Villar-Martin, Colina, Cerrigone	Weighting the massive neutral phase of the wind of IRAS F11506-3851	C3128
Oteo, Ivison, Dunne, Zhang, Thomson, Clements, Bremer, Manilla-Robles, Dannerbauer, Gonzalez-Nuevo, Riechers	Cold gas in the most luminous, unlensed starburst at $z > 4$	C3131
Huynh, Seymour, Davies, Hopkins, Robotham, Shabala, Norris, Sadler, Kapinska, Wong, Meyer, Banfield, Murphy, Prandoni, Smolcic, Delhaize, Franzen, Godfrey, Chow, Butler, Turner, Galvin, Collier, O'Brien, White, Drouart, Mao, Riseley, Gurkanuygun, Swan, Marvil	GAMA Legacy ATCA Southern Survey (GLASS): A Legacy 4cm Survey of the GAMA G23 Field	C3132
Bogdanov, Miller-Jones, Deller, Hessels, Jaodand	An ATCA survey for transitional millisecond pulsars in unassociated Fermi LAT sources	C3133
Pasetto, O'Sullivan, Callingham	Revealing the true nature of Compact Symmetric Objects. A broadband polarimetry study on a sample of CSOs: the pilot project	C3135
Guzman, Garay, Bronfman, Contreras	The Structure of the Ionized Gas within Hypercompact HII Regions	C3138
Kamble, Hancock, Murphy, Kaplan	Search for a relativistic outflow in SN 2016coi/ASASSN-16fp	C3142
Breen, Walsh, Rowell, Ellingsen, Cunningham, Jones, Burton, Federrath, Contreras, Dawson, Schneider, Voronkov, Ott, De wilt, Green, Barnes, Longmore, Indermuehle, Fuller, Avison, Smith, Bronfman, Novak, Toth, Jordan, Fissel, Jackson, Hyland, McCarthy, Kainulainen, Phillips	Dense Gas Across the Milky Way – The "Full-Strength" MALT45	C3145
McGuire, Carroll, Loomis, Remijan, Blake	Mapping the Distribution of the First Interstellar Chiral Molecule, Propylene Oxide, in Sgr B2	C3147
van Velzen, Miller-Jones, Jonker, Shappee, Arcavi	NAPA: Radio emission from stellar tidal disruption flares	C3148

OBSERVERS	PROGRAM	Nº
Jackson, Barnes, Rathborne, Longmore, Contreras, Sanhueza, Hogge, Stephens, Whitaker, Walker, Breen, Smith, Krumholz, Kruijssen, Walsh, Caselli, Jordan, Cunningham, Dawson, Ott	A Comprehensive ATCA Census of High-Mass Cores	C3152
Heywood, Jarvis, Murphy, Smirnov, Whittam	Deep spectral-continuum studies of star formation at high-z	C3156
Popping, de Blok, Chanapote, Dodson, Heald, Gannon, Kaczmarek, Koribalski, Lee-Waddell, Lopez-Sanchez, Spitler, Madrid, Moss, Meyer, Obreschkow, Pisano, Power, Rhee, Robotham, Sardone, Staveley-Smith, Vinsen, Wang, Westmeier, Wicenec, Anderson, Wolf, Wu, Kleiner	Imaging Galaxies Intergalactic and Nearby Environment	C3157
Kilborn, Lutz, Denes, Glazebrook, Obreschkow	What governs the neutral hydrogen content of spiral galaxies?	C3161
Miller-Jones, van Velzen, Jonker, Leloudas	ASASSN-15lh: late-time jets from a tidal disruption event?	C3163
McCarthy, Ellingsen, Voronkov, Chen	Investigating nuclear starbursts through methanol emission	C3167
Kong, Hui	Millimetre Observations of Two Magnetars	C3169
Strader, Miller-Jones, Heinke, Chomiuk, Li	Sleuthing A New Eclipsing Accreting Millisecond Pulsar	C3170
Galvin, Seymour, Norris, Marvil, Filipovic, Tothill, Heywood, Bell, Huynh, Stevens, Murphy, Jarrett, Banfield, Crawford, Collier, O'Brien, Manojlovic, Grieve	Exploring the High Redshift Universe at High Frequency	C3171
Hatsukade, Tominaga, Hayashi, Konishi, Morokuma, Morokuma, Motogi, Niinuma, Tamura	Probing Obscured Star Formation in the Host Galaxies of Superluminous Supernovae	C3174
Gomez, Alberdi, Amado, Anglada, Anglada-Escude, Berdias, Gomez, Lopez-Gonzalez, Morales, Ortiz, Osorio, Perez-Torres, Rodriguez, Rodriguez-Lopez	Searching for star-planet interaction in the radio emission from Proxima Centauri	C3180
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, Simpson, Swinbank, Thomson, Valtchanov, Wardlow	COALAS: CO ATCA Legacy Archive of Star-Forming Galaxies	C3181
Oteo, Ivison, Manilla-Robles, Thomson, Clements, Bremer, Dannerbauer, Gonzalez-Nuevo, Riechers	Looking for the most luminous starbursts at z~7	C3183
Degenaar, Tudor, Miller-Jones, van den Eijnden, Wijnands, Sivakoff	The accretion-jet connection for neutron stars	C3184
Oteo, Ivison, Dunne, Zhang, Thomson, Clements, Bremer, Dannerbauer, Riechers, van der Werf, Serjeant	Cold gas in the most luminous, unlensed starburst at z > 4	C3185
Akahori, Kitayama, Izumi, Ueda, Takakuwa, Ota, Takizawa, Tsutsumi, Yoshikawa, Kohno, Kawabe	High Resolution 15 mm Observation of the Phoenix Galaxy Cluster	C3190
Emonts, Prochaska, Decarli, Cantalupo	Search for cold gas in a Cosmic Web filament around a high-z quasar	C3192
Di Teodoro, McClure-Griffiths, Lockman	Morpho-kinematics of HI clouds in a hot wind	C3195
Ng, Dodson, Shannon	High-Resolution Radio Survey of Pulsar Wind Tori	C3196
Anderson, Heald	Probing conditions in AGN jets on parsec scales using time-resolved spectropolarimetry	C3197
Riseley, Johnston-Hollitt, Duchesne, Zheng, Heald	A new double-relic system in the high redshift cluster MACS J0025.4-1222	C3198
Huber, Quintana, Barclay, Lynch, Villadsen	Simultaneous Observations of Wolf 359 at Optical and Radio Wavelengths	C3199

OBSERVERS	PROGRAM	Nº
Kaczmarek, Wilcots	Faraday Rotation Observations Mapping Group Evolution	C3201
Benson, Stacy, Benner, Edwards, Boyce, Kruzins, Stevens, Phillips, Lazio	Radar Observations of Near Earth Object Florence	C3202
Oteo, Ivison, Dunne, Manilla-Robles, Maddox, Greenslade	The evolution of (by far) the most extreme proto-cluster in the early Universe	C3208
Bannister, Bignall, Reynolds, Stevens, Tuntsov, Walker	Confirming the association of hot stars with intra-day variability with Spica and PKS B1322-110	C3210
Shannon, Bannister, Macquart, Bhandari, Deller, Dodson, Flynn, James, Oslowski, Prochaska, Tejos	NAPA: Radio continuum emission from ASKAP-localised Fast Radio Bursts	C3211
Trigilio, Umana, Leto, Buemi, Cavallaro, Bufano, Riggi, Schillir	Radio Aurorae: Is Trappist-1 a stellar analogue of Jupiter-satellites system?	C3212
Fraga-Encinas, Stevens, Dodson, Zhao, Rioja, Jung, Sohn, Cho, Mueller, Agudo, Brinkerink, Falcke, Issaoun, Janssen, Krichbaum, Marti-Vidal, Roelofs, Ros	Constraining the size of Sagittarius A* with ATCA+KVN observations at 86 GHz	C3213
Bannister, Bignall, Stevens, Tuntsov, Walker, Reynolds	ATIHV: a wideband survey for intra-hour scintillations associated with hot stars	C3214
Massardi, de Zotti, Burkutean, Bonato, Enia, Negrello, Mancuso, Lapi, Vignali, Gilli, Danese	Characterizing the radio emission of lensed dusty star forming galaxies.	C3215
Burkutean, Massardi, Galluzzi, Paladino	Untangling SZ signal and point source contamination in the most massive galaxy cluster above redshift 1	C3217
Plotkin, Miller-Jones, Gallo, Jonker, Russell, Homan, Tomsick, Kaaret	NAPA: The Disk/Jet Connection for Hard State Black Holes	C3219
Galvin, Seymour, Heald, Norris, Marvil, Murphy, Filipovic, Banfield, Huynh, Tothill, Jarrett, O'Brien, Crawford	Unraveling the far infrared to radio correlation	C3221
Riechers, Leung, Perez-Fournon, Ivison, Oteo, Cooray, Clements, Oliver, Weiss, Scott, Farrah	Rise of the Titans: Total Molecular Gas Mass of a Binary Hyper-Luminous Starburst at z~6	C3226
Sano, Yamane, Yoshiike, Fukui, Filipovic, Grieve, Roper	Revealing the Shock-Interacting HI kinematics toward the Magellanic SNR N132D	C3229

Parkes radio telescope

OBSERVERS	PROGRAM	Nº
Burgay, Possenti, Manchester, Kramer, Lyne, McLaughlin, D'Amico, Camilo, Stairs, Lorimer, Yuen, Ferdman	Timing & geodetic precession in the double pulsar	P455
Hobbs, Manchester, Sarkissian, Bailes, Bhat, Keith, Coles, van Straten, Ravi, Oslowski, Kerr, Shannon, Wang, Levin, Wen, Zhu, Dai, Burke, Reardon, Zhang	A millisecond pulsar timing array	P456
Dai, Possenti, Manchester, Johnston, Hobbs, Weltevrede, Kerr, Shannon, Ilie, Sobey	Young Pulsar Timing: Probing the Physics of Pulsars and Neutron Stars	P574
Hobbs, Green, Hollow, Bannister, Shannon, Dai, Ravi, Kerr, Petroff	PULSE@Parkes (Pulsar Student Exploration online at Parkes)	P595
Hobbs, Manchester, Green, Johnston, Sarkissian, Reynolds, Bailes, Keith, van Straten, Kerr, Jameson, Shannon, Dai	Instrumental calibration for pulsar observing at Parkes	P737
Lorimer, Crawford, Ridley	Millisecond Pulsar Timing and High Time Resolution Survey Observations of the Large Magellanic Cloud	P743
Spiewak, Possenti, Manchester, Johnston, Kramer, Hobbs, Burgay, Freire, Camilo, Stairs, Bailes, Ransom, Keith, Burke-Spolaor, Eatough, Lorimer, van Straten, Stappers, Ray, Keane, Levin, Kerr, Champion, Ng, Ferdman, Barr, Jankowski, Morello, Cromartie, Wex	Timing of Binary & Millisecond Pulsars Discovered at Parkes	P789

OBSERVERS	PROGRAM	Nº
Camilo, Ransom, Ray, Kerr, Ferrara	Millisecond pulsar searches in unidentified Fermi sources at high Galactic latitudes	P814
Shannon, Hobbs, Ravi	A Parkes transit survey for pulsed radio emission during windstows and maintenance	P855
Cameron, Possenti, Johnston, Kramer, Burgay, Bailes, Bhat, van Straten, Stappers, Keane, Champion, Jameson, Ng, Petroff, Barr, Flynn, Caleb, Bhandari	Initial Follow-up of Pulsar Discoveries from the HTRU Galactic Plane Survey	P860
Hobbs, Johnston, Hollow, Ravi, Kerr, Shannon, Wang, Dai, Ward, Yuen	Analysis of state switching pulsars	P863
Petroff, Possenti, Johnston, Kramer, Bailes, Burke-Spolaor, van Straten, Stappers, Keane, Champion, Jameson, Ng, Barr, Flynn, Caleb	A follow-up campaign for fast radio bursts	P871
Possenti, Burgay, Belloni, Pellizzoni, de Martino, Papitto	Investigating the "transitional" binary pulsar XSS J12270-4859	P880
Camilo, Johnston, Sarkissian, Reynolds, Scholz	Understanding the Remarkable Behaviour of Radio Magnetars	P885
Keane, Possenti, Green, Johnston, Kramer, Burgay, Bailes, Bhat, Burke-Spolaor, Eatough, van Straten, Stappers, Levin, Jameson, Ng, Tiburzi, Petroff, Barr, Flynn, Jankowski, Caleb, Morello, Bhandari, Krishnan	SUPERBx – The SUrvey for Pulsars & Extragalactic Radio Bursts Extension	P892
Hobbs, Manchester, Sarkissian, Bailes, Bhat, Keith, Coles, Toomey, Russell, You, Ravi, Oslowski, Kerr, Dempsey, Shannon, Wang, Levin, Wen, Zhu, Dai, Lasky, Burke, Reardon, Zhang, Rosado, Spiewak, van Straten	Where are the gravitational waves?	P895
Kerr, Johnston, Hobbs, Shannon	Planets, Plasma, or Precession? Searching for Pulse Profile Variation in Modulated Pulsars	P897
Camilo , Reynolds, Ransom, Halpern, Ray, Kerr	Timing PSR J1417-4402: Observing the Late Phase of Millisecond Pulsar Recyling	P898
Bell, Murphy, Macquart, Johnston, Hobbs, Ekers, Chhetri, Morgan, Flynn, Dobie, Kaplan, Hughes	Searching for pulsars using Murchison Widefield Array imaging techniques	P914
McSweeney , Ord, Bhat, Deshpande, Tremblay	Chasing pulsar emission mechanism via sub-pulse drifting	P920
Camilo, Ray, Frail	Pulsar candidates toward Fermi unassociated sources	P930
van Loon, Green, Al-Sadooni	Unveiling the ionized gas in edge-on disc galaxies	P931
Petroff, Johnston, Burke-Spolaor, Stappers, Keane, Jameson, Tiburzi, Bhandari	A Closer Look at Rotating Radio Transients	P932
Corongiu, Possenti, Burgay, de Luca, Mignani, Salvetti	A search of radio pulsations from the candidate redback 3FGL J0744.1-2523	P933
Shannon, Hobbs, Coles, Ravi, Kerr, Reardon	The structure and magnetization of the high-latitude interstellar medium	P934
Green, Dawson, Mader, Breen, Robishaw	Dark Magnetic Fields	P935
Zhang , Hobbs, Li, Pan, Wang, Wang	A Parkes Pilot Confirmation Study of Parkes Multibeam Pulsar Candidates	P936
Wang, Chang, Lin, Chan, Kwok	Detecting radio signals of dark matter annihilation	P937
Ravi, Kulkarni, Shannon	The blind leading the blind: setting the FRB distance scale	P938
Daniel John Reardon , George Hobbs, William Coles, Matthew Kerr, Ryan Shannon	The Scintillating Pulsar J1603-7202	P939
Papitto, Possenti, Burgay, Corongiu, Stella, Rea, Bozzo, Ferrigno, Sanna, Di Salvo, Burderi, Iaria	Catching the rebirth of a millisecond pulsar in NGC2808 after an X-ray bright accretion event	P941

OBSERVERS	PROGRAM	Nº
Dai, Johnston, Hobbs	Searching for giant pulses from pulsars in the Large Magellanic Cloud	P942
Bhattacharyya, Keith, Weltevrede, Stappers, Ray, Johnson, Ilie, Cooper, Malenta, Roy	Profile, spectra and polarisation study of four newly discovered GHRSS pulsars	P943
van Jaarsveld, Filipovic, Kramer, Stappers, Joseph, McBride, Buckley	Characterising young radio pulsars located in new SMC SNR candidates	P944
Possenti, Burgay, Mereghetti, Ducci	Catching the first transitional pulsar in an early-type binary system	P945
Pisano, Staveley-Smith, Meyer, Popping, de Blok, Moss, Lopez-Sanchez, Kleiner, Heald, Rhee, Sardone	Mapping the Extended HI Environment of IMAGINE Galaxies	P951
Moss, McClure-Griffiths	The hidden iceberg structure of the halo with Parkes	P953
Kerr, Hobbs, Ransom, Lommen, Ray, Shannon, Dai, Deneva	Over the X-ray-nbow: clearing up the effects of interstellar weather on pulsar timing with NICER and Parkes	P957
Shannon, Macquart, Dodson, Deller, James, Bannister, Oslowski, Flynn, Bhandari	Searching for repetition from ASKAP fast radio bursts	P958
Mader, Green, Sarkissian	Receiver characterisation	P960

LBA

OBSERVERS	PROGRAM	Nº
Ojha, Kadler, Edwards, Lovell, Tingay, Angioni, Beuchert, Blanchard, Booth, Carpenter, Buson, Dutkad, Eber, Fey, Graefe, Hase, Hekalo, Horiuchi, James, Jauncey, Johnston, Kappes, Katz, Krauss, Kreikenbohm, Kreter, Langejahn, Lister, McEnery, Muller, Nesci, Pappert, Phillips, Plotz, Pursimo, Quick, Reynolds, Rosch, Schulz, Ros, Taylor, Thompson, Tosti, Tzioumis, Wilms, Zensus	Physics of gamma ray emitting AGN	V252
Hyland, Ellingsen, Reid, Krishnan, Zhang, Green, Honma, Dawson, Zheng, Menten, Fujisawa, Phillips, Goedhart, Xu, Breen, Voronkov, Dodson, Shen, Walsh, Brunthaler, Chen, Rioja, Sakai, Chibueze, Sanna	Astrometric observation of methanol masers: determining galactic structure and investigating high-mass star formation	V255
Loinard, Deller, Forbrich	The distance to the Coronet Cluster in Corona Australis	V329
Miller-Jones, Tzioumis, Maccarone, Jonker, Nelemans, Sivakoff	Constraining black hole formation with LBA astrometry	V447
Marcote, Edwards, Stevens, Ribo, Paredes	On the origin of the gamma-ray binary 1FGL J1018.6-5856	V454
Russell, Altamirano, Miller-Jones, Soria, Sivakoff, Krimm	Jet-disc coupling in black hole X-ray binary outbursts	V456
Baan, Alakoz, An, Ellingsen, Henkel, Imai, McCallum, Moran, Sobolev	Extragalactic megamasers at highest resolution	V477
Miller-Jones, Dodson, Johnston, Deller, Dubus, Moldon, Ribo, Paredes, Shannon, Tomsick	Mapping the orbit of PSR B1259-63 with LBA astrometry	V486
Ellingsen, Lovell, Phillips, Breen, Voronkov	Methanol towards PKS B1830-211: testing cosmological variations in fundamental constants	V492
Gomez, Lobanov, Bruni, Kovalev, Anderson, Fuentes, Vega-Garcia, Casadio, Marscher, Jorstad, Bach, Savolainen, Krichbaum, Lu, Ros, Zensus, Edwards, Phillips, Stevens, McCallum, Molina, Agudo, Marti, Perucho, Hada, Lee	Probing the innermost regions of AGN jets and their magnetic fields	V513
Titov, Lovell, Plank, Edwards, Reynolds, Reynolds, Jauncey, Tzioumis, Dickey, Shabala, McCallum, Gulyaev, Natusch, de Witt, Horiuchi, Watson, Shu	Improving the terrestrial and celestial reference frame through southern hemisphere geodetic VLBI observations	V515
de Witt, Quick, Bertarini, Bourda, Charlot	Southern hemisphere observations towards the accurate alignment of the VLBI frame and the future Gaia frame	V518

OBSERVERS	PROGRAM	Nº
de Witt, McCallum, Phillips, Quick, Bertarini, Horiuchi, Jacobs, Jung	Completing the K-band CRF in the southern hemisphere-2	V521
Burns, Dodson, Ellingsen, Sugiyama, Imai, Honma, Krishnan, Sakai, Orosz, Handa, Omodaka	6.7 GHz maser parallax of a particularly interesting high mass star forming region	V525
Zaw, Greenhill, Dopita, Burtscher, Lopez-Gonzaga	Geometry of an AGN on parsec scales: NGC 5506	V533
Gurvits, Frey, Lobanov, Beskin, Yang, Paragi, Nokhrina, Sokolovsky, Edwards, Horiuchi, Murata, Kondo, Sekido, Xia, Cui	Second-epoch SVLBI visit into core-jet labs in the distant Universe (continued)	V540
Orosz, Gomez, Tafoya, Suarez, Imai	Astrometric measurements of the first water fountain planetary nebula	V544
Krishnan, Ellingsen, Breen, Hyland, Moscadelli	3D kinematics in G339.884-1.259 at 10 to 1000 AU scales	V547
Marsh, Paragi, Stanway, Blanchard, Marcote	A unique radio emitting white dwarf binary	V548
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	Measuring the distance to the Chamaeleon star-forming region	V553
Duev, Cimo, Gurvits, Pogrebenko, Molera, Tatiana, Bahamon	Calibrating phase-referencing VLBI for planetary missions	V554
Savolainen, Asada, Hada, Lobanov, Tchekhovskoy, Edwards, Reynolds	Proper motion of the newly discovered helical filaments in the M87 pc-scale jet	V555
Gurvits, Edwards, Frey, Gabanyi, Kovalev, Lobanov, Perger, Sokolovsky, Voitsik, Yang	Brightest objects in the distant Universe	V556
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
Azulay, Guirado, Reynolds, Jauncey, Marti-Vidal, Marcaide, Lestrade	Search for radio emission of the ultracool dwarf AB Dor C	V559
Petrov, Shu, de Witt, Horiuchi, Lovell, Edwards, Phillips, Gulyaev, Natusch, Weston, Sadler	Revealing milliarcsecond optical structure through VLBI observations of Gaia detected AGNs	V561
Zaw, Greenhill, Burtscher	Resolving AGN obscuration: Circinus	V562
Deane, Lazio	The binary supermassive black hole candidate in NGC 5419	V566
Ghirlanda, Giroletti, Salafia, Ghisellini, Paragi, Agudo, Bacon, Bernardini, Beswick, Branchesi, Campana, Casadio, Chassande-Mottin, Colpi, Covino, Davanzo, D'Elia, Frey, Jonker, Kettenis, Marcote, Melandri, Moldon, Nava, Perego, Salvaterra, Szomoru, Tagliaferri, An, van Langevelde, Vergani	Do binary neutron star mergers always produce a jet?	V567
Baczko	Resolving the jet-collimation region of the NGC1052 twin-jet system	GB079

CDSCC

OBSERVERS	PROGRAM	Nº
Orosz, Gomez, Horiuchi, Imai.	Monitoring of H2O masers in all known water fountains.	T215
Goldman, Gomez, van Loon, Breen, Imai.	Searching for circumstellar masers in the Small Magellanic Cloud.	T216

E: Postgraduate students

Postgraduate students co-supervised by ATNF staff as of 30 June 2018 (PhD, unless marked otherwise).

NAME	UNIVERSITY	PROJECT TITLE
Wayne Arcus	Curtin University	Fast radio bursts as cosmic probes
Shaila Akhter	University of New South Wales	Turbulence in the interstellar medium and its relationship to massive star formation
Ashley Barnes	Liverpool John Moores University	The role of cloud-scale gas properties on the process of stellar mass assembly
Shivani Bhandari	Swinburne University of Technology	Transient searches with ASKAP
Tui Britton	Macquarie University	Methanol masers in star forming regions
Andrew Butler	University of Western Australia	Measuring AGN feedback: black hole kinetic luminosity outputs in the HERG and LERG paradigm
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
Timothy Galvin	Western Sydney University	Radio emission from star forming galaxies at high- and low-z
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
Kieran Luken (MSc)	University of Western Sydney	Applying machine learning techniques to estimate the redshift of galaxies
Perica Manojlovic	Western Sydney University	Origin of the diffuse emission of galaxy clusters in the SPT field
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

NAME	UNIVERSITY	PROJECT TITLE
Van-Hiep Nguyen	Macquarie University	Shining light on the dark Milky Way: probing our Galaxy's hidden gas
Karlie Noon (MSc)	Australian National University	3-D velocity vectors of high velocity clouds
Andrew O'Brien	Western Sydney University	ATCA-SPT: A survey of 100 square degrees of the southern sky
Chikaedu Ogbodo	Macquarie University	Mapping the galactic magnetic field with masers
Aditya Parthasarathy Madapusi	Swinburne University of Technology	High precision pulsar timing in the SKA era
Harry Qiu	University of Sydney	Exploring the dynamic radio sky with ASKAP
Daniel Reardon	Monash University	Bayesian analysis of pulsar timing array data to study noise properties of pulsars
Tristan Reynolds	University of Western Australia	Studying the environmental dependence on HI in galaxy groups with WALLABY
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
Jesse Swan	University of Tasmania	The evolution of star formation and black hole activity across cosmic time
Stuart Weston	Auckland University of Technology	Data mining for statistical analysis of the faint radio sky: the pathway to EMU
Naoyuki Yonemaru	Kumato University	Simulation of gravitational wave signals from cosmic strings and the effects of the interstellar medium
Lei Zhang	National Astronomical Observatory, Chinese Academy of Science (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

F: PhD theses

Theses awarded to PhD students co-supervised by ATNF staff.

NAME	UNIVERSITY	MONTH AWARDED	THESIS TITLE
Shivani Bhandari	Swinburne University of Technology	May 2018	A study of slow and fast radio transients
Joseph Callingham	University of Sydney	January 2017	The extragalactic sky at low radio frequencies
Francesco Cavallaro	University of Catania	February 2017	Stellar radio emission in the SKA era surveys of the galactic plane
Timothy Galvin	Western Sydney University	January 2018	The radio continuum emission of star forming galaxies at low to high redshift
Marcin Glowacki	University of Sydney	December 2017	Atomic hydrogen in the distant Universe with the Australian SKA Pathfinder
Claire-Elise Green	University of New South Wales	November 2017	The relationships between filamentary structures, star formation and magnetic fields in Vela C
Katharina Lutz	Swinburne University of Technology	July 2017	The HIX galaxy survey – How HI eXtreme galaxies maintain their HI reservoir
Andrew O'Brien	Western Sydney University	February 2018	ATCA-SPT: A survey of 100 square degrees of the southern sky
Daniel Reardon	Monash University	June 2018	Precision radio-frequency pulsar timing and interstellar scintillometry
Jesse Swan	University of Tasmania	June 2018	Multi-frequency matching, classification, and cosmic evolution of radio galaxy populations
Ross Turner	University of Tasmania	June 2017	Dynamics and synchrotron emission from radio-loud AGN

G: Publications

This section lists papers citing data from, or related to, ATNF telescopes, and other staff papers, from the calendar year 2017.

Journal publications

*Abbott, B.P.; Abbott, R.; Abbott, T.D.; Abernathy, M.R.; Acernese, F.; Ackley, K.; Adams, C.; Adams, T.; Addesso, P.; Adhikari, R.X.; and 996 coauthors. “First search for gravitational waves from known pulsars with advanced LIGO”. ApJ, 839, 12 (O)

*Abbott, B.P.; Abbott, R.; Abbott, T.D.; Acernese, F.; Ackley, K.; Adams, C.; Adams, T.; Addesso, P.; Adhikari, R.X.; Adya, V.B.; and 3667 coauthors. “Multi-messenger observations of a binary neutron star merger”. ApJ, 848, 12 (C, A)

*Accurso, G.; Saintonge, A.; Catinella, B.; Cortese, L.; Davé, R.; Dunsheath, S.H.; Genzel, R.; Gracia-Carpio, J.; Heckman, T.M.; and 10 coauthors. “Deriving a multivariate alphaCO conversion function using the [C II]/CO (1-0) ratio and its application to molecular gas scaling relations”. MNRAS, 470, 4750-4766 (O)

*Adebahr, B.; Krause, M.; Klein, U.; Heald, G.; Dettmar, R.-J. “M 82 - A radio continuum and polarisation study. II. Polarisation and rotation measures”. A&A, 608, 29 (O)

*Agliozzo, C.; Nikutta, R.; Pignata, G.; Phillips, N.M.; Ingallinera, A.; Buemi, C.; Umana, G.; Leto, P.; Trigilio, C.; Noriega-Crespo, A.; and 3 coauthors. “New ATCA, ALMA and VISIR observations of the candidate LBV SK -67 266 (S61): the nebular mass from modelling 3D density distributions”. MNRAS, 466, 213-227 (C)

Agliozzo, C.; Trigilio, C.; Pignata, G.; Phillips, N.M.; Nikutta, R.; Leto, P.; Umana, G.; Ingallinera, A.; Buemi, C.; Bauer, F.E.; and 5 coauthors. “The luminous blue variable RMC 127 as seen with ALMA and ATCA”. ApJ, 841, 130 (C)

*Alexander, K.D.; Wieringa, M.H.; Berger, E.; Saxton, R.D.; Komossa, S. “Radio observations of the tidal disruption event XMMSL1 J0740-85”. ApJ, 837, 153 (C)

*Allison, J.R.; Moss, V.A.; Macquart, J.-P.; Curran, S.J.; Duchesne, S.W.; Mahony, E.K.; Sadler, E.M.; Whiting, M.T.; Bannister, K.W.; Chippendale, A.P.; and 8 coauthors. “Illuminating the past 8 billion years of cold gas towards two gravitationally lensed quasars”. MNRAS, 465, 4450-4467 (A)

*Andreoni, I.; Ackley, K.; Cooke, J.; Acharyya, A.; Allison, J.R.; Anderson, G.E.; Ashley, M.C.B.; Baade, D.; Bailes, M.; Bannister, K.; and 115 coauthors. “Follow up of GW170817 and its electromagnetic counterpart by Australian-led observing programmes”. PASA, 34, 69 (C,P,A)

*Ao, Y.; Matsuda, Y.; Henkel, C.; Iono, D.; Alexander, D.M.; Chapman, S.C.; Geach, J.; Hatsukade, B.; Hayes, M.; Hine, N.K.; and 15 coauthors. “Deep submillimeter and radio observations in the SSA22 Field. I. Powering sources and the Lyalpha escape fraction of Lyalpha blobs”. ApJ, 850, 178 (O)

*Archibald, R. F.; Burgay, M.; Lyutikov, M.; Kaspi, V. M.; Esposito, P.; Israel, G.; Kerr, M.; Possenti, A.; Rea, N.; Sarkissian, J.; and 2 coauthors. “Magnetar-like x-ray bursts suppress pulsar radio emission”. ApJ, 849, 20 (P)

Asahina, Y.; Kawashima, T.; Furukawa, N.; Enokiya, R.; Yamamoto, H.; Fukui, Y.; Matsumoto, R. “Magnetohydrodynamic simulations of the formation of molecular clouds toward the Stellar Cluster Westerlund 2: Interaction of a jet with a clumpy interstellar medium”. ApJ, 836, 213 (M)

*Ashley, T.; Simpson, C.E.; Elmegreen, B.G.; Johnson, M.; Pokhrel, N.R. “The HI chronicles of LITTLE THINGS BCDs. III. Gas clouds in and around Mrk 178, VII Zw 403, and NGC 3738”. AJ, 153, 132 (O)

*Azulay, R.; Guirado, J.C.; Marcaide, J.M.; Martí-Vidal, I.; Ros, E.; Tognelli, E.; Jauncey, D.L.; Lestrade, J.-F.; Reynolds, J.E. “The AB Doradus system revisited: The dynamical mass of AB Dor A/C”. A&A, 607, A10 (V)

Bahramian, A.; Heinke, C.O.; Tudor, V.; Miller-Jones, J.C.A.; Bogdanov, S.; Maccarone, T.J.; Knigge, C.; Sivakoff, G.R.; Chomiuk, L.; Strader, J.; and 2 coauthors. “The ultracompact nature of the black hole candidate X-ray binary 47 Tuc X9”. MNRAS, 467, 2199-2216 (C)

*Bailes, M.; Jameson, A.; Flynn, C.; Bateman, T.; Barr, E.D.; Bhandari, S.; Bunton, J.D.; Caleb, M.; Campbell-Wilson, D.; Farah, W.; and 13 coauthors. “The UTMOST: A hybrid digital signal processor transforms the Molonglo Observatory Synthesis Telescope”. PASA, 34, 45 (O)

*Bannister, K.W.; Shannon, R.M.; Macquart, J.-P.; Flynn, C.; Edwards, P.G.; O’Neill, M.; Oslowski, S.; Bailes, M.; Zackay, B.; Clarke, N.; and 46 coauthors. “The detection of an extremely bright fast radio burst in a Phased Array Feed survey”. ApJ, 841, 12 (A)

*Barger, K.A.; Madsen, G. .; Fox, A.J.; Wakker, B.P.; Bland-Hawthorn, J.; Nidever, D.; Haffner, L.M.; Antwi-Danso, J.; Hernandez, M.; Lehner, N.; and 3 coauthors. “Revealing the ionization properties of the Magellanic Stream using optical emission”. ApJ, 851, 110 (O)

*Benson, C.; Reynolds, J.; Stacy, N.J.S.; Benner, L.A.M.; Edwards, P.G.; Baines, G.; Boyce, R.; Giogini, J.D.; Jao, J.S.; Martinez, G. and 9 coauthors. “First detection of two near-earth asteroids with a Southern Hemisphere planetary radar system”. Radio Sci., 52, 1344-1351 (T,C,P)

*Bloom, J.V.; Croom, S.M.; Bryant, J.J.; Callingham, J.R.; Schaefer, A.L.; Cortese, L.; Hopkins, A.M.; D’Eugenio, F.; Scott, N.; Glazebrook, K.; and 15 coauthors. “The SAMI Galaxy Survey: the low-redshift stellar mass Tully-Fisher relation”. MNRAS, 472, 1809-1824 (O)

*Bonafede, A.; Cassano, R.; Bruggen, M.; Ogrean, G.A.; Riseley, C.J.; Cuciti, V.; de Gasperin, F.; Golovich, N.; Kale, R.; Venturi, T. and 3 coauthors. “On the absence of radio haloes in clusters with double relics”. MNRAS, 470, 3465-3475 (O)

*Brown, C.; Jordan, C.; Dickey, J.M.; Anderson, L.D.; Armentrout, W.P.; Balser, D.S.; Bania, T.M.; Dawson, J.R.; McClure-Griffiths, N.M.; Wenger, T.V. “The Southern H II Region Discovery Survey (SHRDS): Pilot survey”. AJ, 154, 23 (C)

*Brown, S.; Vernstrom, T.; Carretti, E.; Dolag, K.; Gaensler, B.M.; Staveley-Smith, L.; Bernardi, G.; Haverkorn, M.; Kesteven, M.; Poppi, S. “Limiting magnetic fields in the cosmic web with diffuse radio emission”. MNRAS, 468, 4246-4253 (P)

*Buemi, C.S.; Trigilio, C.; Leto, P.; Umana, G.; Ingallinera, A.; Cavallaro, F.; Cerrigone, L.; Agliozzo, C.; Bufano, F.; Riggi, S.; and 2 coauthors. “Exploring the multifaceted circumstellar environment of the luminous blue variable HR Carinae”. MNRAS, 465, 4147-4158 (C)

*Calistro Rivera, G.; Williams, W.L.; Hardcastle, M.J.; Duncan, K.; Röttgering, H.J.A.; Best, P.N.; Brüggen, M.; Chyzy, K.T.; Conselice, C.J.; de Gasperin, F.; and 13 coauthors. “The LOFAR window on star-forming galaxies and AGNs - curved radio SEDs and IR-radio correlation at $0<z<2.5$”. MNRAS, 469, 3468-3488 (O)

Legend
* Authors include ATNF staff
A – ASKAP
C – ATCA
M – Mopra
O – Other staff paper
P – Parkes
S – SKA
T – Tidbinbilla (CDSCC)
V – VLBI

*Callingham, J.R.; Ekers, R.D.; Gaensler, B.M.; Line, J.L.B.; Hurley-Walker, N.; Sadler, E.M.; Tingay, S.J.; Hancock, P.J.; Bell, M.E.; Dwarakanath, K.S.; and 14 coauthors. "Extragalactic peaked-spectrum radio sources at low frequencies". ApJ, 836, 174 (O)

*Ching, J.H.Y.; Sadler, E.M.; Croom, S.M.; Johnston, H.M.; Pracy, M.B.; Couch, W.J.; Hopkins, A.M.; Jurek, R.J.; Pimbblet, K.A. "The Large Area Radio Galaxy Evolution Spectroscopic Survey (LARGESS): survey design, data catalogue and GAMA/WiggleZ spectroscopy". MNRAS, 464, 1306-1332 (O)

*Clarke, A.O.; Heald, G.; Jarrett, T.; Bray, J.D.; Hardcastle, M.J.; Cantwell, T.M.; Scaife, A.M.M.; Brienza, M.; Bonafede, A.; Breton, R.P.; and 33 coauthors. "LOFAR MSSS: Discovery of a 2.56 Mpc giant radio galaxy associated with a disturbed galaxy group". A&A, 601, 25 (O)

*Contreras, Y.; Rathborne, J.M.; Guzman, A.; Jackson, J.; Whitaker, S.; Sanhueza, P.; Foster, J. "Characterizing the properties of cluster precursors in the MALT90 survey". MNRAS, 466, 340-354 (O)

*Coughlan, C.P.; Ainsworth, R.E.; Eislöffel, J.; Hoeft, M.; Drabent, A.; Scaife, A.M.M.; Ray, T.P.; Bell, M.E.; Broderick, J.W.; Corbel, S.; and 8 coauthors. "A LOFAR detection of the low-mass young star T Tau at 149 MHz".

ApJ, 834, 206 (O)

Cui, B.-Y.; Boyles, J.; McLaughlin, M.A.; Palliyaguru, N. "Timing solution and single-pulse properties for eight rotating radio transients". ApJ, 840, 5 (P)

*Curran, S.J.; Hunstead, R.W.; Johnston, H.M.; Whiting, M.T.; Sadler, E.M.; Allison, J.R.; Bignell, C. "Further observational evidence for a critical ionizing luminosity in active galaxies". MNRAS, 470, 4600-4607 (O)

*Curran, S.J.; Whiting, M.T.; Allison, J.R.; Tanna, A.; Sadler, E.M.; Athreya, R. "Atomic and molecular absorption in redshifted radio sources". MNRAS, 467, 4514-4525 (O)

*da Cunha, E.; Hopkins, A.M.; Colless, M.; Taylor, E.N.; Blake, C.; Howlett, C.; Magoulas, C.; Lucey, J.R.; Lagos, C.; Kuehn, K.; and 30 coauthors. "The Taipan galaxy survey: Scientific goals and observing strategy". PASA, 34, 47 (O)

*Dai, S.; Johnston, S.; Hobbs, G. "Prospects for discovering pulsars in future continuum surveys using variance imaging". MNRAS, 472, 1458-1464 (O)

*Dai, S.; Smith, M.C.; Wang, S.; Okamoto, S.; Xu, R. X.; Yue, Y.L.; Liu, J.F. "The identification of the white dwarf companion to the millisecond pulsar J2317+1439". , 842, 105 (O)

*Dannerbauer, H.; Lehnert, M. D.; Emonts, B.; Ziegler, B.; Altieri, B.; De Breuck, C.; Hatch, N.; Kodama, T.; Koyama, Y.; Kurk, J.D.; and 11 coauthors. "The implications of the surprising existence of a large, massive CO disk in a distant protocluster". A&A, 608, 48 (C)

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*Deng, X.; Chippendale, A.P.; Hobbs, G.; Johnston, S.; Dai, S.; George, D.; Kramer, M.; Karuppusamy, R.; Malenta, M.; Spitler, L.; and 2 coauthors. "Observing pulsars with a Phased Array Feed at the Parkes Telescope". PASA, 34, 26 (P)

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Legend
* Authors include ATNF staff
A – ASKAP
C – ATCA
M – Mopra
O – Other staff paper
P – Parkes
S – SKA
T – Tidbinbilla (CDSCC)
V – VLBI

H: Abbreviations

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

ABBREVIATION	DESCRIPTION
AAVS	Aperture Array Verification System
ACES	ASKAP Commissioning and Early Science
ACMA	Australian Communications and Media Authority
AGN	Active Galactic Nucleus/Nuclei
ALMA	Atacama Large Millimeter/ submillimeter Array
ASKAP	Australian SKA Pathfinder
ATCA	Australia Telescope Compact Array
ATLAS	Australia Telescope Large Area Survey
ATNF	Australia Telescope National Facility
ATOA	Australia Telescope Online Archive
ATSC	ATNF Steering Committee
ATUC	Australia Telescope User Committee
CASDA	CSIRO ASKAP Science Data Archive
CASS	CSIRO Astronomy and Space Science
CDSCC	Canberra Deep Space Communication Complex
CPU	Central Processing Unit
CRAFT	Commensal Real-time ASKAP Fast Transients
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAP	Data Access Portal
DINGO	Deep Investigations of Neutral Gas Origins
DIIS	Department of Innovation, Industry and Science (Australian Government)
EDGES	Experiment to Detect the Global Epoch of reionisation Signature
EMU	Evolutionary Map of the Universe
FAST	Five hundred meter Aperture Spherical Telescope (China)
FLASH	First Large Absorption Survey in HI
FPGA	Field Programmable Gate Array
FRB	Fast Radio Burst
GASKAP	Galactic ASKAP Spectral Line Survey
GAMA	Galaxy And Mass Assembly
GPU	Graphics Processing Unit
GRB	Gamma-Ray Burst
HERA	Hydrogen Epoch of Reionization Array
HI	Neutral hydrogen
HIPASS	HI Parkes All Sky Survey

ABBREVIATION	DESCRIPTION
HTRU	High Time Resolution Universe pulsar survey
IAU	International Astronomical Union
ICRAR	International Centre for Radio Astronomy Research
ISM	Interstellar Medium
LBA	Long Baseline Array
LFAA	Low Frequency Aperture Array
LGBTI	Lesbian Gay Bisexual Transgender Intersex
LIGO	Laser Interferometry Gravitational Wave Observatory
LMC	Large Magellanic Cloud
LNA	Low Noise Amplifier
LOFAR	LOw Frequency ARray (Netherlands)
MALT	Millimetre Astronomer's Legacy Team
MRO	Murchison Radio-astronomy Observatory
MWA	Murchison Widefield Array
NAPA	Non A-Priori Assignable
NARIT	National Astronomical Research Institute of Thailand
NASA	National Aeronautics and Space Administration
NGC	New General Cataologue
PAF	Phased Array Feed
PI	Principal Investigator
POSSUM	Polarisation Sky Survey of the Universe's Magnetism
RFI	Radio Frequency Interference
SCORPIO	Spectral Camera with Optical Reducer for Photometrical and Interferometrical Observations
SKA	Square Kilometre Array
SMC	Small Magellanic Cloud
SNR	Supernova remnant
SPT	South Pole Telescope
TAC	Time Assignment Committee
UWB	Ultra Wideband
VAST	Variables and Slow Transients
VLBI	Very Long Baseline Interferometry
VO	Virtual Observatory
WA	Western Australia
WALLABY	Widefield ASKAP L-band Legacy All-sky Blind survey

22 September 2017 marked the 50th anniversary of the opening of the radio heliograph at what is now the Paul Wild Observatory (named after the heliograph's chief architect and likely the man pictured with this prototype antenna in 1963). The heliograph comprised 96 antennas each 13.7 m in diameter spaced evenly around a 3 km ring. For 17 years it provided valuable insights into the Sun's effect on terrestrial activities. Image: ATNF Archive.

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