Australia's National Science Agency

Australia Telescope National Facility

Annual Report 2021–22

CSIRO Australia Telescope National Facility
Annual Report 2021–22

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This is the report of the CSIRO Australia Telescope National Facility for the period 1 July 2021 to 30 June 2022 and is endorsed by its Steering Committee. Telescope usage data spans the April to September 2021 and October 2021 to March 2022 observing semesters. Publication data is from the calendar year 2021.

Editor: Nic Svenson

Cover: (Top) Our ASKAP radio telescope. Image: Dragonfly Media. (Bottom) One of the first ASKAP images to be made with the Setonix supercomputer (see page 11). Image: science data processing teams at ASKAP and the Pawsey Supercomputing Research Centre.

Each of ASKAP's survey science projects will be presented with a painting by a Wajarri Yamatji artist.

Phillipa Boddington, *DINGO*, 2019, acrylic on canvas.

Traditional owners

We acknowledge the Traditional Owners of the lands of all our sites and pay respects to their Elders past and present.

Marsfield, Sydney, Wallumattagil people

Paul Wild Observatory, Narrabri, Gomeroi people

Parkes Observatory, Wiradjuri people

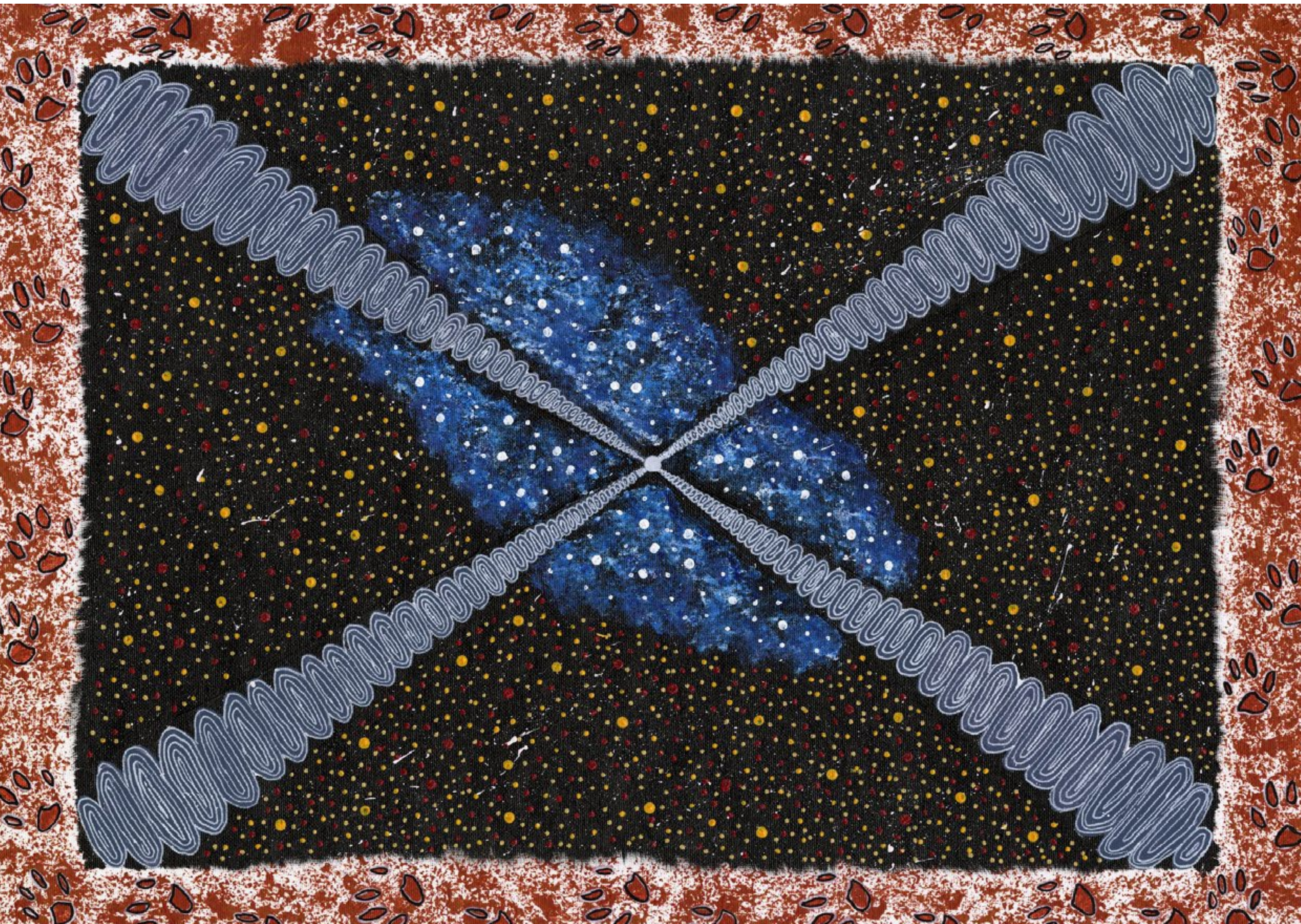
Mopra, Coonabarabran, Gamilaroi people

CDSCC, Ngunnawal and Ngambri people

Kensington, Perth, Whadjuk people of the Noongar nation

Geraldton, Nhanhangardi, Naaguja, Wilunyu and Amangu peoples

Inyarrimanha Ilgari Bundara, our Murchison Radio-astronomy Observatory, Wajarri Yamaji people



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About us

On behalf of the Australian Government we develop and operate world-class radio astronomy facilities for researchers from across Australia and around the world. We attract and retain the best staff and are also leaders in technology and research.

The Australia Telescope National Facility (ATNF) comprises the Australia Telescope Compact Array (ATCA), the ASKAP radio telescope, and the Parkes radio telescope, Murriyang. We manage Australian astronomers' access to NASA's Canberra Deep Space Communication Complex (CDSCC) and we manage the combination of these antennas with ATCA, Parkes, our Mopra telescope, and others in the southern hemisphere, as the Long Baseline Array (LBA). Through our research and development program we ensure our telescopes remain world class and support development of facilities around the world.

Astronomers from all over the world can access our telescopes free of charge based on the scientific merit of their observing proposal. We receive about 200 unique proposals annually, this year representing more than 700 astronomers. Time can also be purchased; for example, the National Astronomical Observatories of the Chinese Academy of Sciences buys time on Parkes to follow up potential pulsars found with their FAST telescope.

The primary output from the ATNF is scientific research. In 2021, astronomers published 138 papers using data enabled by our telescopes and specialist instrumentation. Our impact is realised by building innovation capacity for Australia and by inspiring the next generation. We achieve this through: programs for students and teachers, in telling the stories of our people, infrastructure, and the excellent science we enable, and how this delivers benefit for Australia.

Protecting our telescopes, and others around the world, from increasing levels of radio frequency interference is more important than ever before. Our experts in this field are deeply involved with the international regulatory bodies that manage uses of the radio spectrum. In Australia there are Radio Notification Zones around ATCA and Parkes while a Radio Quiet Zone gives special protection to the Inyarrimanha Ilgari Bundara, CSIRO's Murchison Radio-astronomy Observatory, home to ASKAP and soon the SKA-Low telescope.

The ATNF Steering Committee (ATSC) is an advisory body appointed by the CSIRO Board to provide advice to the ATNF Director on CSIRO's ongoing delivery of radio astronomy capabilities for the nation. The ATSC appoints the ATNF Users Committee (ATUC), which represents the interests of astronomers using our telescopes, and the Time Assignment Committee (TAC), which reviews observing proposals (see page 26).

Four of ATCA's six dishes in moonlight
Image: Alex Cherney

Chair's report

This year the ATNF Steering Committee was taken on a tour of the Inyarrimanha Ilagari Bundara, the CSIRO Murchison Radio-astronomy Observatory during our May meeting. This was an incredible opportunity to appreciate the natural beauty of the site, and also the inherent challenges in building and operating cutting edge scientific facilities in such a remote environment. We were impressed by the maturity of the operations and the commitment of the site staff. It was a particular highlight for me to stand on Wajarri Yamaji country alongside ASKAP for the first time.

I have come to the role of Chair at a critical point as the ATNF looks to a future dominated by SKA telescopes. The Steering Committee has provided guidance as the ATNF begins to think about its role and how Australia's national facility in radio astronomy will adapt to this changing landscape.

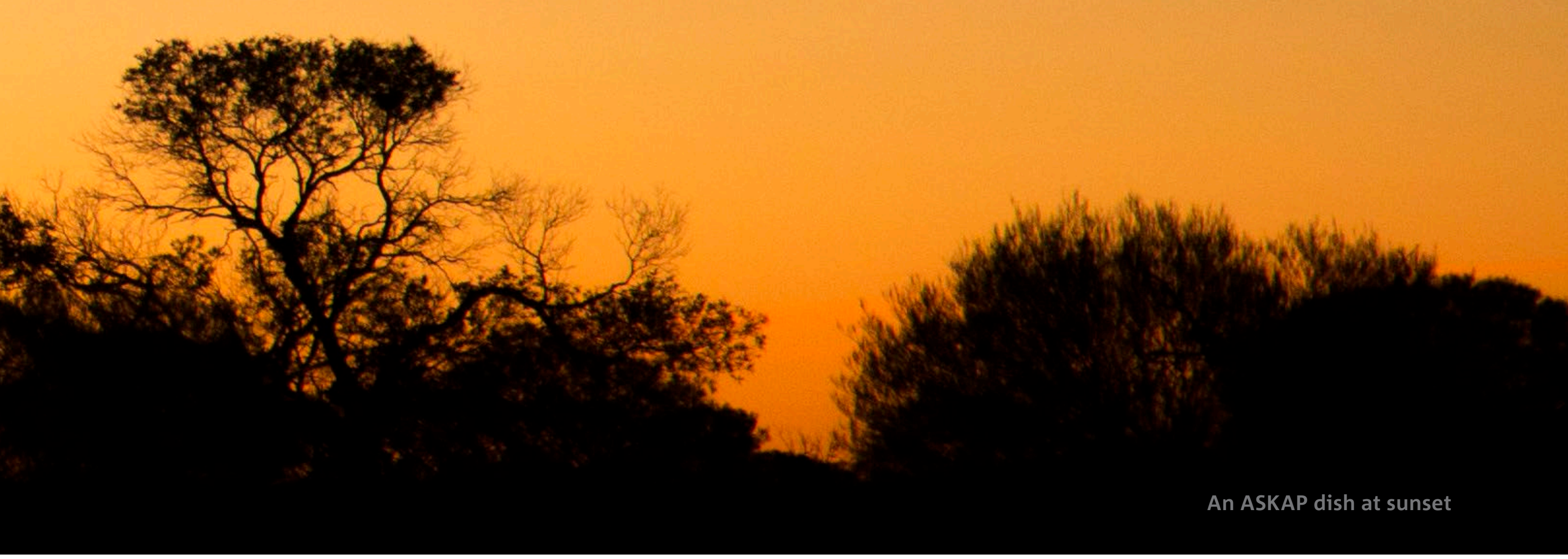
One element of this future could be very long baseline interferometry (VLBI), particulaly at low frequencies. In line with an Steering Committee recommendation, the ATNF hosted the VLBI *in the SKA Era* conference, which was one of the best-attended VLBI events ever. The outcomes of this are being folded into the ATNF's planning, along with input from the astronomy community and the ATNF's engineering team.

An important role that ATNF continues to play, is in providing hands-on training for young astronomers – it's not every observatory where you get to help commission a new receiver! ATNF staff and junior astronomers are expected to help other astronomers with their observing, and the Steering Committee have discussed ways of keeping this important function, while updating it to fit the current observing modes. Following our recommendation, the ATNF is trialling a new model that supports users based on the type of observing they are doing, rather than the telescope they are using.

As a leader of one of ASKAP's survey science projects, I was intimately involved in this year's review of the projects, which outline ASKAP's observation scope for the next five years. The review process was thorough but fair and, while no project got everything it wanted (collectively, the projects asked for 1.7 times more observing hours than were available), the final allocations will enable the project teams to deliver great science. We are all looking forward to the surveys getting underway in the coming months. The Steering Committee commends the ASKAP staff, including scientists, engineers and software developers, in getting ASKAP to this point.

My thanks to the management and staff of the ATNF and to the two committees the ATNF Steering Committee appoints – the ATNF User Committee and the Time Assignment Committee – whose advice and diligence is crucial to the smooth operation of the ATNF. The ATNF Steering Committee is a sub-committee of the CSIRO Board and we commend this report to it.

Prof Tara Murphy



An ASKAP dish at sunset

Director’s report

Our Parkes radio telescope, Murriyang, celebrated its 60th anniversary on 31 October 2021. Over the decades, astronomers around the world have used our iconic dish to make all-sky surveys of atomic hydrogen (such as HIPASS), detect almost half the known pulsars, map the Milky Way and the Magellanic system, and discover fast radio bursts. With our ultra-wideband receiver in high demand and our new cryogenically cooled phased array feed (CryoPAF) on the way, Parkes can look forward to more discoveries for years to come.

We strive to keep all our telescopes at the cutting edge by upgrading systems and processes. Work continued during the year on a much-needed replacement correlator for ATCA. An ASKAP transient search system, which is under construction, will soon be able to find and localise one fast radio burst every day. ASKAP continued to impress with many more results from commissioning and the pilot surveys. With ASKAP about to start the surveys for which it was designed, I look forward to the ASKAP team adding more awards to those won this year.

A major activity this year was preparing for SKA-Low construction and operations. CSIRO will employ the majority of people operating the SKA telescope in Australia. This year saw the operating model defined and the first 30 staff (11 SKAO and 19 CSIRO) join the team. We also finalised contracts for CSIRO’s roles in SKA-Low construction.

Central to the success of the ATNF has been the close interaction of people working on instrumentation, astrophysics and observatory support. In the longer term, we will still develop novel instrumentation and operate our own telescopes alongside SKA-Low. We are turning our attention to the role of the ATNF in this era. This year we worked with partners to define the future SKA Regional Science Centre and examined the potential for low-frequency VLBI in Australia.

The pandemic and floods in eastern Australia impacted us this year. While many other facilities were forced to close at various times, the ATNF’s investment in remote operation technology and careful management by our people on site saw no disruption in service to our astronomy users. I thank our people for their dedication and commitment throughout.

After more than ten years on the ATNF leadership team, Sarah Pearce and Ant Schinckel left CSIRO this year to join the SKA Observatory. They have each left a lasting legacy in the ATNF and SKA project. It has been a privilege to work with them and it remains a pleasure to work alongside them to make the SKA project a reality.

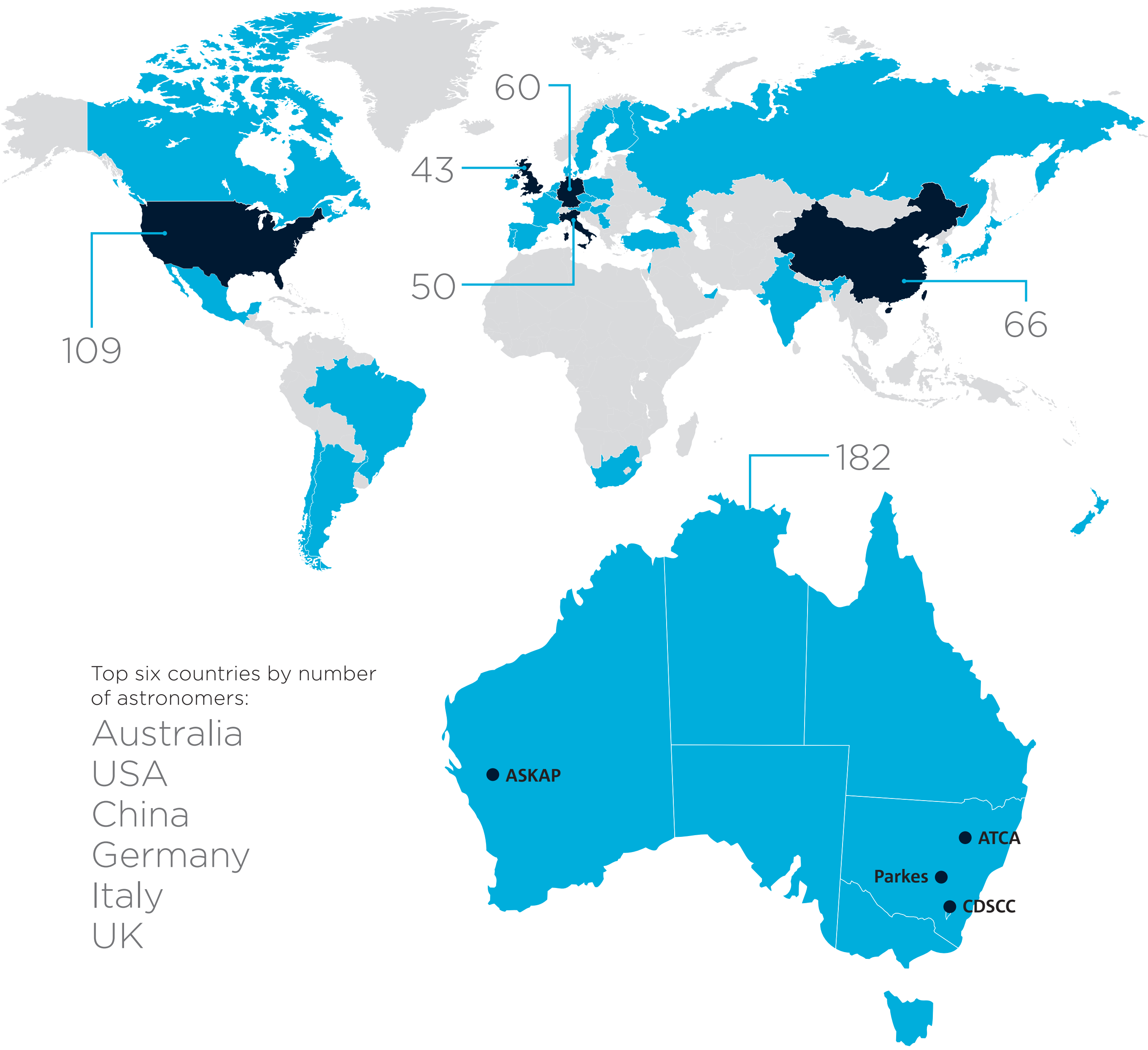
I also thank the ATNF Steering Committee, ATUC and TAC for their advice and guidance. I particularly acknowledge outgoing chair of the Steering Committee David Skellern for his contributions over the past 5 years as a member and then chair. David took a personal interest in our commercialisation, including supporting the creation of Quasar Satellite Systems, which is now applying the ASKAP phased array feed technology to satellite communications.

Finally, I’d like to thank all staff for what has been a tremendous year.

Dr Douglas Bock

2021–22 snapshot

241 observing proposals
718 astronomers
from 31 countries



Top six countries by number of astronomers:

Australia
USA
China
Germany
Italy
UK

Time spent observing
63% ATCA
72% Parkes

6.5
petabytes
in the data archives

159
papers
by our staff

138
papers
cite ATNF data

210
staff

30
postgraduate students

650+
school students
did PULSE@Parkes

83 352 people
attended our visitor centres

Performance indicators

Telescope usage

Our KPIs for ATCA and Parkes are:

- At least 70% of telescope time successfully used for observing.
- No more than 5% of time lost during scheduled observations due to equipment failure.

Use of Parkes remains stable, with slightly more maintenance time this year due to infrastructure upgrades in preparation for the CryoPAF (Figure 1). ATCA fell below its KPI, with 63% of telescope time successfully used for observing. This was due to a combination of circumstances including a change in observing programs from long-term surveys to rapid responsiveness, which brings high scientific return but low predictability, and scheduling inefficiencies driven by the telescope's ageing correlator, which is in the process of being replaced.

ASKAP is incrementally building towards these KPIs and exceeded its FY21/22 target of 50%, achieving 65% observing time. This year just 1.6% of scheduled observing time was lost due to equipment failure.

CDSCC antennas were used for 41 hours in single dish observing, contributed to the LBA for 86 hours and spent a further 82 hours as part of bistatic radar observations of near-Earth objects.

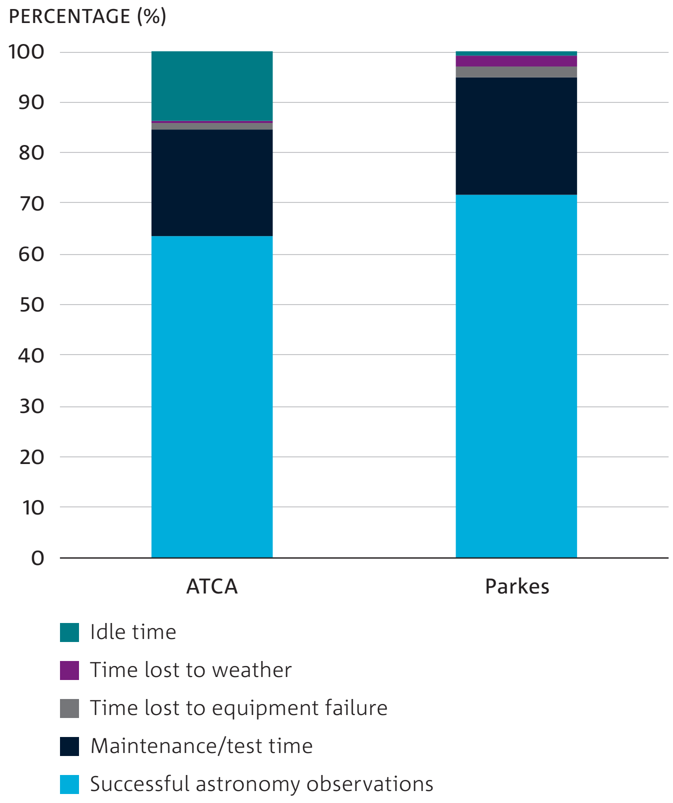


Figure 1: Use of ATCA and Parkes in this reporting period.

Parkes and the Milky Way. Image: Alex Cherney

Time allocation

There were 241 observing proposals received for ATCA, Parkes, the LBA, and for CDSCC antennas in this reporting period: 183 of these were unique proposals. The telescopes were in demand with an oversubscription rate of 1.5 for Parkes, 1.4 for ATCA (after excluding legacy projects) and 1.5 for the LBA. The observing teams consisted of 718 researchers from 31 countries. After Australia, most proposers came from the USA, China, Germany, Italy and the UK. CSIRO people led 11% of unique proposals, 31% were led by staff and students of other Australian institutions and 58% by overseas researchers.

In total 152 proposals were allocated time based on TAC gradings: 80 on ATCA, 55 on Parkes, 15 on the LBA and two on CDSCC antennas. Time allocation for ATCA and Parkes is shown in Figures 2 and 3. There were 44 other proposals allocated Director's discretionary time, most on a 'target of opportunity' basis in response to observations made with other telescopes: 14 on Parkes, 30 on ATCA (see page 30).

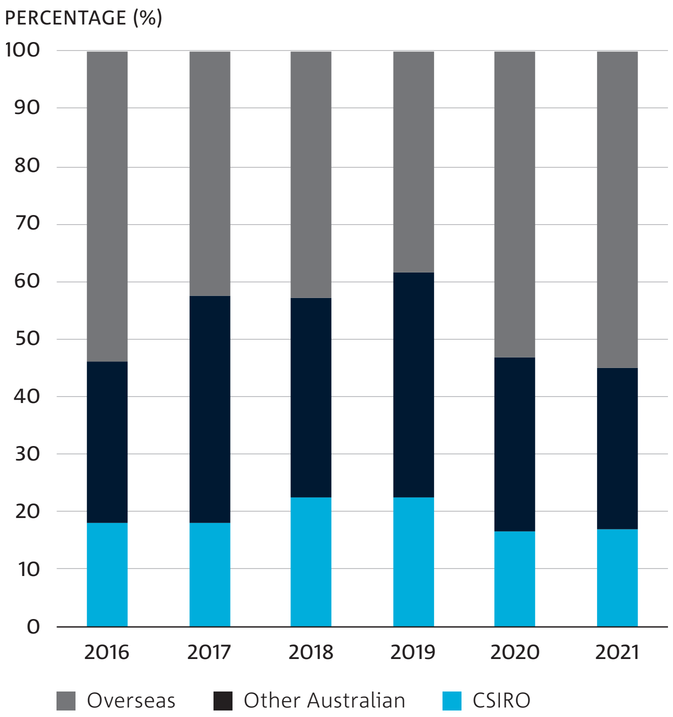


Figure 2: Time allocation on ATCA by affiliation of researcher.

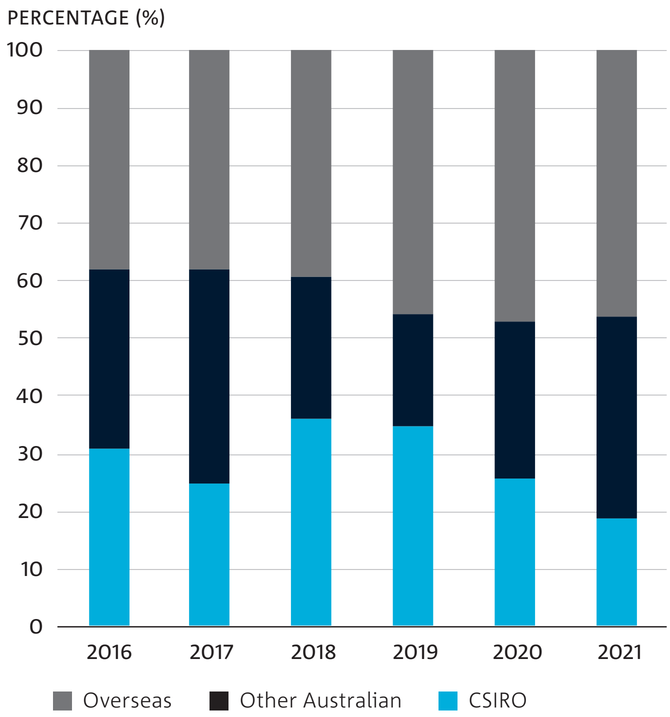


Figure 3: Time allocation on Parkes by affiliation of researcher.

Publications

In 2021, 138 refereed papers were published that used data from ATNF telescopes: 78 (57%) included a CSIRO author. Our people published 159 refereed papers, including those using data from other facilities. Altogether, there were 220 refereed journal papers and 14 conference papers that used ATNF data and/or had ATNF authors, listed at: www.atnf.csiro.au/research/publications.

ASKAP publications rose significantly, while ATCA and Parkes remain on a par with previous years.

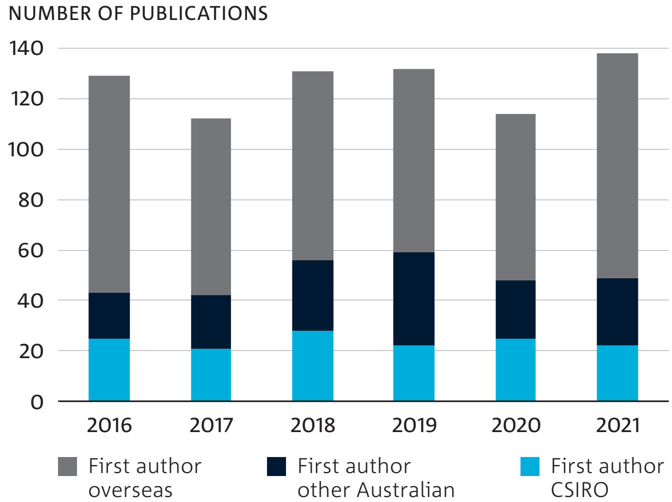


Figure 4: Publications using data from ATNF telescopes.

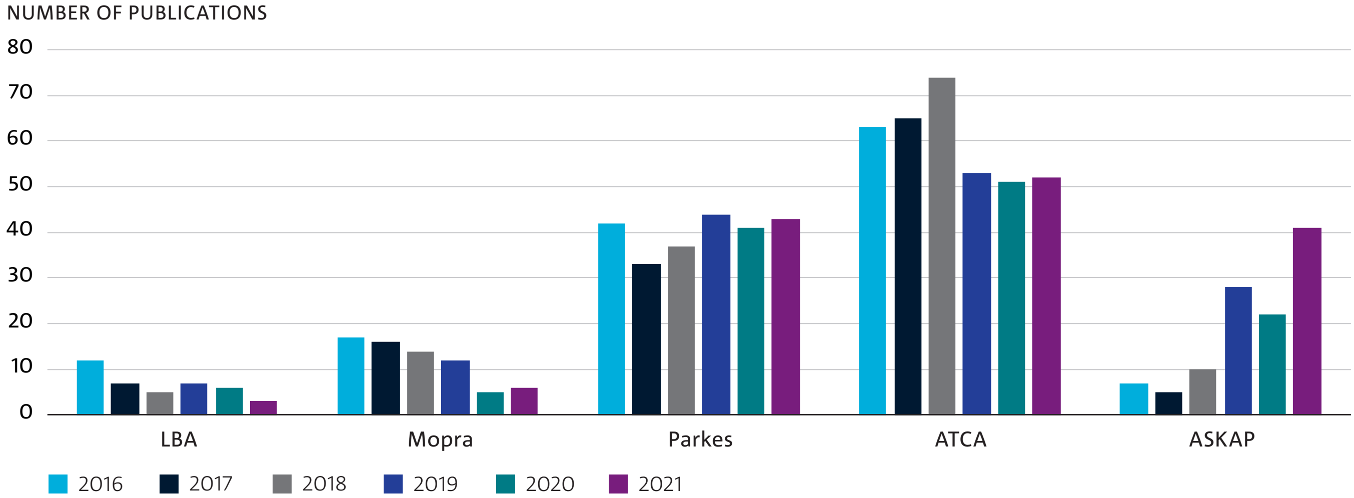


Figure 5: Publications using data from the ATNF, grouped by telescope.
A few papers with data from more than one telescope are counted more than once.

Data archives

Our data archives, currently totalling around 6.1 PB, play an important part in the research work of our astronomer user community. Every day, the CSIRO ASKAP Science Data Archive (CASDA) receives about 4500 virtual observatory requests and 18 enquiries from the web user interface. Over 70 pulsar collections are accessed each month from the Parkes pulsar archive and about 3 TB of files from the Australia Telescope Online Archive (ATOA) are downloaded every month, representing some 50 astronomy users.

CASDA has migrated to the new Acacia disk-based storage system at Pawsey. This new storage will result in better performance for users, as files can be served immediately instead of being queued to come off tape.

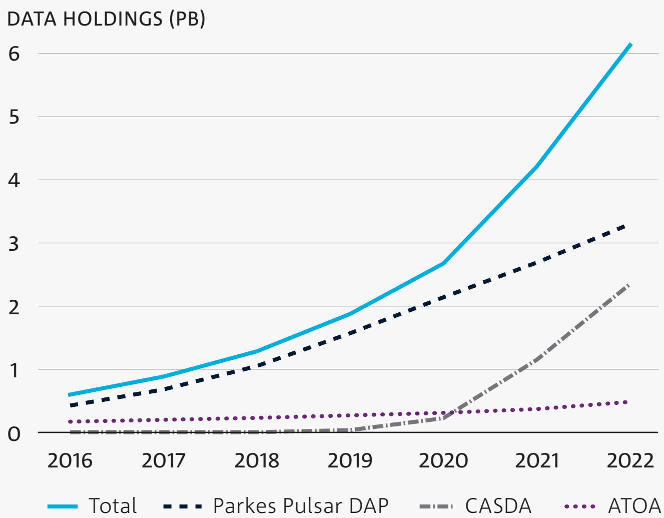


Figure 6: ATNF data archives over time.

ASKAP radio telescope

All-sky surveys

Four all-sky surveys are now complete, one at each of ASKAP's three frequency bands, plus a second pass at the telescope's lowest frequency. These Rapid ASKAP Continuum Surveys (RACS) are the new benchmark surveys for three quarters of the sky. We will use our record of the millions of galaxies observed in RACS to improve calibration and imaging of deeper observations during the full science survey campaign.

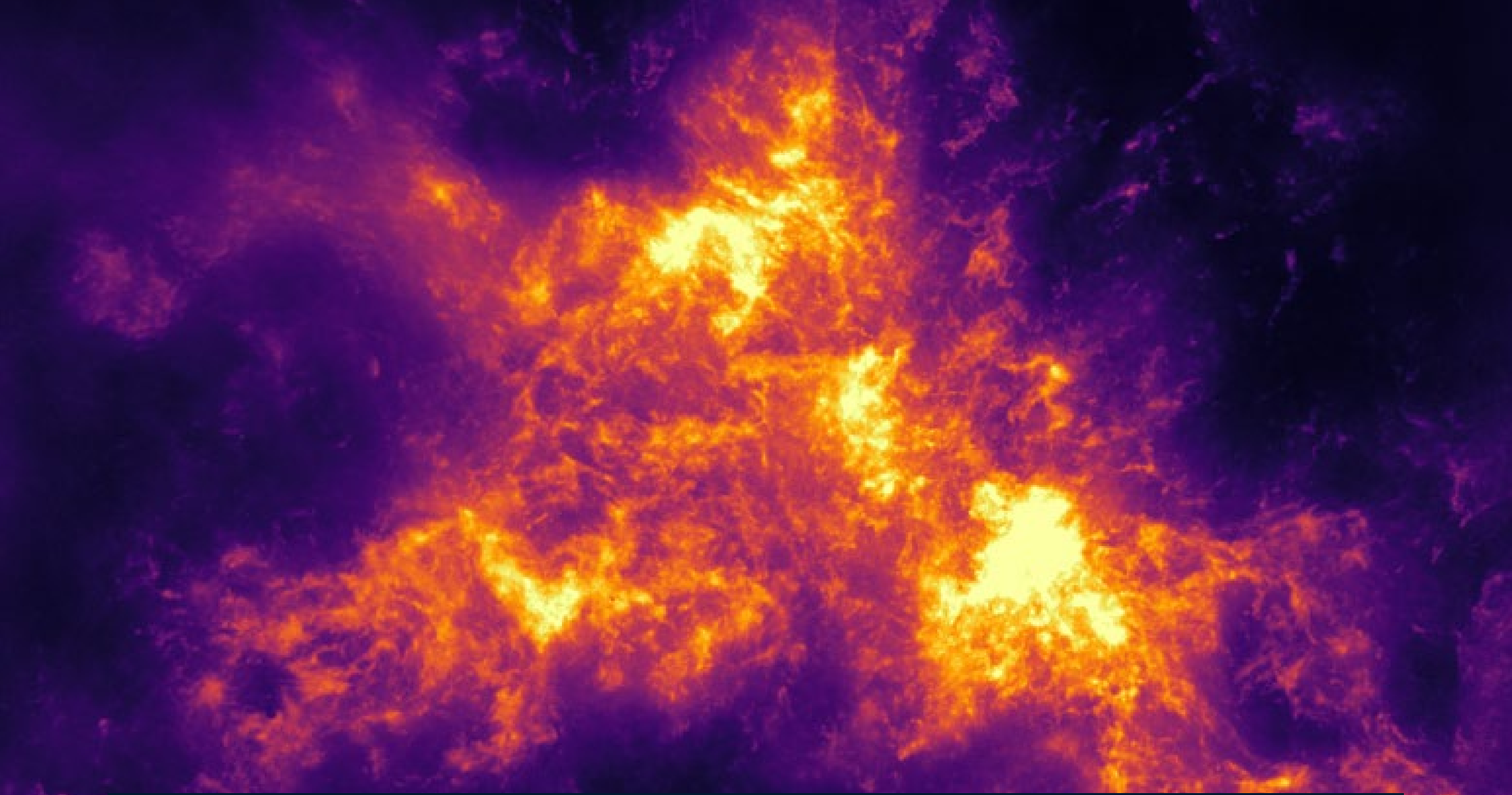
Science surveys

A second round of pilot surveys has taught us how to run full surveys more efficiently and given the survey science teams data approaching full survey quality.

This was crucial input to an international review of ASKAP's survey science projects. The review was important because the survey teams and ASKAP's operations team have gained a lot of experience over the 12 years since the initial review. Also, the scientific landscape has evolved (fast radio bursts were barely known in 2009) and the operating environment has changed (interference from satellites is a much bigger problem now).

With the panel's recommendations for time allocation in hand, we are now preparing for full surveys, starting by transitioning ASKAP data processing from Galaxy to the new Setonix machine at the Pawsey Supercomputing Research Centre in Perth.

Named after an Australian native animal, the quokka, Setonix has more memory bandwidth and faster cores and should allow processing to keep up with the incoming data stream – full surveys would be impossible without it. While global supply chain issues meant we had access to Setonix later than anticipated, we hope to start full surveys in late 2022.



SCIENCE HIGHLIGHT

This stunning image of the Small Magellanic Cloud captured by ASKAP reveals small-scale structures of hydrogen gas associated with our galactic neighbour. High-tech software was used to capture and process 100 hours of data to produce this final image, which shows areas of star formation and gaps where hydrogen has interacted with supernovae.

This research is helping to explain the role hydrogen plays in a galaxy's evolution. With further work, connecting images can be used to show how the Small Magellanic Cloud connects to its nearby neighbours.

Pingel et al. 2022 PASA 39 e005

Next-gen FRB finder

ASKAP is receiving a major upgrade to its ability to find fast radio bursts (FRBs) – those mysterious, high-power, millisecond pulses from across the Universe. Supported by a grant from the Australian Research Council to our partners at Swinburne University of Technology, CRACO (the CRAFT coherent upgrade, CRAFT being an ASKAP Survey Science Project) promises to help ASKAP find an FRB every day – and localise it as well (see page 18). Pinpointing the source of FRBs is critical to determining what causes them: nothing that we know of could come from so far away and yet be so bright.

AI for ASKAP

We have joined the Collaborative Intelligence Future Science Platform, a cross-disciplinary effort within CSIRO to develop new ways for humans and machines to collaborate effectively. Our project involves humans using artificial intelligence to augment anomaly detection in ASKAP's control and monitoring system. Human expertise is key to interpreting ASKAP's status, but machines can help deal with the vast amounts of data from 36 dishes.

ASKAP on Wajarri Yamaji Country. Image: Dragonfly Media

SCIENCE HIGHLIGHT

Within 24 hours of getting access to the Pawsey Supercomputing Research Centre's new supercomputer, Setonix, ASKAP's science data processing team demonstrated end-to-end processing of datasets from the radio telescope, which meant the software suite and processing pipeline had been successfully integrated on the new machine. The image of a supernova remnant used on the cover is one the first to be made – in just three hours from a ten-hour test observation. Processing times will reduce as the team continues to optimise Setonix.

This incredible result is due to the team having access to Setonix precursors, Mulan and Joey, which helped our preparations, and to our collaboration with the Pawsey Supercomputing Research Centre.


JLG ULTRA BOOM
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1850SJ
CAB

Parkes radio telescope, Murriyang

This year marked a significant milestone for Parkes: 60 years of operation. Those six decades have witnessed numerous upgrades (including new surfaces, receivers and 'backend' signal processing systems) and different modes of operation (including the shift from onsite to remote operation and the introduction of purchased observing time), all of which have contributed to maintaining Parkes' science impact (see page 9).

Preparations for the cryogenically cooled phased array feed (CryoPAF, see page 18) continued this year with significant upgrades to supporting infrastructure. For example, high-capacity helium lines (to keep the CryoPAF cold and maintain its sensitivity), and multicore fibre optic cables (to carry the high data rates of our modern receivers) were run through the tower and up to the focus cabin suspended over the dish. Further developments included a 100 Gbps ethernet switch and six GPU computing servers to handle the substantial data the CryoPAF will produce.

The telescope control software, DHAGU?, was improved to enable continued use of our existing high frequency receiver fleet as we seek funding for a high frequency ultra-wideband (UWB-H) receiver to complement our low frequency receiver (UWB-L).

SCIENCE HIGHLIGHT

General relativity has stood the test of time but to really test Einstein's theory researchers have needed to track the behaviour of extremely dense celestial objects in a very strong gravitational field. A double pulsar system – detected by the Parkes radio telescope, Murriyang – was the perfect candidate. Researchers have continued monitoring this pulsar system for 16 years using Parkes and other international instruments, carefully recording 20 billion flashing radio signals. The final results were astounding: the best test so far of general relativity in strong gravitational fields, and the team detected relativistic effects never seen before. It all matched Einstein's predictions to near perfection. Though we're still not sure how general relativity matches up to quantum mechanics, we can now be sure that this theory of gravity really is the best we have.

Kramer et al. 2021 Phys Rev X 11 041050

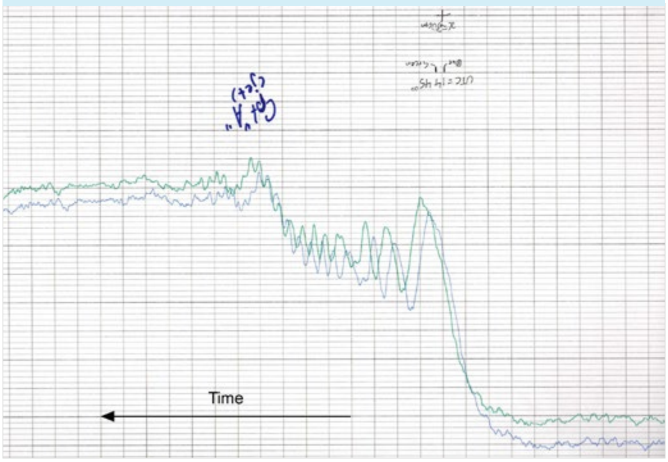
Parkes being prepared for the new CryoPAF receiver which promises up to 30 times the survey speed of the Multibeam receiver. Image: John Sarkissian

This year we built a ground-based testing facility for the new receivers we develop. Known as the hot box, the receiver stays on the ground while a 'hot' load is rolled over the receiver to test its performance against the 'cold' sky. A significant amount of cabling now connects the hot box with the backend systems in the telescope tower allowing full end-to-end receiver system testing.

Our spacecraft tracking program was boosted with installation of equipment from Intuitive Machines for tracking its lunar probes to be launched early in 2023. Simulated tracking and receiver tests have been completed using existing instruments such as NASA's Lunar Reconnaissance Orbiter.

SCIENCE HIGHLIGHT

In 1962 – exactly 60 years ago – researchers observing with Parkes watched the bright radio source 3C273 being occulted by the Moon. An occultation is a large object passing in front of something smaller and is useful for helping astronomers pinpoint the position of objects. The observations of the occultation of 3C273 led to the discovery of quasars: galaxies powered by a supermassive black hole. After being so precisely located, 3C273 was shown to be further away than expected. For such a bright source to be so far away transformed our concept of the Universe.



Data as it would have originally appeared, taken during the 2022 occultation. Image: John Sarkissian

SCIENCE HIGHLIGHT

The centre of our Galaxy, the Milky Way, contains unique magnetised structures that appear to radio telescopes as long, glowing threads. These threads, also known as filaments, usually contain magnetic fields running parallel to the overall structure. However, an area of filaments had been found with magnetic fields rotated at a different angle. To explore the cause for this unusual alignment pattern, researchers turned to broadband ATCA data of the galactic centre. The wide frequency range ATCA can detect revealed complicated internal structure within some of these filaments, along with the influence of external magnetic fields.

Paré et al. 2021 ApJ 923 82

Australia Telescope Compact Array

Our program of legacy projects, which commenced in 2016, is now complete. Most recently Star Formation in the Southern Hemisphere (StarFISH) completed 1018 hours observing this year and will provide insight into how stars and planetary systems form. Intended to create data of lasting importance to the astronomy community, over 10 000 hours observing was devoted to legacy projects: 40% of observing time at the peak of their campaigns. All the raw data are available through the Australia Telescope Online Archive.

We have continued our program of modernisation and standardisation of infrastructure across the observatory. Electrical upgrades include two new switchboards in the screened room (designed to shield the telescope from the radio noise generated by the internal electrical and computing equipment). Each piece of equipment in this room is now connected to its own circuit on each switchboard, allowing it to be powered from the mains or the uninterruptible power supply, meaning we can conduct maintenance on the mains, or the generator, or the UPS without interrupting telescope operations.

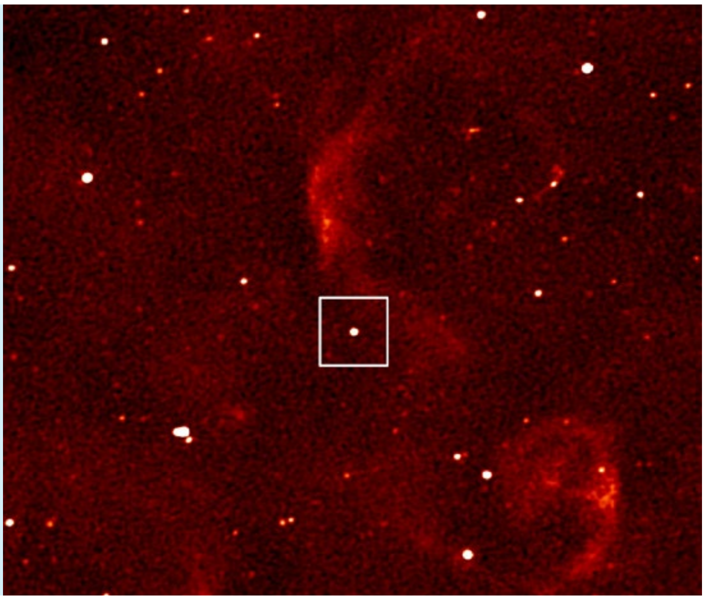
To improve the reliability of the telescope, we are upgrading the dry air system and cryogenic compressors. The dry air system dehumidifies the air passed in front of the 15 mm receiver window, to ensure that moisture does not collect and lower the receiver's sensitivity. The new system uses better components and plumbing that should suffer fewer failures. The cryogenic compressors keep the 16 cm and 4 cm receivers cooled to below 20 Kelvin. We are also upgrading the monitoring systems, to keep them running better for longer.

On the software side, ATCA's observing control systems are being upgraded in preparation for the arrival early in 2023 of BIGCAT (the Broadband Integrated GPU Correlator for the Australia Telescope, see page 18). This new correlator system will have much more flexibility than the current Compact Array Broadband Backend, so the control software needs to be rewritten to take advantage of this.

SCIENCE HIGHLIGHT

A research team applied a new method of seeking out pulsars to ASKAP. By using the astronomical version of 'sunglasses' to capture polarised light, the team found a new pulsar ten times brighter than any other detected outside our Galaxy. A pulsar is a rapidly rotating neutron star that emits two beams of polarised radio light. Traditional methods of finding pulsars look for a timing signature but can miss those that are too fast or too slow. Parkes and ATCA observations added more data to the research on this strange new object. Further examinations with South Africa's MeerKAT telescope – also 'wearing sunglasses' – did show the source to be a pulsar.

Wang et al. 2022 ApJ 930 38



Four of ATCA's six dishes with the Milky Way.
Image: Alex Cherney

Long Baseline Array

The Long Baseline Array (LBA) is a partnership between CSIRO, the University of Tasmania and Auckland University of Technology, which we manage as a national facility by joining ATNF instruments with radio telescopes across the southern hemisphere to perform very long baseline interferometry (VLBI). The fine angular resolution achieved by having telescopes spread between continents means astronomical phenomena can be studied in such detail that the physics behind their origin can be probed.

The bulk of this year's LBA observations occurred during six VLBI sessions. There were 18 projects involving 29 observations, including four target of opportunity observations.

Data from LBA observations were correlated using the distributed FX (DiFX) software correlator running on Magnus at the Pawsey Supercomputing Research Centre in Perth. This year we correlated data from 634 hours of observations and used 112 000 hours of CPU time, with a total data volume of 995 TB. The median time from observation to data release was 118 days, partially due to problems converting data from the ultra-wideband receiver from linear to circular polarisation post-correlation. All correlated data were verified and uploaded to the Australia Telescope Online Archive.

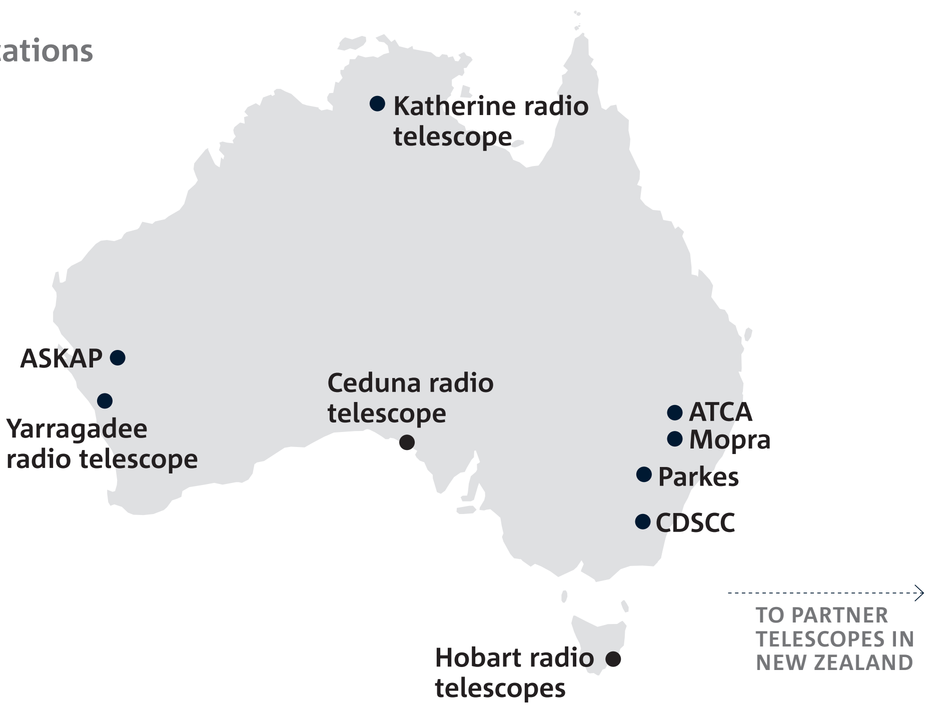
We prepared to move DiFX from Magnus to the new more powerful Setonix machine at Pawsey by migrating the DiFX installation to a Singularity container. This step should ensure complete portability of the entire suite of applications. The move is expected to take place in July 2022.

SCIENCE HIGHLIGHT

To look into the heart of a black hole – especially the one at the centre of our Milky Way, Sagittarius A* – requires a radio telescope with baselines larger than the diameter of the Earth. Very long baseline interferometry, or VLBI, provides the highest resolution in astronomy. Breaking out of Earth's boundaries to include space telescopes allows researchers to probe a black hole even better than before. The first VLBI research with a space telescope, Spektr-R, and a global network of 20 ground-based telescopes including ATCA and Mopra highlighted challenges but showed promise in measuring gravitational signatures in black holes.

Johnson et al. 2021 ApJL 922 L28

LBA telescope locations



WA Observatory Site Entity

CSIRO operates operates Inyarrimanha Ilgari Bundara, our Murchison Radio-astronomy Observatory, on behalf of the nation through the observatory's Site Entity. The Site Entity supports the existing telescopes on site and is responsible for preparing the observatory for the SKA-Low telescope by ensuring all necessary agreements and licences are in place.

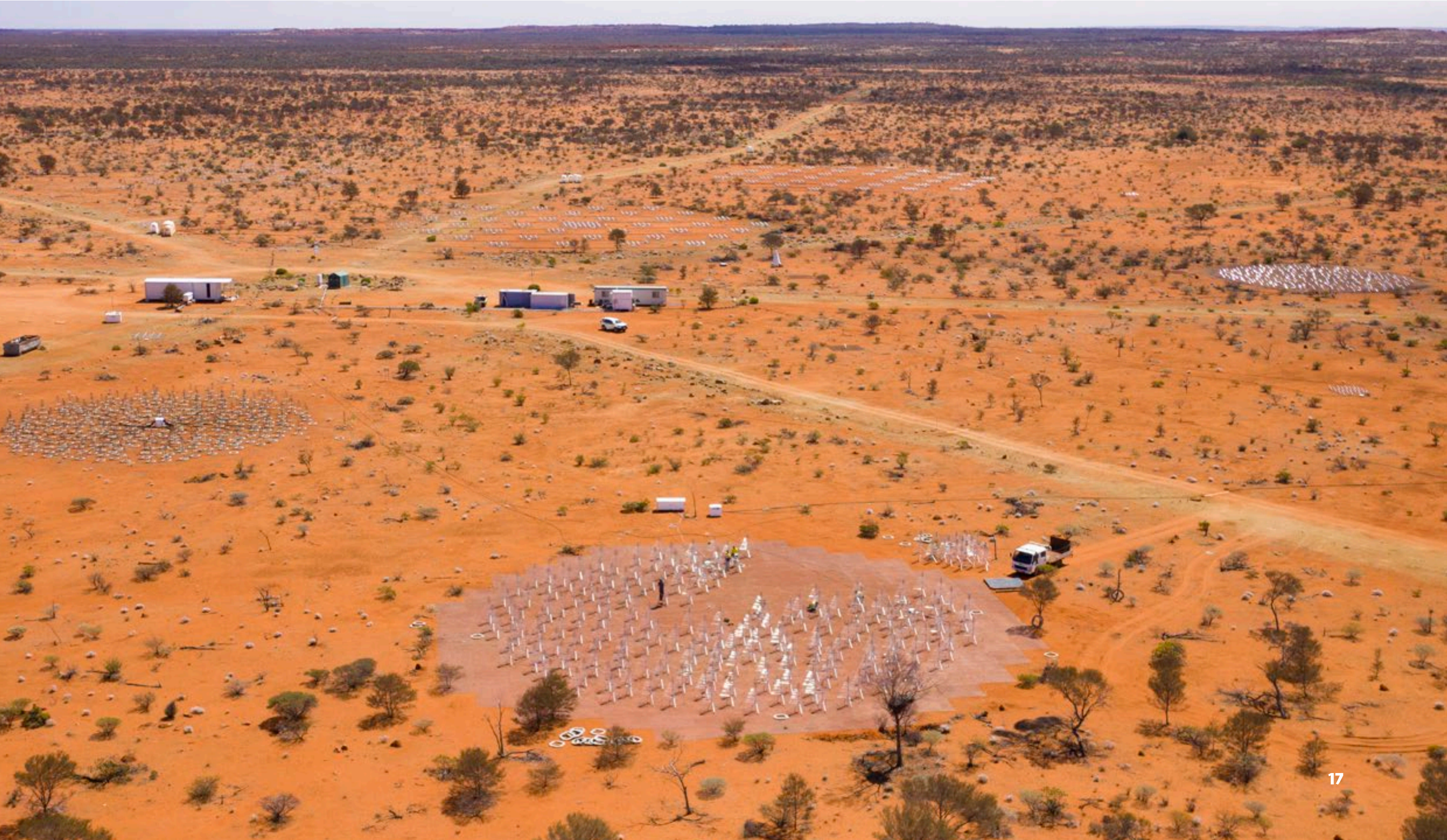
The Australian Government has undertaken to provide new facilities for the SKA-Low telescope, such as an expanded Boolardy Accommodation Facility (BAF) at the observatory, an Engineering Operations Centre (EOC) in Geraldton and a Science Operations Centre (SOC) in Perth. CSIRO is also managing delivery of these facilities through the Site Entity. The SKA-Low operations team is now accommodated in an interim SOC in CSIRO's building opposite the Pawsey Supercomputing Research Centre and has moved into an interim EOC in Geraldton.

The SKA project

The SKA is a €2b international project to build the world's most advanced radio telescopes in Australia (SKA-Low) and South Africa (SKA-Mid). CSIRO is involved in several aspects of the SKA project:

- Operation of the observatory on behalf of the Australian Government (the observatory's Site Entity)
- Construction of SKA-Low through several contracts ranging from overseeing site civil infrastructure to software for the science data processing pipeline (see page 19).
- Operation of SKA-Low in partnership with the SKA Observatory
- Establishment of the Australian SKA Regional Centre (AusSRC), one in a global network of facilities through which astronomers will access data from SKA-Low. The AusSRC is being formed in partnership with The University of Western Australia and Curtin University with funding from the Australian Government.

Looking across our observatory on Wajarri Yamaji Country with SKA test arrays in the foreground. Image: ICRAR/Curtin.



Technology development

We are developing new receivers and backend processing systems for Parkes, ATCA and ASKAP in collaboration with our partners in Australian universities and with financial support from the Australian Research Council.

Components of the CryoPAF. Image: Karl Schwerdtfeger

CryoPAF

Our cryogenically cooled phased array feed (CryoPAF) receiver for Parkes will, for the first time, feature signal digitisation in the same module as the analog signal processing components of the receiver.

The sooner the signal is digitised, the less degradation occurs, but digitisers contain switching electronics, which generates radio frequency interference (RFI), so substantial shielding or separation from the analog components of the receiver is required. The ultra-wideband receiver (UWB) at Parkes has its digitiser in a separate shielded enclosure.

The UWB has revealed that the radio environment at Parkes has become markedly noisier this year. There is too much RFI for the CryoPAF to use fibre to move the analog radio frequency signal to the digitiser (as is done for ASKAP) and other types of cables would be prohibitively heavy because so many are needed. This means that moving the analog signal even a short distance to the digitiser is no longer an option for the CryoPAF: the two components have to be in the same module.

To achieve this with conventional technology for all 197 channels of the CryoPAF would make it bulky and heavy. The advent of radio frequency system on a chip (RFSoC) technology has allowed us to build smaller, less radio noisy and more energy efficient digitisers, as implemented in our Jimble platform. With appropriate RFI shielding the digitisers will be installed on the back of the CryoPAF.

Redesigning the RF electronics to cope with the increased RFI was one setback affecting development of the CryoPAF this year, with COVID and global supply chain issues causing the most delay. Installation is planned for early 2023.

BIGCAT

ATCA's BIGCAT is a hybrid system combining our RFSoC-based Jimble digitiser with GPUs for astronomical signal processing. This will double the processed bandwidth from 4 GHz to 8 GHz.

The basic GPU correlator pipeline is complete, and the team is working on advanced observing modes, such as zoom bands and tied array (VLBI) functionality. Work is also proceeding on ATCA's control system to allow more flexible observing (such as prompt follow up of rapid response triggers), software-based processing and RFI mitigation.

CRACO

ASKAP revolutionised our understanding of FRBs and our new CRACO system promises to have ASKAP changing the scientific landscape once again.

CRACO's FRB trigger is five times more sensitive than the existing system and CRACO now 'taps' ASKAP's correlator for its information, rather than the beamformers. CRACO will search trillions of pixels per second to find and localise FRBs.

Recent end-to-end system tests were a success and, critically, showed that CRACO does not interfere with other observations.

SKA construction

CSIRO has secured five SKA construction contracts, many of which draw upon our engineering and software expertise. Commencing this year is construction of the correlator and beamformer (CBF) for SKA-Low, and work on testing, integration and verification of SKA-Low subsystems (AIV).

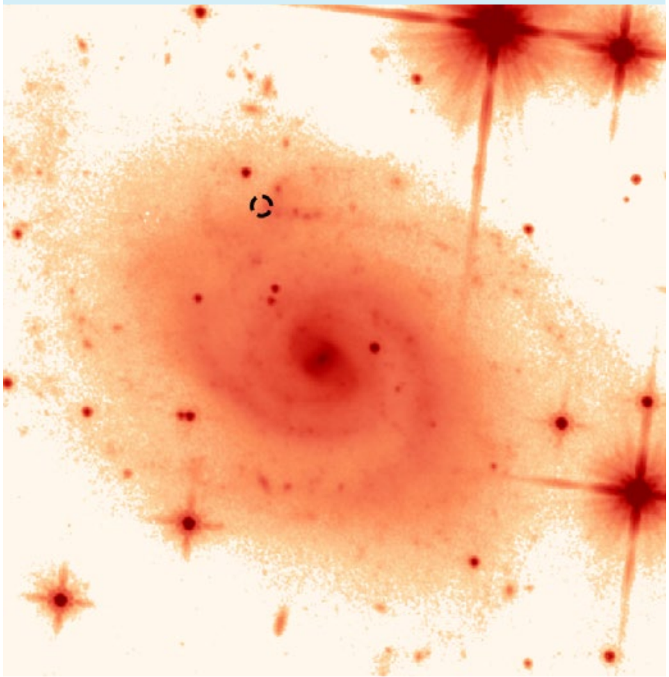
The CBF team has already built a demonstration system (using the latest Alveo FPGA platform technology) which can sustain the complex high-speed, multi-terabit data distribution needs of this telescope.

The CBF team works alongside software experts from the AIV team to test SKA systems destined for the observatory on Wajarri Yamaji Country in the purpose-built SKA-Low Prototype System Integration room at our Sydney laboratory.

SCIENCE HIGHLIGHT

Study of fast radio bursts (FRBs), first discovered with the Parkes radio telescope, Murriyang, has become a leading scientific output of our ASKAP radio telescope. The bursts have allowed researchers to solve some of astronomy's greatest mysteries, like finding the Universe's missing normal matter. What causes the bursts remains elusive. However, recent studies with optical and infrared telescopes, following up on detections made by ASKAP and the Hubble Space Telescope, showed most bursts came from arms of spiral galaxies, not in the brightest sections of those galaxies. This implies the bursts are not generated by massive stars or star mergers. As technology advances with ASKAP (such as the new CRACO system), as well as with the FAST and CHIME radio telescopes, researchers will narrow in on the origin of FRBs.

Mannings et al. 2021 ApJ 917 75



Hubble Space Telescope image in infrared of fast radio burst host galaxy, FRB 180916. The black dashed ellipse represents the proposed location of the burst. Image: Manning et al.

Students, education and engagement

Postgraduate students

This year we co-supervised 30 PhD students, two Masters and two Honours students. The students came from 15 universities. Awarded this year were ten PhDs and two Honours degrees (see page 28).

Undergraduate students

Our undergraduate vacation student program had 15 students from nine universities undertaking astrophysics, engineering and space projects over the summer, both on site and in hybrid mode. With their observing trip to ATCA cancelled due to the COVID-19 pandemic, the students observed remotely from Sydney and Perth. The students presented their work at a hybrid symposium in February.

We now also have three Women in Engineering scholars from Macquarie University.

Schools and teachers

COVID restrictions limited direct school engagement in eastern Australia until early 2022. However, CSIRO's STEM Professionals in Schools program was still running around the country with the involvement of ATNF staff and researchers. In Western Australia, some of our people with a passion for astronomy and Indigenous culture visited the Pia Wadjarri Remote Community School in October, taking students to the nearby observatory.

PULSE@Parkes

This year we held 14 online PULSE@Parkes sessions, enabling 650 students in high schools across Australia to take control of the Parkes radio telescope, Murriyang, and observe pulsars. In September we ran an online workshop for 15 teachers interested in bringing PULSE@Parkes to their schools.

We ran PULSE@Parkes for the National Youth Science Foundation and broke attendance records when 346 students joined. We also ran sessions for the Young Indigenous Women's STEM Academy and for winners of the BHP Foundation Science and Engineering Awards and the Indigenous Education awards.

We also offer upper high school students work experience, as part of a CSIRO-wide initiative. We put on PULSE@Parkes for this year's virtual program.

Vacation scholars Tamsyn O'Beirne, Robert Lee and Bernise Roelofse observe with ATCA from Perth. Image: Kirsten Fredericksen

Communications

This year, telling stories about ASKAP was a major focus: there was the completion of pilot surveys; a new chapter in the unfolding mystery of odd radio circles; finding the brightest known pulsar with the telescope's polarisation capabilities; and sharing the most impressive images from across ASKAP's diverse spectrum of research. We also worked closely with the Pawsey Supercomputing Research Centre to engage users in the installation of the first phase of their new supercomputer, Setonix, which will enable full survey science with ASKAP later in 2022 (see page 11).

There were celebrations for the 60th anniversary of Parkes. The telescope's six decades of operation were highlighted on CSIRO's social media channels, through mainstream media engagement and a virtual stakeholder event. And the community's fondness for the telescope was reinforced with 'The Dish' featuring on Cadbury Australia's centenary chocolate packaging.

After studying a double pulsar system for 16 years, an international team used telescopes around the world, including Parkes, to complete the most challenging tests yet of Einstein's general theory of relativity (see page 16). The story generated widespread media coverage and reached a broad audience by using social media to clearly explain this complex science.

With easing COVID restrictions we returned to in-person events. In the Murchison region we participated in community activities including the local Children's Week and Christmas Tree events. We again participated in Perth Astrofest and contributed to the development of a new virtual reality documentary on the observatory and SKA precursors that was launched at the WA Museum Boola Bardip. The beauty of the the observatory on Wajarri Yamaji Country and ASKAP were also shown on the global stage in a film made for the Australian Pavilion at World Expo 2020.

Visitor centres

A new 3D movie *Beyond the Barrier* debuted in the Visitor Centre at Parkes this year and features our people exploring the telescope and explaining the science undertaken with 'The Dish'.

Visitor numbers are down due to COVID. Whereas last year visitor numbers boomed once lockdowns lifted, that was not the case this year. The Visitors Centre at Parkes was closed from 15 August to 27 September 2021 and at ATCA from early July to 17 January 2022.

Perth Astrofest in November 2021 saw over 3000 astro-enthusiasts have a great time and get inspired to maybe take up a STEM career. Image: Kirsten Fredericksen

Number of visitors to ATCA and Parkes visitor centres.

	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22
Parkes	83 851	105 085	112 224	100 013	103 185	72 612
ATCA	10 965	12 081	10 363	7434	19 659	10 740

Our people

As of 30 June 2022, we have 210 people working on radio astronomy. Five people identify as Indigenous and our gender breakdown is in line with previous years. The figures on this page show our people and others receiving financial support from CSIRO, including joint appointments and, from 2020, those employed under contractor or labour hire arrangements. These data exclude honorary fellows, students and those working in SKA-Low telescope operations.

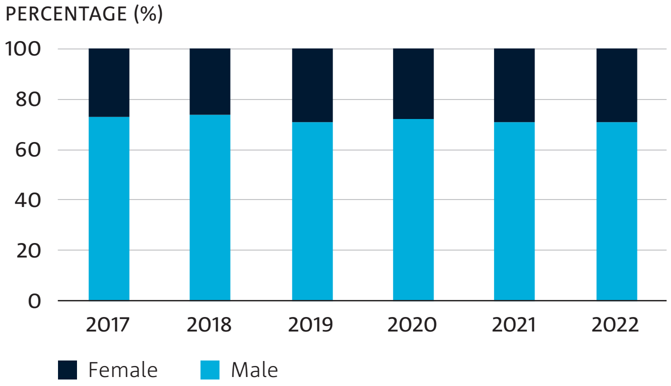


Figure 7: Gender breakdown over time.

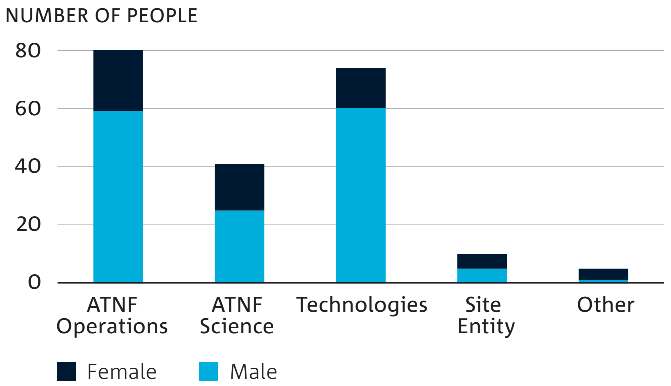


Figure 8: Gender breakdown by research program. Note: people working on SKA construction are in the Technologies program.

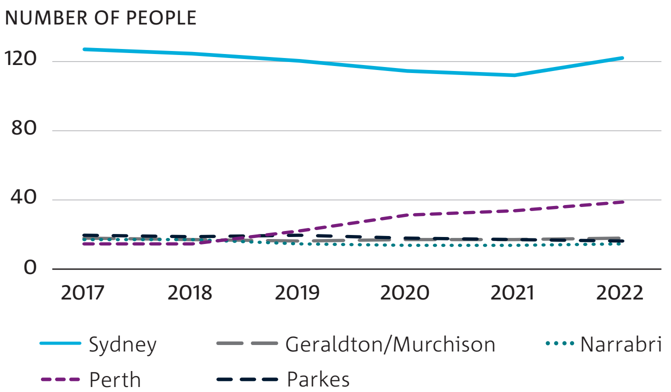


Figure 9: Our people by site over time.

Diversity and inclusion

The Diversity and Inclusion (D&I) Committee has been working alongside executive team sponsors through an action plan developed after extensive consultation with our people. This year's highlight was the creation of a dedicated D&I Manager role, currently under recruitment, to replace the part time Diversity Champion.

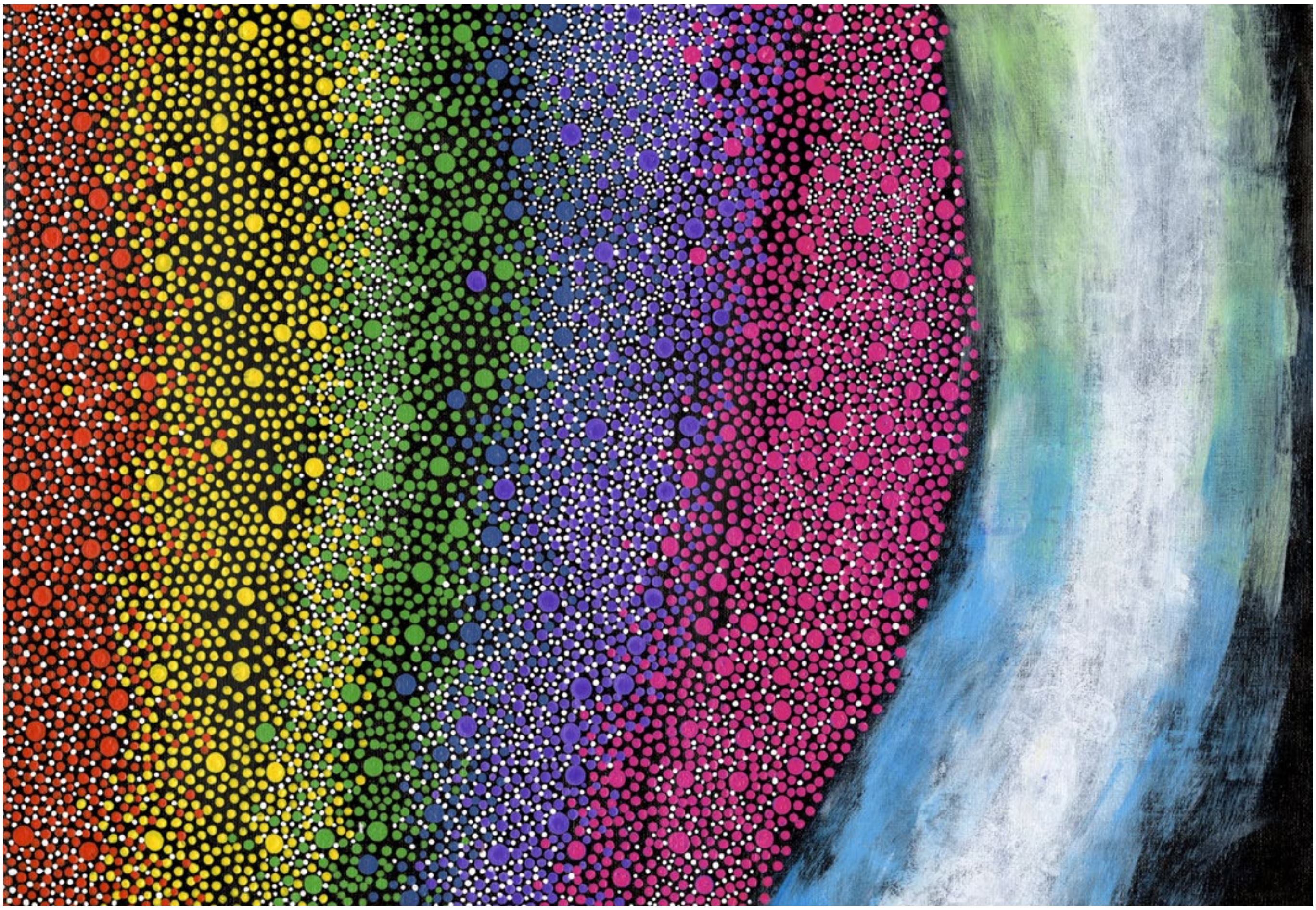
The D&I Committee reviewed Space and Astronomy's rewards process, and many of the Committee's recommendations to improve equity have been implemented. The Committee is also driving change in other processes and committees (such as ATUC) to make them more inclusive.

The D&I Committee provided input to CSIRO's Reconciliation Action Plan (RAP), which reflects CSIRO's commitment to invest in Aboriginal and Torres Strait Islander cultural knowledge in relation to science, and the greater participation of Indigenous peoples in Australia's research and innovation landscape. The Committee is now working to achieve the goals of Space and Astronomy's contribution to implementing the RAP.

Awards and honours

Our award-winners this year included:

- ASKAP Team – Astronomical Society of Australia's Peter McGregor Prize for innovation in astronomical instrumentation.
- Keith Bannister – Malcolm McIntosh Prize for Physical Scientist of the Year (one of the Prime Minister's Prizes for Science) for pioneering research into fast radio bursts.
- Keith Bannister – Australian Academy of Science Pawsey Medal for outstanding research in physics by an early career researcher for detecting fast radio bursts with ASKAP, opening up new fields of study and enabling measurement of the Universe's missing matter.



Artwork by Wajarri Yamatji artist, Agnes Boddington, representing an ASKAP survey science project. "This is my interpretation of our night sky. The coloured dots represent the stars and new stars forming, gases that the GASKAP-OH survey is seeking in our own Milky Way. GASKAP will trace changes in the gas on its way to forming a star." – Agnes Boddington, *GASKAP-OH*, 2019, acrylic on canvas.

Health, safety and environment

Improving our safety culture has been a priority and we have paid particular attention to proactive management of risk. For example, our hazard reporting has tripled (see table below) which is positive to see as identifying hazards helps us prevent incidents from occurring. We are seeing the benefits of this approach with just one injury requiring medical treatment this year.

Our recordable injury frequency rates.

PERIOD	HAZARDS REPORTED	SLTIFR	LTIFR	MTIFR	TRIFR	COMCARE REPORTABLE
2017–18	1	-	3.6	-	3.6	-
2018–19	3	-	3.6	-	3.6	1
2019–20	8	-	2.9	-	2.9	1
2020–21	6	-	2.8	2.8	5.5	-
2021–22	35	-	-	-	-	1

Frequency rate is per million hours worked by employees. SLTFR Serious Lost Time Injury Frequency Rate. LTIFR Lost Time Injury Frequency Rate. MTIFR Medical Treatment Injury Frequency Rate. TRIFR Total Reportable Injury Frequency Rate.

Finance

CSIRO funding for the ATNF this year was $44.3m for direct and indirect operating costs and $2.2m for capital investment. This was supplemented with $16.8m external funding for our SKA work, the Murchison observatory site management, commercialisation activities for radio astronomy, grants from the Australian Research Council and sale of telescope time. Also included is $1.3m for ASKAP operations from the National Collaborative Research Infrastructure Strategy, administered by Astronomy Australia Limited.

The table below summarises revenue and expenditure for CSIRO's radio astronomy activities (excluding SKA-Low telescope operations). Notable factors affecting the financial results for the year included a decrease in external revenue, a return to pre-pandemic baseline appropriation and a temporary increase in direct appropriation for commercialisation. Salary cost increases are in line with CSIRO's Enterprise Agreement pay rises and the growth in SKA Construction activities. There was higher operating expenditure for required infrastructure maintenance.

OPERATING	YEAR TO 30 JUNE 2017	YEAR TO 30 JUNE 2018	YEAR TO 30 JUNE 2019	YEAR TO 30 JUNE 2020	YEAR TO 30 JUNE 2021	YEAR TO 30 JUNE 2022
Revenue						
External	15 418	14 889	13 806	16 648	18 086	16 839
CSIRO direct appropriation	19 532	20 632	20 612	20 550	17 904	22 256
CSIRO indirect appropriation[1]	25 099	25 637	25 261	18 754	19 521	22 080
Total revenue	60 049	61 158	59 679	55 952	55 511	61 675
Proportion of appropriation funded	74%	76%	77%	70%	67%	72%
Expenditure						
Salaries	22 784	20 959	22 289	24 096	22 724	24 407
Travel	1 866	1 713	1 879	1 269	412	445
Other operating	11 708	13 250	10 562	11 977	12 640	15 478
Overheads[2]	13 492	13 316	14 947	13 394	13 735	16 081
Depreciation	11 607	12 321	10 314	5 360	5 786	5 999
Total expenses	**61 457**	**61 559**	**59 991**	**56 096**	**55 297**	**62 410**
Operating result	-1408	-401	-312	-144	214	-1 235

$'000s.

1. CSIRO indirect appropriation is funding for overheads and depreciation.
2. Overheads include support services such as human resources, health and safety, IT, finance and property services.

The table below shows CSIRO capital investment, including from the Science and Industry Endowment Fund.

CAPITAL INVESTMENT	YEAR TO 30 JUNE 2017	YEAR TO 30 JUNE 2018	YEAR TO 30 JUNE 2019	YEAR TO 30 JUNE 2020	YEAR TO 30 JUNE 2021	YEAR TO 30 JUNE 2022
ATNF	547	2 360	1 445	1 823	3 143	2 165
ASKAP	3 121	1 235	-	-	-	-

Parkes with the Pleiades, or Seven Sisters, constellation.
Image: Alex Cherney

ATNF Management team

Director, Dr Douglas Bock

Chief Scientist, Prof Elaine Sadler

Program Director ATNF Science, Dr Phil Edwards and Dr George Heald (commenced November 2021)

Program Director Technologies for Radio Astronomy, Dr Tasso Tzioumis

Program Director ATNF Operations, Dr John Reynolds

SKA Program Leader, Mr Mark Bowen (acting) and Dr Mita Brierley (commenced November 2021)

Chief Operating Officer, Ms Kate Callaghan

Committee membership

ATNF Steering Committee

Chair

Dr David Skellern AO, RoZetta Institute (21 March 2018 to 30 April 2022)

Prof Tara Murphy, University of Sydney (1 May 2022 to 31 March 2025)

Australian astronomy community

Prof Sarah Brough, University of NSW (1 April 2020 to 31 March 2023)

Prof David Davidson, Curtin University (1 April 2020 to 31 March 2023)

Prof Naomi McClure-Griffiths, Australian National University (1 April 2019 to 31 March 2024)

Prof Tara Murphy, University of Sydney (1 April 2020 to 31 March 2025)

International astronomy community

Prof Jayaram Chengalur, National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, India (1 April 2021 to 31 March 2024)

Prof Scott Ransom, National Radio Astronomy Observatory, USA (1 April 2020 to 31 March 2023)

Prof Michael Wise, Netherlands Institute of Space Research (1 April 2019 to 31 March 2024)

Australian stakeholder communities

Ms Catherine Livingstone AO (1 January 2019 to 31 March 2024)

Dr David Skellern AO, RoZetta Institute (1 April 2017 to 30 April 2022)

Ms Rosie Hicks, Australian Research Data Commons (1 April 2022 to 31 March 2025)

Ex-officio

Mr Brendan Dalton, Chief Information Officer, CSIRO

Prof Elanor Huntington, Executive Director, Digital, National Facilities and Collections, CSIRO

Secretariat

Nic Svenson

ATNF User Committee

Chair

Dr Ramesh Bhat, ICRAR/Curtin University
(April 2020 to October 2022)

Members

Dr Martin Bell, University of Technology, Sydney
(July 2020 to November 2021)

Dr Michelle Cluver, Swinburne University of Technology
(May 2020 to October 2022)

Dr Emil Lenc, CSIRO
(October 2020 to May 2023)

Dr Nickolas Pingel, Australian National University
(October 2020 to May 2023)

Dr Ryan Shannon, Swinburne University of Technology
(October 2020 to May 2023)

Dr Ivy Wong, CSIRO
(October 2021 to May 2024)

Student members

Mr James Kwanyin Leung, University of Sydney
(October 2021 to May 2022)

Ms Yuanming Wang, University of Sydney
(October 2020 to May 2022)

Secretariat

Mr Vincent McIntyre, CSIRO

ATNF Time Assignment Committee

Chair

Dr Adam Deller, Swinburne University of Technology
(February 2021 to July 2023)

Voting members

Prof Geoff Bicknell, Australian National University
(February 2020 to July 2022)

Dr Jess Broderick, ICRAR/Curtin University
(February 2021 to July 2023)

Dr Manisha Caleb, University of Sydney
(February 2022 to July 2024)

Dr Barbara Catinella, ICRAR/University of Western Australia
(January 2019 to December 2021)

Dr Shi Dai, Western Sydney University
(February 2022 to July 2024)

Dr Kathryn Grasha, Australian National University
(February 2022 to July 2024)

Dr Katie Jameson, CSIRO
(February 2020 to July 2022)

Dr Elizabeth Mahony, CSIRO
(January 2019 to December 2021)

Dr Jongwhan Rhee, ICRAR/University of Western Australia
(February 2021 to July 2023)

Dr Nick Seymour, ICRAR/Curtin University
(January 2019 to December 2021)

Dr Charlotte Sobey, CSIRO
(January 2019 to December 2021)

Dr Tessa Vernstrom, ICRAR/UWA
(February 2022 to July 2024)

Ex-officio

Dr Douglas Bock, CSIRO

Dr Joanne Dawson, CSIRO

Dr Jimi Green, CSIRO

Dr Jamie Stevens, CSIRO

Secretariat

Dr Hayley Bignall, CSIRO

Dr Elizabeth Mahony, CSIRO (commenced January 2022)

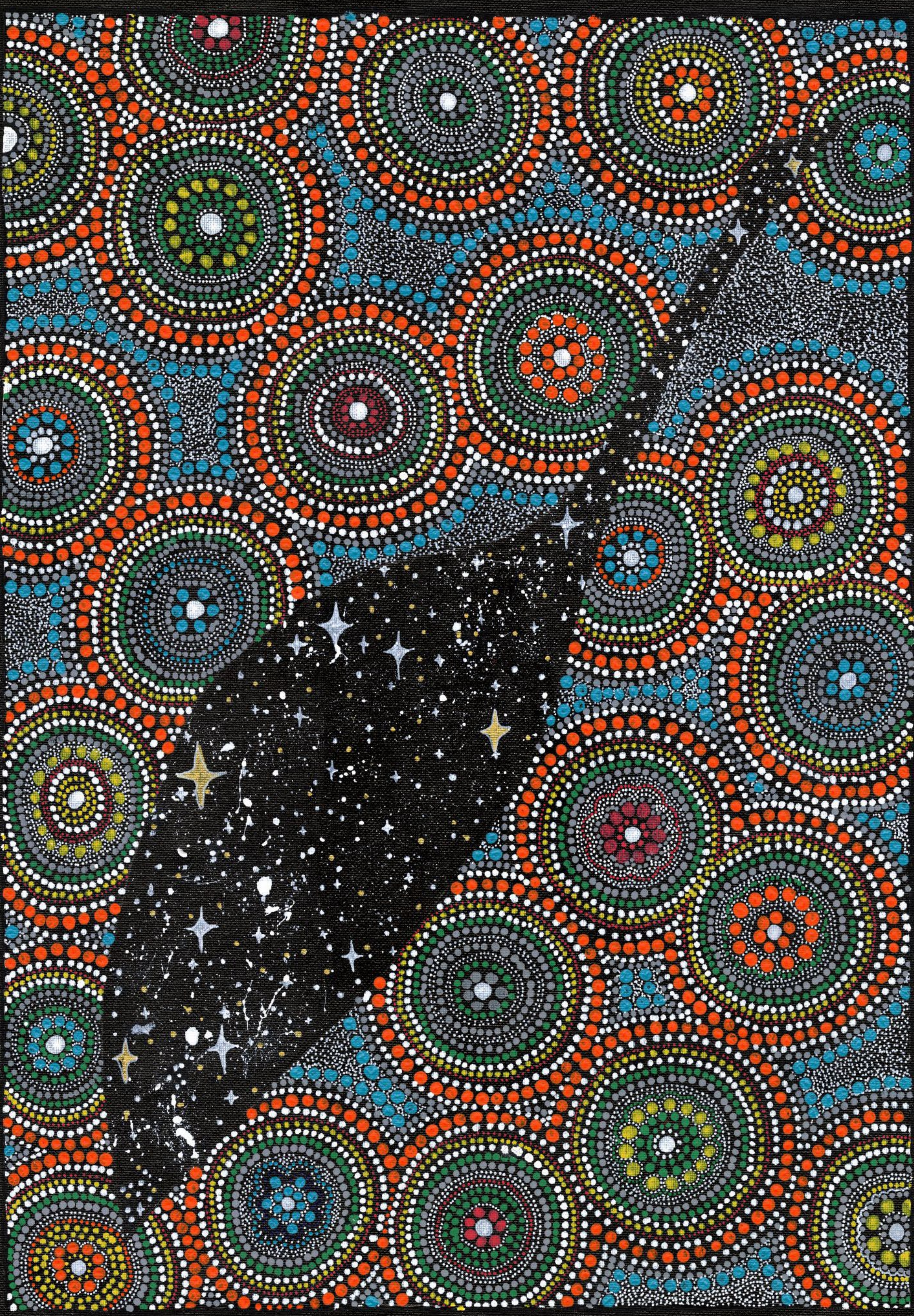
PhD theses

Theses awarded to co-supervised postgraduate students (PhD, unless marked otherwise).

NAME	UNIVERSITY	MONTH AWARDED	THESIS TITLE
Cherie Day	Swinburne University of Technology	January 2022	Pinpointing the origins of fast radio bursts
Yi Feng	National Astronomical Observatory of China	June 2021	Detecting gravitational waves using pulsar timing arrays
Lucas Hyland	University of Tasmania	September 2021	SpiRALS – Southern hemisphere parallax interferometric radio astrometry legacy survey
Dilpreet Kaur	Curtin University	June 2022	Probing the interstellar medium toward timing array millisecond pulsars with the Murchison Widefield Array
Emily Kerrison (Hons)	University of Sydney	December 2021	Probing the gaseous environment of active galactic nuclei through radio and X-ray absorption
Marcus Lower	Swinburne University of Technology	January 2022	Exploring the magnetospheric and rotational properties of radio pulsars
Noor Masdiana Md Said	University of Tasmania	November 2021	Intraday variability of active galaxies
Chikaedu Ogbodo	Macquarie University	March 2022	Mapping the Galactic magnetic field with OH masers
Dylan Pare	University of Iowa, USA	April 2022	Investigating properties of multi-stranded filament structures in the Galactic Center
Jonathan Rogers	University of Tasmania	November 2021	The environments of radio sources in the GLASS survey
Abhimanyu Susobhanan	Tata Institute of Fundamental Research, India	September 2021	Perspectives in nanohertz gravitational wave astronomy
Brandon Venville (Hons)	Swinburne University of Technology	December 2021	Investigating the gaseous nature of young radio galaxies

Artwork by Wajarri Yamatji artist, Zachriah George, representing an ASKAP survey science project.

"Inside the emu, the many, many galaxies are represented by dots and stars. The emu is looking at and looking into deep space." – Zachriah George, *EMU*, 2019, acrylic on canvas.



Observing programs

Proposals allocated time on ATCA, Parkes, the LBA and CDSCC over the April 2021 – September 2021 and October 2021 – March 2022 semesters.

ATCA

OBSERVERS	PROGRAM	NO
Stevens, Edwards, Wieringa, Moss	ATCA Calibrators	C007
Lundqvist, Perez Torres, Ryder, Bjornsson, Fransson, Filipovic, Kundu, Venkattu	Probing Type Ia Supernova progenitors with ATCA	C1303
Ryder, Kundu, Filipovic, Alsaberi, Anderson, Stockdale, Maeda, Renaud, Kotak, Marnoch	NAPA Observations of Core-Collapse Supernovae	C1473
Possenti, Wieringa, Esposito, Israel, Rea, Burgay	Continuum radio emission from magnetars in outburst	C2456
Atri, Miller-Jones, Jonker, Maccarone, Sivakoff, Tzioumis	Constraining black hole formation with LBA astrometry	C2538
Russell, Miller-Jones, Sivakoff, Altamirano, Soria, Krimm, Tetarenko	Jet-disc coupling in black hole X-ray binary outbursts	C2601
Piro, Ricci, Troja, Piranomonte, Fiore, Bannister, Wieringa, Sanchez Ramirez	ATCA observations of the new class of ultralong GRBs: a local proxy of popIII explosions?	C3001
Russell, Altamirano, Ceccobello, Lucchini, Markoff, Miller-Jones, Russell, Sivakoff, Soria, Tetarenko	The evolving jet properties of transient black hole X-ray binaries	C3057
Breen, Walsh, Rowell, Ellingsen, Cunningham, Jones, Burton, Contreras, Voronkov, Ott, de Wilt, Green, Barnes, Longmore, Indermuehle, Fuller, Avison, Smith, Bronfman, Novak, Toth, Jordan, Hyland, McCarthy, Phillips, Federrath, Jackson, Fissel, Kainulainen, Dawson, Schneider	StarFISH	C3145
van Velzen, Miller-Jones, Anderson, Goodwin, Shappee, Jonker, Arcavi, Holoien, Gezari	Radio emission from stellar tidal disruption flares	C3148
Perez-Torres, Gomez, Ortiz, Leto, Anglada, Trigilio, Alberdi, Amado, Gomez, Osorio, Umana, Peña	Confirming star-planet interaction in the radio emission from Proxima Centauri	C3180
Anderson, Bell, Hancock, Miller-Jones, Bahramian, Rowlinson, Aksulu, Bannister, van der Horst, Ryder, Plotkin, Wijers, D'antonio, Macquart	ATCA rapid-response triggering on Swift detected short gamma-ray bursts: Exploring the link with gravitational wave events	C3204
Shannon, Bhandari, Bannister, Mahony, Deller, Dodson, Flynn, James, Prochaska, Sadler, Tejos, Day, North-Hickey, Oslowski	Accurate positions and host-galaxy properties of ASKAP-localised FRBs	C3211
Chernyakova, Malyshev, van Soelen, Sobey, O'Sullivan, Mc Keague	Radio observations of PSR B1259-63 during the 2021 periastron passage in a multi-wavelength context.	C3218
Plotkin, Miller-Jones, Gallo, Jonker, Russell, Homan, Tomsick, Kaaret, Shaw	The Disk/Jet Connection for Hard State Black Holes	C3219
Piro, Troja, Ricci, Wieringa, Ryan, van Eerten	Late-time emergence of the radio kilonova of GW170817	C3240
Dobie, Murphy, Kaplan, Lenc, Brown, Stewart, Hotokezaka, Bannister	Long term radio follow-up of GW170817	C3251
Laskar, Alexander, Berger, Bhandari, Chornock, Coppejans, Drout, van Eerten, Fong, Guidorzi, Margutti, Mundell, Schady, Schroeder	GRB Physics with ATCA: Direct Implications for the Explosions and Progenitors	C3289
van Den Eijnden, Degenaar, Russell, Miller-Jones, Wijnands, Sivakoff, Hernandez, Santisteban, Rouco Escorial	Observing evolving jets during a Be/X-ray binary outburst	C3299
Horiuchi, Benner, Benson, Edwards, Stevens, Phillips, Stacy, Kruzins, Giorgini, Molyneux, Cashman, Slade	Southern Hemisphere Radar Observations of Near-Earth Asteroids	C3319
Orosz, Ellingsen, Voronkov, Burns, McCarthy, Hyland, Green, Breen	ATCA follow-ups of maser flares	C3321

OBSERVERS	PROGRAM	NO
Alexander, Wieringa, Berger, Blanchard, Bright, Cendes, Chornock, Coppejans, Cowperthwaite, Eftekhari, Fong, Gomez, Hosseinzadeh, Komossa, Laskar, Margutti, Nicholl, Saxton, Terreran, Williams, Hajela	Exploring Mass Ejection in SMBHs via Radio Observations of TDEs	C3325
Anderson, Miller-Jones, Rau, Malyali, Wilms, Kawka, Goodwin, Liu, Grotova	ATCA follow-up of eROSITA-detected Tidal Disruption Events	C3334
Bhandari, Mahony, Deller, Bannister, Shannon, North-Hickey	Monitoring host galaxies of fast radio bursts	C3347
Tothill, Rowell, Cunningham, Filipovic, Jordan, Voronkov, Crocker, Krumholz, Breen	Mapping the ionisation tracer HCO near the W28 SNR	C3348
Mader	Snap-shot observations of water masers for Parkes 13MM pointing	C3352
Uscanga, Imai, Orosz, Gomez, Tafoya, McCarthy, Villafranca	Southern sky monitoring of water fountains with FLASHING program	C3361
Carotenuto, Corbel, Tzioumis, Coriat	Constraining black hole accretion-ejection coupling at low accretion rate	C3362
Murphy, Kaplan, Stewart, O'Brien, Leung, Pritchard, Wang, Bell, Lenc, Dykaar, Gaensler, Wang, Horesh	Follow-up of transients from the ASKAP Variables and Slow Transients survey	C3363
Pritchard, Murphy, Zic, Lynch, Heald, Kaplan, Lenc, McConnell, Edwards, Perez-Torres	A survey of circularly polarised M-dwarf stars discovered by ASKAP	C3369
Anderson, Bell, Rowell, Schussler, Taylor, Miller-Jones, van der Horst, D'antonio, Aksulu, Bahramian, Einecke, Hancock, Ohm, Plotkin, Rowlinson, Ryder, Wagner, Wijers, Zhu	ATCA Rapid-Response and Monitoring Follow-up of HESS-detected TeV Gamma-ray Bursts	C3374
Miller-Jones, Anderson, Middleton, Rau, Wilms, Schmidt, Goodwin	Jet-disc coupling at the Eddington limit: transient ultraluminous X-ray sources with eROSITA	C3375
Murugeshan, Dzudzar, Kilborn, Wong, Cluver, Lutz, Parkash, Elagali, Gurvarinder	The lords of rings: HI gas and kinematic properties of ring galaxies	C3385
Dobie, Murphy, Kaplan, Stewart, Bell, Lenc, Bannister, Hotokezaka, Brown, Qiu, Zic	Searching for Radio Emission from Gravitational Wave Event S190814bv	C3386
Su, Sadler, Allison, Mahony, Moss, Whiting, Gu, Yoon, Glowacki, Weng	Searching for HI absorption lines in Luminous Infared Galaxies	C3392
Perez-Torres, Horesh, Schulze, Mattila, Nicholl, Mandel, Roy, Wevers, Leloudas	ATCA follow-up of e-PESSTO TDEs	C3394
Dobie, Murphy, Kaplan, Lenc, Stewart, Bell, Hotokezaka, Brown, Wang, D'antonio	ATCA Follow-up of Neutron Star Mergers	C3395
Perez-Torres, Tartaglia, Ryder, Kundu, Peña	ATCA observations of the Type IIn SN 2019esa	C3399
Imanishi, Horiuchi, Hagiwara	22 GHz H2O megamaser emission in the Superantennae at z = 0.0617	C3408
Ho, Dobie, Yao, Perley, O'Brien, Kaplan	A New Class of Engine-Driven Stellar Explosions	C3409
Wenger, Balser, Anderson, Armentrout, Bania, Dawson, Dickey	The Internal Kinematics of Galactic HII Regions	C3410
Shang, Zic, Ravi, Hobbs, Luo	A wide-band study of CU Virginis	C3411
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