Australia's National Science Agency

Australia Telescope National Facility

Annual Report 2020–21

CSIRO Australia Telescope National Facility
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This review of the CSIRO Australia Telescope National Facility spans the year from 1 July 2020 to 30 June 2021. Telescope usage data spans the April to September 2020 and October 2020 to March 2021 observing semesters. Publication data is from the calendar year 2020.

Editor: Nic Svenson

Cover: (Top) The sky over our ASKAP telescope. Image: Alex Cherney. (Bottom) Our cryogenically cooled phased array feed under construction. Image: Karl Schwerdtfeger.

ASKAP's RACS survey (the largest and most detailed survey of the southern sky ever undertaken in radio) as seen by Wajarri Yamatji artist, Margaret Whitehurst.

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 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

New Norcia, Yued people of the Noongar nation

Geraldton, Nhanhangardi, Naaguja, Wilunyu and Amangu

Murchison Radio-astronomy Observatory and Boolardy Station, Wajarri Yamatji

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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 leaders in technology and research.

The Australia Telescope National Facility (ATNF) is comprised of the Parkes radio telescope, Murriyang, Australia Telescope Compact Array (ATCA), and the Australian Square Kilometre Array Pathfinder (ASKAP). 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 radio astronomy research and development program we ensure our telescopes remain world class and support future facilities, such as the international SKA project.

Astronomers 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 800 astronomers from all over the world. Time can also be purchased. For example, we have a five-year agreement with US space technology company Intuitive Machines to use Parkes to gather and downlink data from its spacecraft carrying NASA payloads to the Moon.

The primary output from the ATNF is scientific research. In 2020, astronomers published 115 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 through our student learning and teacher training programs and in the stories of our people, infrastructure and the excellent science we enable and how this delivers benefit for Australia.

Radio telescopes are so sensitive they could detect a mobile phone on the far side of the Solar System. Our people work with the international regulatory bodies that manage uses of the radio spectrum to protect our telescopes, and others around the world, from increasing interference. In Australia there are Radio Notification Zones around ATCA and Parkes while a Radio Quiet Zone gives special protection to the 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 28).

Our Parkes radio telescope was given the name Murriyang by the Wiradjuri people, the traditional owners of the observatory site. Murriyang is the skyworld where Wiradjuri creator spirit Biyaami (Baiame) lives. Image: CSIRO/Farmpix.

Chair's report

There is a different look and feel to this Annual Report as we seek to make the outstanding science and engineering of the Australia Telescope National Facility (ATNF) more accessible.

This year, the ATNF Steering Committee (ATSC) backed use of ASKAP for finding fast radio bursts (FRBs). While this investment continues to pay scientific dividends, with more being discovered about these elusive phenomena every day, even more is promised by an Australian Research Council grant to our partners at Swinburne University of Technology. This will see the ATNF build the next-generation FRB detector for ASKAP.

With completion of ASKAP's first all-sky survey (page 13), we are witnessing the telescope's realisation as the world's leading rapid survey instrument. To maximise scientific return and efficient use of telescope time, the ATSC has overseen formation of an international committee to re-assess ASKAP's Survey Science Projects (originally reviewed in 2009). The review will occur next year.

Also this year, start-up company Quasar Satellite Technology was launched to apply the next generation of ASKAP receiver technology to satellite communications (page 20). The ATSC has long championed this effort and we are immensely proud of this ATNF commercialisation achievement.

Additionally, the ATNF vigorously pursued commercial opportunities for using telescope time. Spacecraft communication surfaced as the key opportunity and one company is already signed up. This external revenue enables the ATNF to maintain its decades-long astronomy commitment to telescope access free of charge based on scientific merit.

The ATSC met twice this year, with COVID-19 again meaning many members joined virtually. The ATSC appoints the ATNF Users' Committee (ATUC) and the Time Assignment Committee (TAC). We are grateful for the connection to the community provided by ATUC and of the diligence of the TAC.

I am stepping down after five years with the ATSC. I have witnessed both the transformation of the ATNF into a strategic R&D and business organisation and the early stages of what will be a massive ramp-up in people and capacity as the SKA gets underway in Australia.

The ATSC is an advisory committee to the CSIRO Board. As such, we commend this Annual Report to the Board and to the astronomy community.

Dr David Skellern AO

ASKAP after the rains. Image: Kurt Warhurst.

Director's report

The first radio astronomy observation in Australia occurred on 3 October 1945 when our researchers observed the Sun using radar equipment they helped develop as part of Australia's war effort. Now, 75 years later, the Parkes radio telescope, Murriyang, ATCA and ASKAP – collectively the ATNF – are used by astronomers around the world to improve our understanding of the Universe.

For example, ASKAP pinpointed the origin of fast radio bursts, as published in *Science* last year, which led to the discovery of the missing 'normal' (baryonic) matter of the Universe. The localisation work won the American Association for the Advancement of Science Newcomb Cleveland Prize. And the Rapid ASKAP Continuum Survey, published this year, revealed three million galaxies, a million of which we've never seen before. ATCA was used to find evidence of planets forming around young stars, and Parkes to observe unusual behaviour in a new magnetar.

Our Murchison Radio-astronomy Observatory, home to ASKAP, will soon also house the low frequency telescope of the international SKA project, SKA-Low. This year the SKA Observatory was formed by its member countries, and the SKAO approved construction. This was the conclusion of a decade's work designing the SKA telescopes and the Observatory in a global effort that CSIRO has supported since the first discussions in the late 1990s. In a bittersweet moment, I farewelled two of my leadership team. Deputy Director, Sarah Pearce, was appointed the inaugural Director of the SKA-Low telescope and Antony Schinckel, who led construction of ASKAP and our SKA design work, will now head construction of SKA-Low.

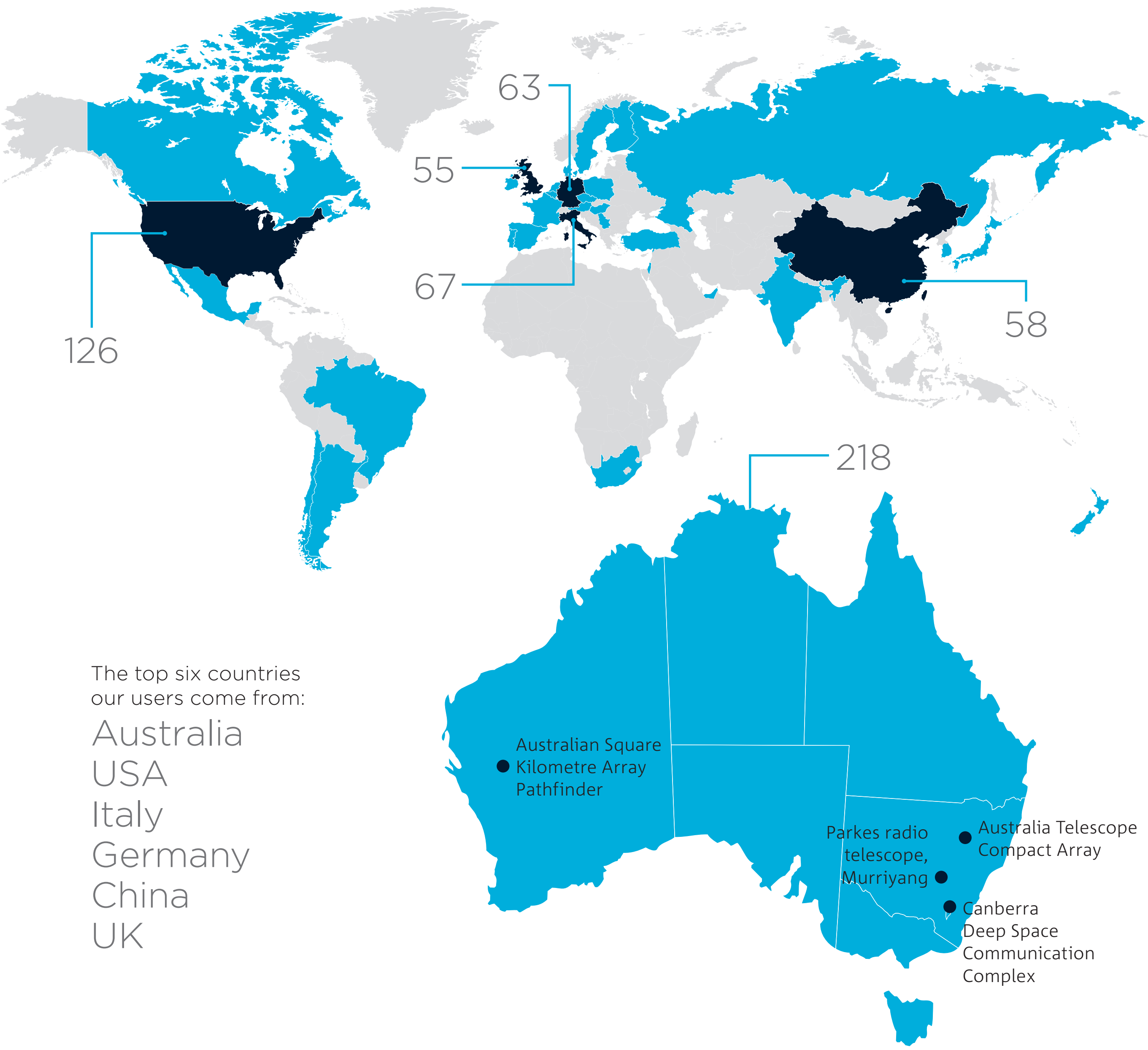
This year again saw great disruption to the normal way of doing things due to COVID-19. There were few international scientific meetings and those that did occur were virtual. We saw this as an opportunity to explore using new technology to make these meetings more effective, accessible and environmentally sustainable. The Future of Meetings symposium we ran attracted over 1000 participants globally. Its findings, detailed in an invited comment piece in *Nature Astronomy*, are motivating worldwide change for the better.

After yet another challenging year, I thank our people for their strength and commitment, and the ATSC, ATUC and TAC for their advice and guidance in keeping the ATNF at the forefront of discovery.

Dr Douglas Bock

2020–21 snapshot

268 observing proposals
802 astronomers
from 35 countries



The top six countries our users come from:

Australia
USA
Italy
Germany
China
UK

Time spent observing
73% ATCA
78% Parkes

4.07
petabytes
in the data archives

150
papers
by our staff

115
papers
cite ATNF data

194
staff

35
postgraduate
students

180
school students
did PULSE@Parkes

122 844 people
came to our visitor centres

Square Kilometre Array

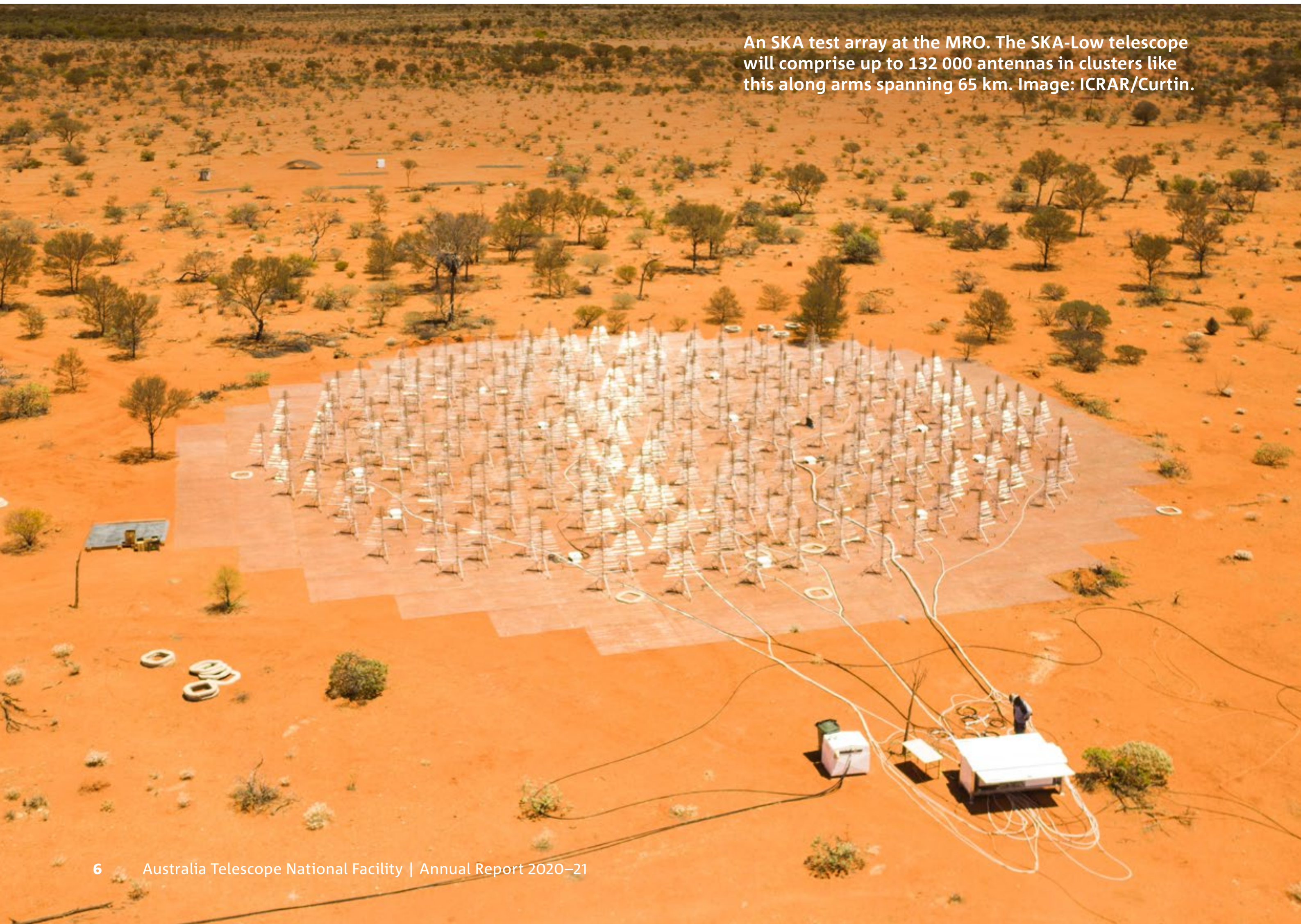
The coming years will see a massive growth in radio astronomy in Australia and in CSIRO due to the international effort by twelve member countries to build the world's largest, most advanced radio telescopes in South Africa and Australia.

The SKA-Low site

Our Murchison Radio-astronomy Observatory (MRO) in Western Australia will be home to the SKA's low frequency telescope, SKA-Low. We will continue to manage the MRO on behalf of the nation to support radio astronomy, including with our own ASKAP telescope, and we will operate SKA-Low in partnership with the SKA Observatory.

In June the SKA Observatory's governing Council approved construction of the two SKA telescopes. Construction of SKA-Low at the MRO is expected to start in 2022.

An Indigenous Land Use Agreement (ILUA) with the Wajarri Yamatji traditional owners is necessary for SKA-Low to be built and operated in Australia. The ILUA process includes surveying the land on which SKA-Low will be built for artefacts or sites of significance to the traditional owners. Adjustments to the configuration of the telescope have been made to protect cultural heritage. At a community meeting in June of over 200 Wajarri people, a resolution was passed that provided in-principle support to both the SKA Project and to a process for finalising the ILUA. Other agreements, such as the lease over the land from the WA Government, are contingent on the ILUA being agreed.



An SKA test array at the MRO. The SKA-Low telescope will comprise up to 132 000 antennas in clusters like this along arms spanning 65 km. Image: ICRAR/Curtin.


SKA-Low antennas in a test array at the MRO. Image: Michael Goh and ICRAR/Curtin.

One of our roles as manager of the MRO is to maintain radio quiet protections. Low population density in the Murchison means there is less radio frequency interference (RFI) that can drown out or mimic the weak signals radio telescopes are trying to detect, so it is essential that the radio quiet environment be protected. The primary protection is afforded by a series of concentric zones established by the Australian Communications and Media Authority. Radio astronomy is the primary user of spectrum within 70 km of the centre of the MRO, and protections extend out to 260 km. We also have strict on-site standards and RFI monitoring to keep local interference to a minimum.

The telescope

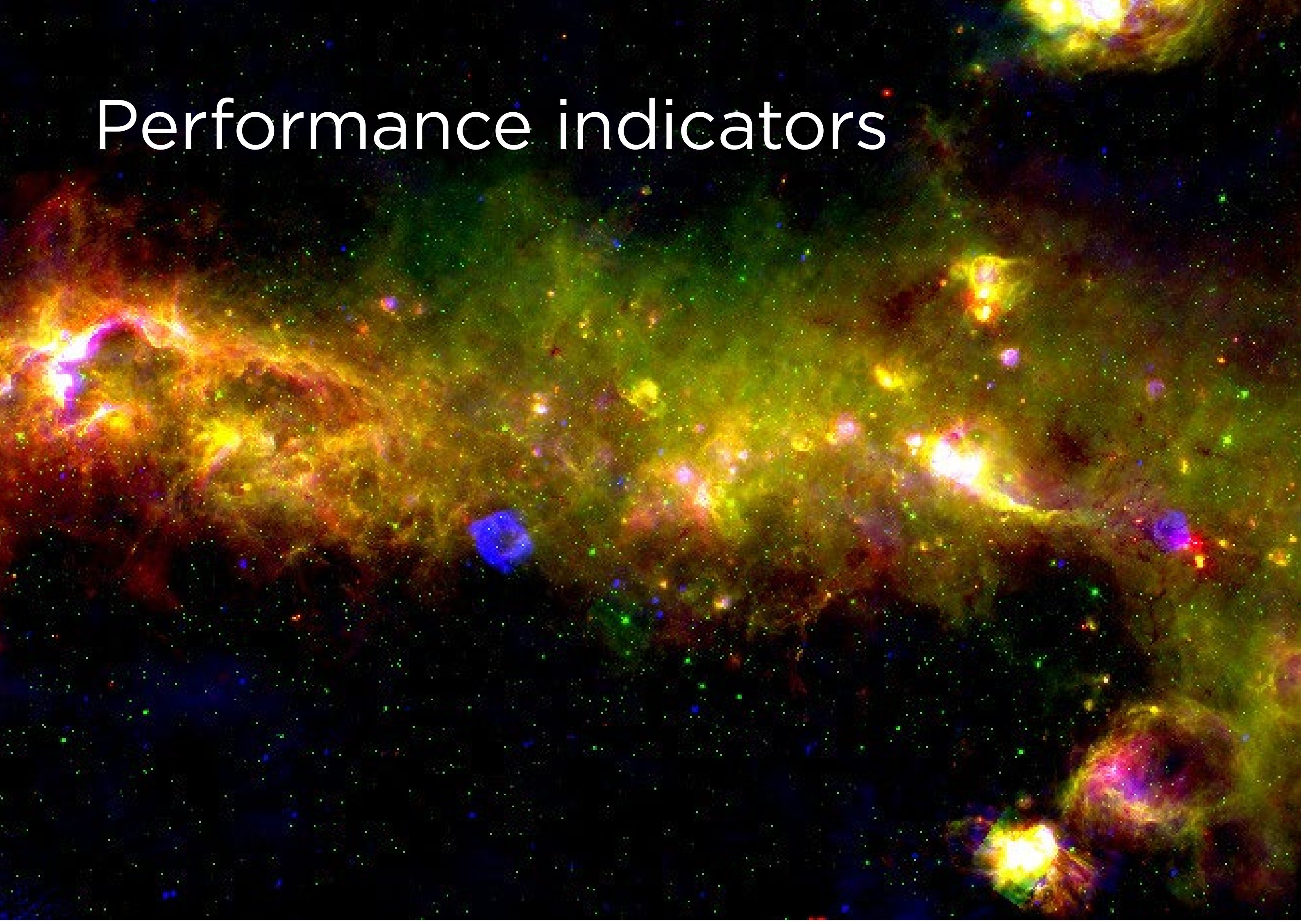
CSIRO will take a leading part in construction of site infrastructure, the telescope's correlator and beamformer, and assembly integration and verification of SKA-Low, among other roles.

This year we supported a range of activities contributing to ongoing development of telescope software, SKA-Low correlator beamformer design, site infrastructure design, system reviews, and contracting strategies, all aimed at ensuring readiness for SKA construction. Our astronomers contributed to the SKA Science Working Groups.

The software development teams (YANDA and VIOLA) will continue throughout SKA construction; this year has seen the Scaled Agile Framework® method embedded in practice, refine the three-monthly program increment planning processes, and assist in forming the core teams. The correlator beamformer team developed a new scalable architecture based on commercially available components. Detailed design work for SKA-Low site infrastructure continued, including development of tender documentation. The SKA-Low prototype system integration facility was set up at our site in Sydney, providing a platform for early integration of the SKA-Low system.

Additional funding for the SKA of $387m, announced by the Australian Government in April, included $66m for the Australian SKA Regional Centre (AusSRC), through which astronomers will access SKA data. The AusSRC is a collaboration between ICRAR, CSIRO and the Pawsey Supercomputing Centre.

Performance indicators



Telescope usage

We continue to meet our KPIs for ATCA and Parkes, with performance in line with recent years (Figure 1):

- At least 70% of telescope time successfully used for observing: ATCA achieved 73%, Parkes 78%.
- No more than 5% of time lost during scheduled observations due to equipment failure: ATCA lost 1.7%, Parkes 2.8% of time.

ASKAP is incrementally building towards these KPIs and this year achieved 39% observing time, just below its 2020–21 target of 40%. ASKAP lost 6.5% observing time when the fire suppression system in the MRO control building was twice triggered by user-supplied equipment overheating; steps have been taken to prevent a recurrence.

CDSCC antennas were included in the LBA for 51 hours of observing time. In addition, the antennas at CDSCC were used for 107 hours to do bistatic radar observations of near-Earth objects, transmitting signals later received by ATCA.

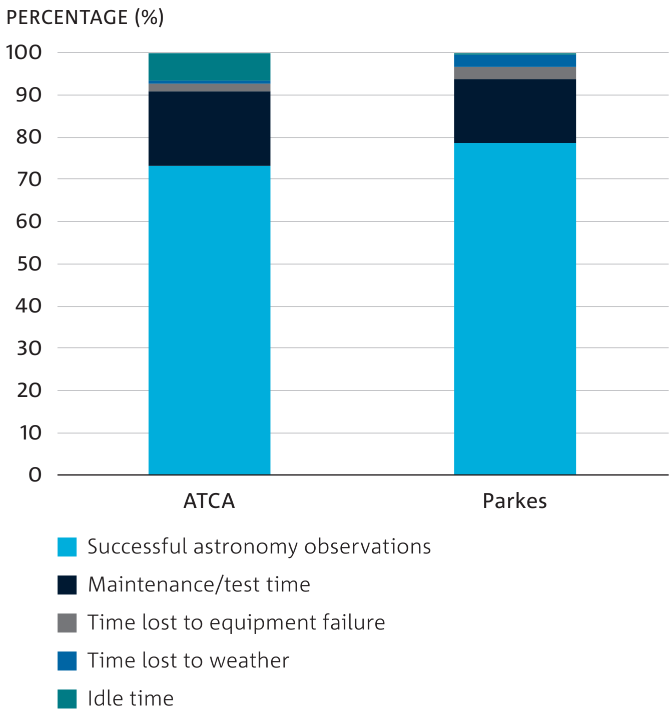
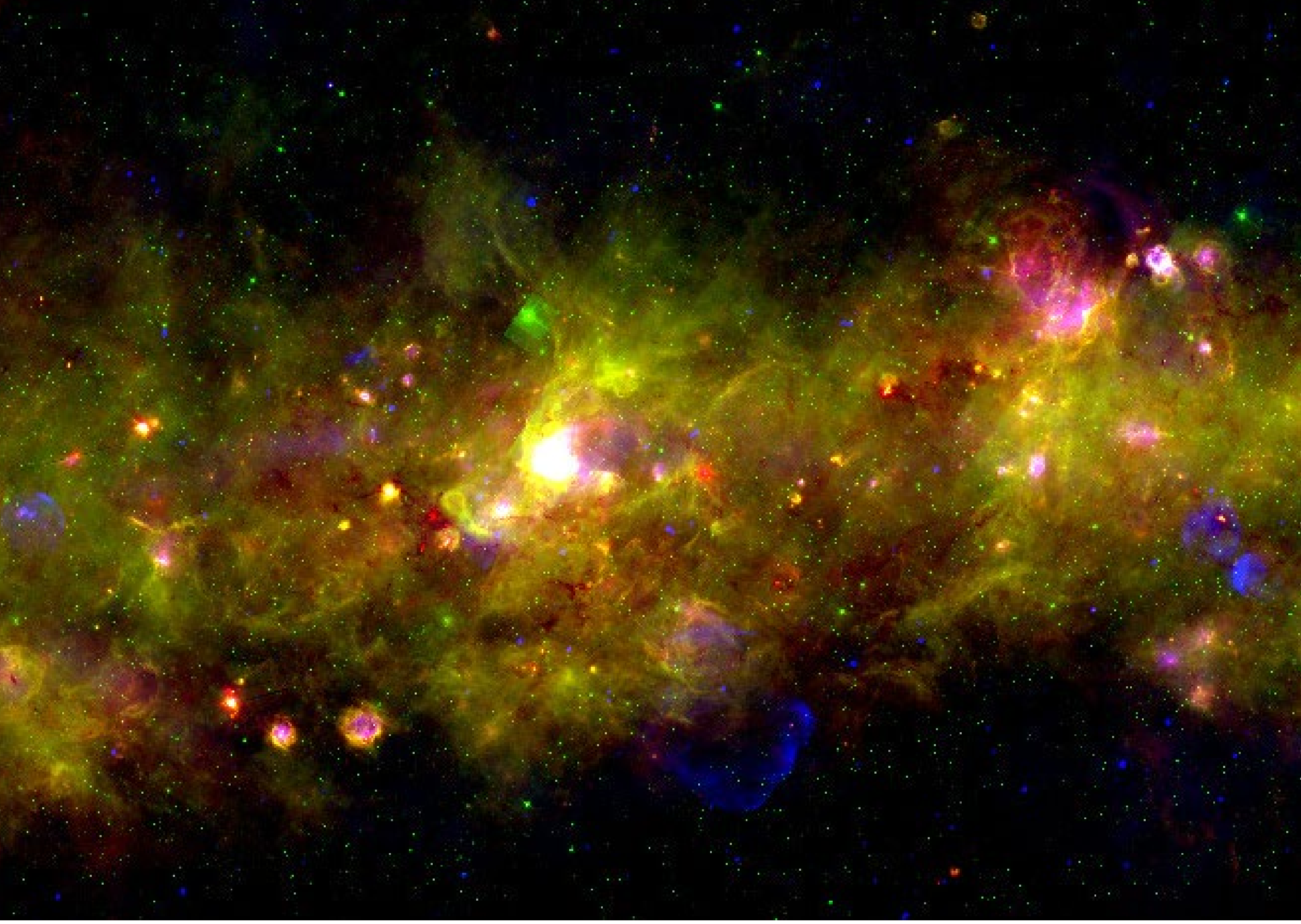


Figure 1: Use of ATCA and Parkes in this reporting period.



SCIENCE HIGHLIGHT

This image shows results from the first ASKAP survey of the Galactic Plane – the band of stars, dust and gas across the southern sky. The Evolutionary Map of the Universe (EMU) survey science team looked at a region of the Milky Way covering 40 square degrees as part of its early science program with the telescope. Although only 15 of the 36 antennas were operational at the time, ASKAP's ability to map complex or extended sources in our Galaxy is clearly demonstrated.

The sources shown here include both stellar 'nurseries' of newly formed stars, and the remnants of stars that have ended their lives, sometimes in supernova explosions. These radio sources are embedded in diffuse radio emission from the Galaxy, which has made it more difficult for radio astronomers to study before now.

This image combines data from ASKAP and two infra-red surveys: blue is ASKAP; green is the GLIMPSE survey from NASA's Spitzer space telescope; red is the Hi-GAL survey from ESA's Herschel space telescope. Image: INAF.

Umana et al. 2021 MNRAS (accepted) and Riggi et al. 2021 MNRAS 502, 60.

Time allocation

There were 268 observing proposals received for ATCA, Parkes and the LBA: 201 of these were unique proposals. The telescopes were in demand with an oversubscription rate of 1.3 for Parkes, 1.8 for ATCA (after excluding legacy projects) and 1.5 for the LBA. The observing teams consisted of 802 researchers from 35 countries. CSIRO people led 18% of unique proposals, 26% were led by staff of other Australian institutions and 56% by overseas researchers. After Australia, the highest demand for our telescopes came from the United States, followed by Italy, Germany, China and the United Kingdom.

In total 172 proposals were allocated time: 76 on ATCA, 79 on Parkes and 17 proposals on the LBA (see page 31). More proposals were granted time as ATCA legacy projects requiring significant observing time concluded, and the sensitivity of the ultra-wideband receiver on Parkes has made it a popular instrument. Time allocation for ATCA and Parkes is shown in Figures 2 and 3.

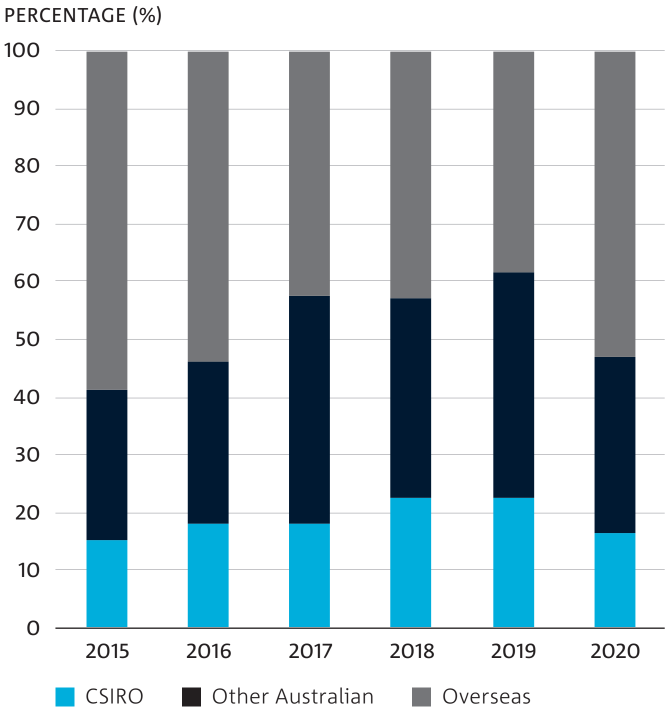


Figure 2: Time allocation on ATCA by all investigators.

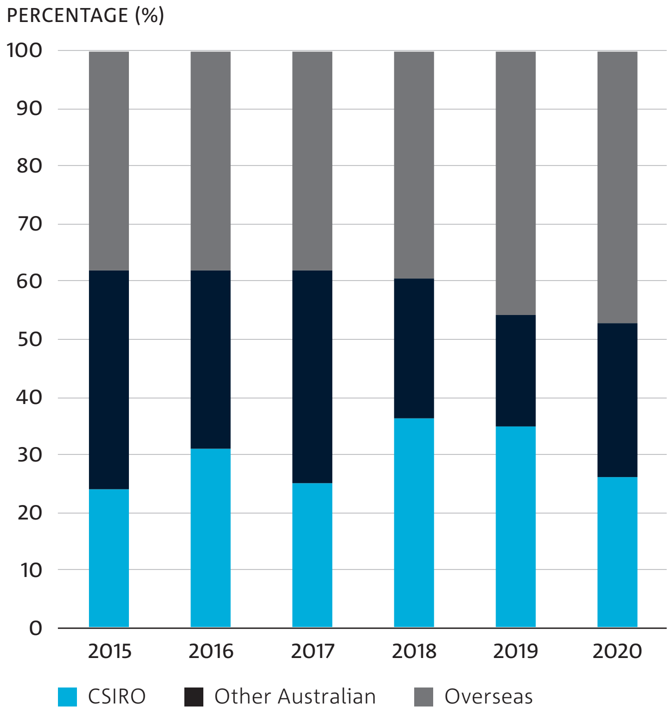


Figure 3: Time allocation on Parkes by all investigators.

Publications

In 2020, 115 refereed papers were published that used data from ATNF telescopes: 64 (57%) included a CSIRO author. Our people published 150 refereed papers, including those using data from other facilities. Altogether, there were 199 refereed journal papers and 16 conference papers that used ATNF data and/or had ATNF authors, listed at: www.atnf.csiro.au/research/publications.

Publication output from ATCA, Parkes and the LBA remain steady. The Mopra figure reflects archival data as the telescope has not been offered as part of the ATNF since 2012. ASKAP publications were lower in 2020 but there were 18 refereed publications in the first six months of 2021.

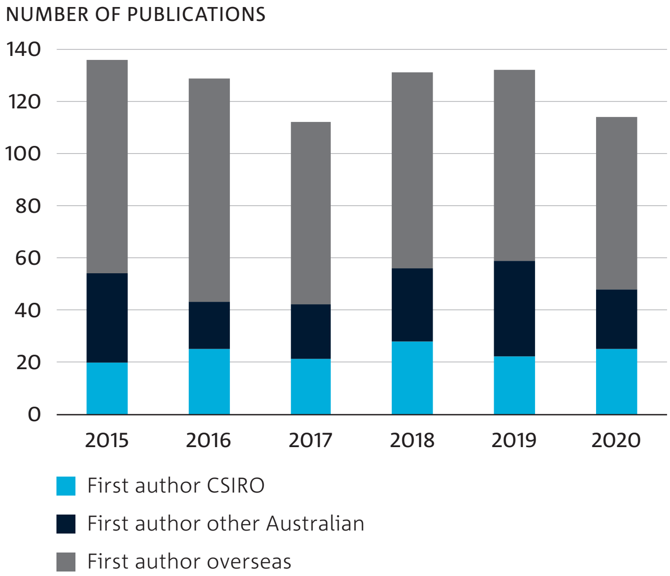


Figure 4: Refereed publications using data from ATNF telescopes.

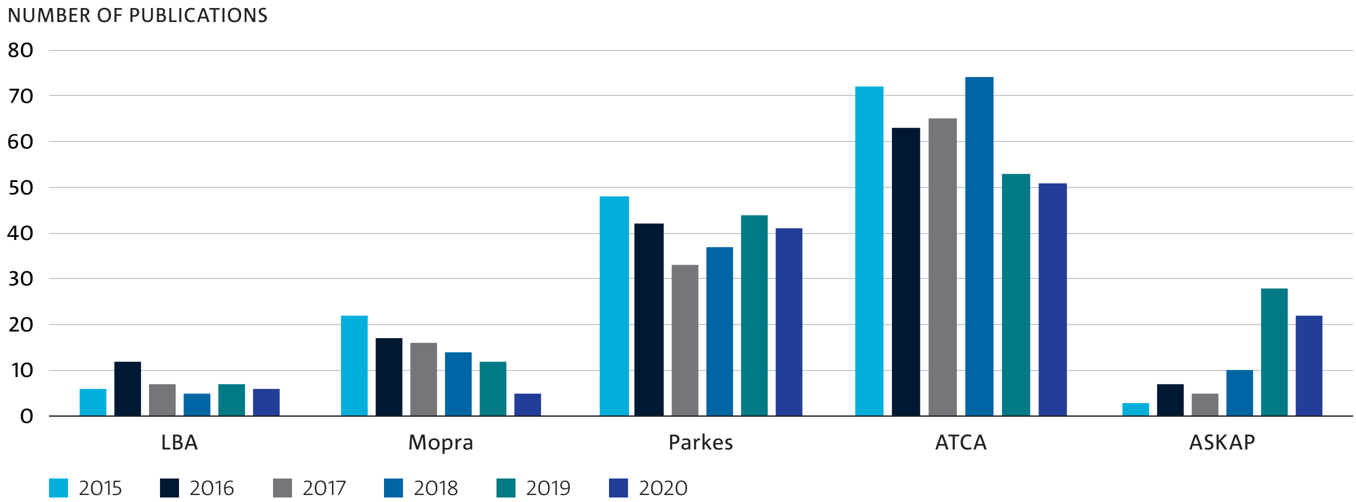


Figure 5: Refereed publications using data from the ATNF, grouped by telescope. A few papers with data from more than one telescope are counted more than once.

Australian Square Kilometre Array Pathfinder

The ASKAP system description paper describes the design and capabilities of the telescope so will be cited in all future ASKAP publications: Hotan et al. 2021 PASA 38, e009.

First all-sky survey

ASKAP completed its first all-sky survey, ably demonstrating its power as a highly sensitive, rapid survey machine. Late in 2020, 903 images were released into the data archive CASDA, comprising the first pass of the Rapid ASKAP Continuum Survey (RACS). This first survey was made at ASKAP's lowest frequencies, centred at 888 MHz and spanned 288 MHz. We have since observed the same area in a second band (centred on 1296 MHz, 144 MHz wide) and will soon make a third pass (at around 1700 MHz and about 200 MHz wide), completing ASKAP's frequency coverage and enabling the galaxies to be better characterised. RACS is the new benchmark survey at these frequencies and a key component of our calibration strategy, which will use prior knowledge of the sources in any observed field to calibrate the telescope, eliminating the need for dedicated calibration observations.

Pilot surveys

ASKAP's first round of pilot surveys, completed in May 2020, showed the power of the telescope and highlighted areas for development. Most of the data from the first round of pilot surveys has been processed and the images, data cubes and catalogues released via CASDA. The ASKAP operations team worked closely with the survey science teams and the technical working groups to refine the processing pipeline. Together we gained a much better understanding of how to process data sets to meet the research teams' science goals.

Another round of pilot surveys and simultaneous (commensal) observing will prepare the telescope and research teams for full surveys to start in 2022.

SCIENCE HIGHLIGHT

The Rapid ASKAP Continuum Survey (RACS) is the most detailed radio survey of the southern sky ever undertaken and was completed in record time: less than 300 hours of observing time. ASKAP's wide field of view and large number of antennas enabled it to produce images significantly better than previous surveys, which took years to complete.

RACS revealed about three million galaxies, a million of which had not been previously catalogued. These 'new' galaxies are intrinsically fainter, or are further away, but are important for a better census of the Universe. Most specks in this image are galaxies, not stars, while the insets show galaxies at the full survey resolution.

Image: Red Empire Media, Emil Lenc and Sam Moorfield.
McConnell et al. 2020 PASA 37, e048

Sharper view

ASKAP's rapid survey speed originates from its advanced phased array feed receivers. ASKAP's receivers form multiple electronically steered beams that can cover a large field of view with a single antenna. There are more beams formed near the edge of the receiver (off-axis), than near the middle (on-axis). Those at the edge suffer more distortion than those in the middle and astronomers must account for this when combining data from all the beams and forming an image. We developed an advanced holographic measurement technique to map the shape of each beam, allowing us to better mosaic the full field of view. Testing on RACS data reveals we have improved the accuracy of the outer regions of ASKAP images by more than 10%.

We have started applying this know-how to polarisation leakage. Studying polarisation is fundamental to understanding magnetic fields and the role they play in galaxy evolution. Leakage of unpolarised signal from a bright radio source can create fake polarisation that is not a property of the source itself. Using our new holographic technique may provide some of the most accurate and reliable rotation measure data ever published.

SCIENCE HIGHLIGHT

ASKAP has been used to detect a strong radio burst from Proxima Centauri, the star closest to our Solar System. The influence of solar flares and radio bursts from our Sun on planets like the Earth is well known. Proxima Centauri is smaller than the Sun and it has two rocky planets in its 'habitable zone', which held the promise of harbouring life. However, these planets orbit close to the star and the strong radio burst indicates the accompanying radiation on these planets would snuff out any form of life. If these flares happen from Proxima Centauri, then there's every chance they're happening from other stars too, something to take into account when considering which distant planets might harbour life.

Zic et al. 2020 ApJ 905 23.

Parkes radio telescope, Murriyang

'The Dish' was honoured twice this year: it was included on Australia's National Heritage List and given a complementary name by Wiradjuri Elders, traditional owners of the region. The 64-m dish was named Murriyang, after the sky world home of prominent creator spirit Biyaami (Baiame) who is represented by the stars also known as the constellation Orion. Two decommissioned antennas at Parkes Observatory were also named: the 18-m antenna was dubbed Giyalung Guluman or 'smart dish', because it is on tracks and could observe while in motion; and the 12-m antenna was named Giyalung Miil or 'smart eye', because it was used to test receivers for ASKAP.

It was the end of an era when the 13-beam multibeam receiver was decommissioned on 2 November 2020. Over its 23-year career, researchers using the multibeam surveyed the entire southern sky, detecting neutral hydrogen emission from over 5000 galaxies and also that a stream of gas and was being pulled by our Galaxy off our galactic near-neighbours the Magellanic Clouds; finding over 1000 pulsars including the only known double pulsar; and discovering the first known fast radio burst (and going on to lead research in this field for a decade).

Preparations for Parkes' new receiver, the cryogenically cooled phased array feed (CryoPAF), dominated this year's maintenance schedule; we increased the diameter of the helium lines for greater cooling, installed new fibre optic cable and renovated the computing racks. We plan to deploy the CryoPAF to Parkes for ground-based testing early in 2022.

Meanwhile, the low frequency ultra-wideband (UWB-L) receiver is in high demand – almost all observing proposals request it – and generating exciting results. Looking to future developments, we submitted a funding proposal to build a high frequency ultra-wideband (UWB-H) receiver to cover higher frequencies: 4 GHz to 26 GHz, or even 32 GHz.

The major maintenance activity was replacement of Parkes' drive control and interface system, which links the telescope master control panel with the motors that move the dish. The project to design, build and install the modern drives interface control enclosure, or DICE, called on people from across the ATNF and took about a year to complete.

SCIENCE HIGHLIGHT

Parkes has detected more pulsars – rapidly rotating neutron stars – than all the other radio telescopes in the world combined. Parkes' new low frequency ultra-wideband receiver is now enabling a rare sub-class of pulsar known as a magnetar to be better understood. A team led by one of our co-supervised students observed previously unseen behaviour from a new magnetar discovered in March 2020. Observations in May showed the magnetar to be behaving like a regular pulsar, appearing brighter at lower frequencies. But in July it was flickering between this pulsar-like state and a magnetar-like state where it was brighter at higher frequencies. This bizarre behaviour is best explained if the magnetic axis of the magnetar is not aligned with the axis around which it is spinning. There have been theories that some fast radio bursts originate from magnetars, and these will now have to account for radio pulses coming from multiple sites within their magnetic fields.

Lower et al. 2020 MNRAS 502 1

Our Parkes radio telescope, Murriyang was one of many iconic structures to be lit orange during National Volunteers Week 2021. For us, it was a gesture of thanks to the volunteer-based State Emergency Service, which is a major contributor to our large public events such as the Apollo 11 anniversary weekend held in 2019. Image: John Sarkissian.

SCIENCE HIGHLIGHT

Protoplanetary discs – gas, dust and debris swirling around young stars – are, as the name suggests, where planets form. ‘Transition discs’ are particularly interesting because it looks like there’s a cavity, or gap, between the disc and the star. Is this because, as the disc spins, larger grains are thrown further out? Is there some kind of gravitational boundary where dust on one side falls into the star and the rest stays in the disc? Or is this cavity the very early signs of a new planet: the gathering up of the first particles? The Discs Down Under project compared ATCA observations of 15 transition discs in the 7 mm band with data from the millimetre-wave ALMA telescope, and lean towards the presence of companion object – either a star or a new planet – as being the cause of the cavities.

Norfolk et al. 2021 MNRAS 502 4

Australia Telescope Compact Array

ATCA's long-running program of legacy projects (major projects to generate data of lasting importance to the astronomy community) continued. After beginning in October 2016, IMAGINE (Imaging Galaxies Intergalactic and Nearby Environments) completed observing this year. IMAGINE's 2591 hours will reveal how diffuse hydrogen gas surrounding some galaxies clumps together to form a new star. There are two legacy projects yet to finish.

With COVID-19 restricting the number of people on site, we improved emergency communications between those at the observatory and those working from home by installing a UHF-cellular relay. This allows people on site to use their handheld UHF radio, which is standard equipment for our team, to link to the mobile phone network and call a colleague. Being a radio quiet site, mobile phones are switched off at the observatory.

The ATCA visitors centre offers a self-guided experience and many visitors, despite all the signs, don't turn off their phones. We built a detector to pick up the radio frequency interference from mobile phones and trigger broadcast of a message over loudspeakers asking visitors to turn off their devices.

BIGCAT is a new digital system to replace the aging Compact Array broadband backend (CABB) system. This year, 90 participants, mostly astronomers, attended an online workshop to develop science requirements for BIGCAT. Testing at site will begin in 2022.

In our ongoing program to upgrade electrical infrastructure in the antennas, this year we improved controls for the back-up power generators in two of ATCA's six antennas. This new hardware enables us to reset fault conditions remotely, if nobody is on site, saving time and effort. We will now roll this out to all the antennas.

We run monthly photography nights during winter when the Galactic centre is directly over Narrabri. Up to 50 people come each month to take photos of ATCA against the sky. Image: Jong Lee.

SCIENCE HIGHLIGHT

One of our co-supervised students led work in the emerging field of applying machine learning to radio astronomy. In this era of all-sky surveys, the advantages of automatically classifying hundreds of thousands of sources of radio waves are clear. One common classification is Faraday complexity/simplicity – a measure of polarisation, which offers insights into both the source itself and what lies between the source and us.

The team took five Faraday features, used those to train two types of machine learning classifiers, then fed the classifiers both simulated data and real data taken with ATCA. On simulated data the team achieved state-of-the-art accuracy. The results on real data were entirely plausible, a promising start for this approach.

The main problem in using machine learning in radio astronomy is that a lot of well-classified data is needed to train the engines. Training engines on simulated data means the simulation must be realistic if the results are going to be useful. With the huge data sets ASKAP and the SKA will produce, further advances in this field can be expected to follow.

Alger et al. 2021 PASA 38 e022

Long Baseline Array

The 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 observe together (a technique called very long baseline interferometry, VLBI). The massive resolution achieved by having telescopes spread between continents means astronomical phenomena, such as black holes, can be studied in such detail that the physics behind their origin is revealed.

The bulk of this year's LBA observations occurred during five VLBI sessions. An increasing number of proposals seek to use VLBI to follow up detections made by other instruments, particularly the big X- and Gamma-ray space telescopes.

SCIENCE HIGHLIGHT

The bright radio galaxy PKS 2153-69 was the first galaxy imaged by ATCA over 30 years ago. The LBA has now produced images of the centre of the galaxy that are 1000 times more detailed. The study was part of the Tracking Active Nuclei with Austral Milliarcsecond Interferometry (TANAMI) collaboration, which is primarily surveying galaxies detected by NASA's Fermi gamma-ray satellite. While PKS 2153-69 shares many radio properties with gamma-ray emitting galaxies, it has to date been gamma-ray quiet for reasons that are not yet clear.

Angioni et al. 2020 A&A 641 A152

SCIENCE HIGHLIGHT

Apep is a system of two massive stars, each 20 times the mass of our Sun. Both are in the final stages of life before they collapse and go supernova. Apep is unusual in that it is very radio bright, but why? Astronomers used the LBA (in this case 10 telescopes across Australia and New Zealand) to achieve an angular resolution sufficient to see a truck on the Moon, which revealed the answer. The radio emission is coming not from the stars but from the collision of the tremendous solar winds ejected from the two stars at millions of kilometres an hour.

Marcote et al. 2021 MNRAS 501 2

Data from all LBA observations were correlated using the distributed FX (DiFX) software correlator running on the Magnus machine at the Pawsey Supercomputing Centre in Perth. This year we correlated data from 742 hours of observations and used 190 000 hours of CPU time. The median time from observation to data release was 188 days. A new datastore using Pawsey's Nimbus virtual machine has now reduced the turnaround time to 63 days. All correlated data was verified and uploaded to the Australia Telescope Online Archive.

This year we have been testing the GPU processing cluster at Parkes as a replacement for the aging VLBI digital backend system, also located at Parkes. The tests were successful, and the GPU-based system will be put into use by the end of 2021. This approach means a single digital backend can be used for all Parkes' observing.

The LBA this year used three 34-m antennas of the CDSCC. Image: CSIRO-NASA.

Data archives

Data from our telescopes is maintained in three archives, all in regular use by astronomers downloading the latest observations, or undertaking archival research, such as studying how astronomical phenomena have changed over time.

Parkes pulsar archive

Our pulsar data is now about 2.7 PB in volume and is increasing at about 0.8 PB annually. Pulsar data makes up over 90% of the CSIRO's Data Access Portal (DAP). Over 2 PB are now publicly available. On average, 70 pulsar collections are accessed each month.

Australia Telescope Online Archive

The ATOA is now around 370 TB in size and growing steadily at about 50 TB annually. About 2 TB of ATOA files are downloaded in a typical month. The ATOA will soon have to grow to accommodate the higher data rates of BIGCAT and CryoPAF, as it did when Parkes' ultra-wideband receiver came online. We plan to migrate the ATOA into a renovated CASDA in the latter half of 2022.

CSIRO ASKAP science data archive

There has been sustained high usage of CASDA since the release of data from ASKAP's RACS and pilot surveys. CASDA now contains over 1 PB of data and every day sees it handling about 500 virtual observatory requests and 15 enquiries direct from the web user interface.

Developments to CASDA included new functionality that allows users to easily find and see 'events', such as new deposits to, or releases from, the archive.

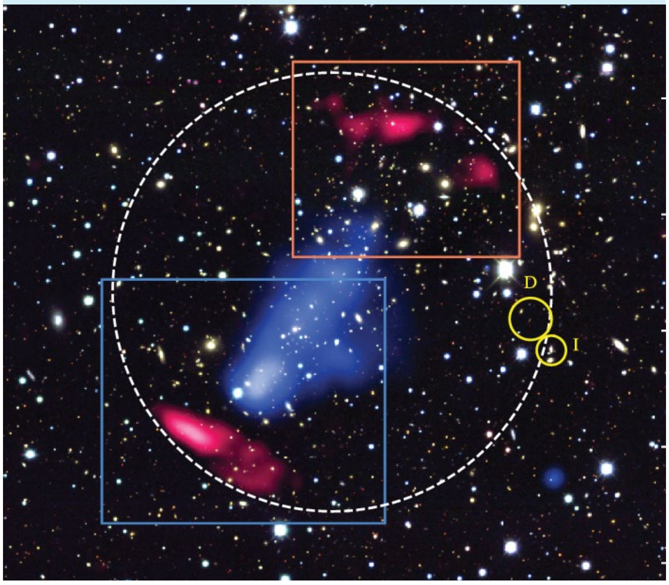
CASDA storage is currently housed on a tape-based system at the Pawsey Supercomputing Centre in Perth. Later in 2021 it will be moving to new disk-based infrastructure. Much of our work this year has been preparing for the migration.

CASDA's data-related software is migrating to Pawsey's Nimbus virtual machines, replacing the aging CASDA servers. This is expected to be complete by the end of 2021.

SCIENCE HIGHLIGHT

It took the sensitivity of ASKAP and archival ATCA data to find rare radio relics at either side of galaxy cluster SPT-CL J2032–5627. These spectacular arcs (ASKAP data is magenta in the image) are rare because their emission is faint and diffuse, making them difficult to spot. Astronomers think relics are evidence of shockwaves between clusters as they crash together. Relatively few radio relics have been found to date, but surveys such as ASKAP's Evolutionary Map of the Universe (EMU) will uncover many more, helping to build our understanding of how clusters of galaxies merge as the Universe evolves.

Duchesne et al. 2021 PASA 38 e005



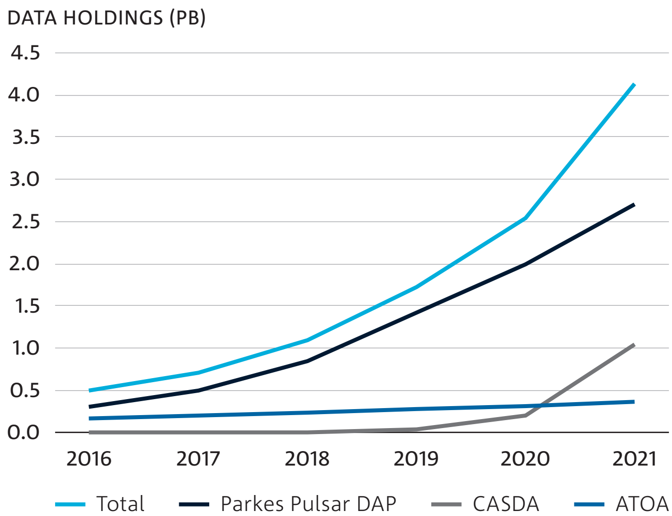


Figure 6: Our radio astronomy data archives over time.

Technology development

CryoPAF

The colder a telescope receiver is, the less 'noisy' it is, which is an advantage when trying to detect faint radio waves from space. Development of the cryogenically cooled phased array feed (CryoPAF) receiver for Parkes reached a major milestone this year with assembly of the cryostat, the cooled part of the receiver. Our work was rewarded when a test 'cooldown' reached the target temperature of 35 Kelvin (-238 °C). The CryoPAF promises performance up to 30 times better than existing instrumentation and, like the ultra-wideband receiver, is funded by the Australian Research Council.

The cryostat will be opened just once more to install the low noise amplifier modules. Outside the cryostat sit 'warm' electronics modules providing additional amplification and filtering and our 8-channel, 4 gigasamples per second (GSps) Jimble digitiser platform, based on state-of-the-art radio frequency system on a chip (RFSoC) devices.

We are now applying this modular approach and Jimble technology to the phased array system for Quasar Satellite Technology.

The digital output of the CryoPAF will be sent over multiple high-bandwidth optical fibre links to an FPGA-based beamformer. The beamformer has also been designed to mitigate radio frequency interference through techniques such as adaptive nulling. The correlator we are building for SKA-Low is also based on this architecture.

COMMERCIAL HIGHLIGHT

A new company, Quasar Satellite Technology, launched on 4 May 2021 will apply our phased array technology to solving a looming bottleneck in space communications. The next decade will see tens of thousands of satellites launched, each needing to communicate with the Earth's surface. Current ground station technology uses traditional dishes to link with satellites (one dish per satellite). Phased arrays, however, have the potential to 'talk' to hundreds of satellites at once. The market is expected to grow to hundreds of billions of dollars over the longer term.

Quasar is backed by $12m in funding, technology and industry expertise from CSIRO, CSIRO's venture capital fund Main Sequence, the Office of the NSW Chief Scientist & Engineer, and Australian companies Vocus, Saber Astronautics, Fleet Space Technologies and Clearbox Systems.

Quasar founding Director Ilana Feain and CEO Phil Ridley visited the Parkes' CryoPAF while it was under construction in Sydney. Image: Karl Schwerdtfeger.

BIGCAT

The Australian Research Council is also funding the upgrade of ATCA's digital system. The broadband integrated-GPU correlator for the Australia Telescope (BIGCAT) will double the instrument's bandwidth from 4 GHz to 8 GHz. Jimble boards will replace the existing radio signal chain and the digitiser. Design and prototyping are underway. Using a common Jimble platform allows the development of digitisers for CryoPAF and BIGCAT to occur in parallel.

BIGCAT's new GPU-based correlator will enable innovative signal processing techniques and active RFI mitigation.

Emerging technologies

Another RFSoC technology under development is Bluering, a 16-channel, 2 GSps device which targets array-based instruments, such as SKA-Low.

Jimble and Bluering use a common time and frequency distribution system called Irukandji, which is currently under development. Irukandji synchronises multiple boards, such as the Jimble digitisers in the CryoPAF, a very necessary step for applications with multiple antennas. Irukandji will also form the basis of the timing system for Quasar's phased array.

SCIENCE HIGHLIGHT

Many fast radio bursts – millisecond-duration flashes of radio waves – appear to be one-off events, but a small fraction have been found to repeat. Observations led by one of our postdocs using China's FAST telescope, which combined the huge collecting area of the telescope with a sensitive CSIRO-built 19-beam receiver, showed that a fast radio burst previously discovered with Parkes is actually 'a repeater'. Over 12 hours' observing with the FAST multibeam receiver, 15 bursts were detected from the same spot on the sky. Confirming the burst was a repeater gave the team a rare opportunity to study the source of the burst, which the team believes to be the magnetosphere of a neutron star.

This image is taken from the surface of the FAST dish looking up at the receiver. Image: Lin Huang, Qingliang Yang, Bojun Wang, Chunfeng Zhang, Jincheng Jiang and Qisheng Cui.

Luo et. al. 2020 Nature 586 693

Students, education and outreach

Postgraduate students

This year we supervised 34 PhD students, one Masters and two Honours students. The students came from 17 universities, with fewer than usual from overseas due to COVID restrictions. Ten PhDs, one Masters degree and two Honours degrees were awarded (p31). The scheduled radio school was not held this year.

Undergraduate vacation scholars

Our undergraduate vacation scholarship program saw 16 summer students, and our first Women in Engineering scholar from Macquarie University, working on projects in astrophysics, engineering and Earth observation. Due to COVID, most students worked at a CSIRO site in their home state. Their trip to ATCA had to be cancelled, so the students shifted to remote observing from hubs in Perth and Sydney, or online. The students' end-of-summer symposium was also held online.

Schools and teachers

School visits and in-person activities were heavily restricted this year. Even so, several of our people involved in the STEM Professionals in Schools program managed to get out into the classroom. For the first time since the pandemic began, our team in Geraldton ran a booth at the careers' day of Nagle College, one of the largest schools in town.

Most of our science teacher workshops were online, allied with the teachers' state conferences. We ran two workshops in-person before restrictions were again imposed.

PULSE@Parkes

Our earlier move to online delivery of the PULSE@Parkes program (where students get to observe with the Parkes radio telescope and add to our store of pulsar knowledge) proved valuable this year, with 13 sessions held. The last session in June was in-person at our science operations centre in Sydney.

We also ran special sessions reaching 30 students across three programs: CSIRO's Young Indigenous Women's STEM Academy, BHP Foundation Science and Engineering Award finalists, and as part of CSIRO's virtual work experience program.

In all, over 180 school students from more than 20 schools in five states and territories, plus 15 undergraduate students, took part in PULSE@Parkes. Our first online teacher workshop for the program in February involved 12 teachers from around Australia.

An in-person PULSE@Parkes session in Sydney. Image: Karl Schwerdtfeger.

Communications

This year we continued to tell stories of our people, infrastructure and the excellent science we enable and how this delivers benefit for Australia.

Our promotion of ASKAP's RACS survey generated widespread media coverage, which reached 8.6m people. To celebrate the survey, and as part of our ongoing commitment to acknowledging and supporting Indigenous culture and heritage, we commissioned a painting by Wajarri Yamatji artist Margaret Whitehurst that now hangs in our Murchison support facility in Geraldton.

Media coverage of the launch of company Quasar Satellite Technologies included page three of the prominent business publication *The Australian Financial Review*, and overall reached 1.8m people. Following the announcement, Quasar CEO Phil Ridley received a dozen queries and more than 30 subscribers to the Quasar newsletter.

We supported astronomy events hosted by the Pawsey Supercomputing Centre, and ASKAP was profiled in exhibitions at the Australian Space Discovery Centre in Adelaide and the WA Museum in Perth.

Many in-person events were postponed or cancelled due to the ongoing COVID-19 pandemic. We responded by creating engaging online events, such as a panel event on the SKA during National Science Week that attracted 250 participants from across Australia and around the world. We celebrated International Women in Engineering Day by profiling some of our people on the ATNF Twitter account, which reached nearly 4500 followers, and we held our first 'Instagram Live' event.

This online event was one small part of our public engagement highlight of the year: the total lunar eclipse on 26 May. Vanessa Moss was the expert guest on board a special scenic Qantas flight from Sydney, which generated more than 100 media stories. In the west, we streamed the eclipse and expert commentary live from New Norcia for the European Space Agency.

Visitors centres

The visitors centres at the Parkes radio telescope and ATCA reopened on 4 July 2021 and stayed open all year, benefitting from the boom in Australian domestic tourism.

This year record numbers of Australians holidayed in regional areas. The Visitors Centre at Parkes, which implemented COVID-safe measures, welcomed over 100 000 people. Image: John Sarkissian.

Number of visitors to ATCA and the Parkes radio telescope.

	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21
Parkes	95 212	83 851	105 085	112 224	100 013	103 185
ATCA	11 511	10 965	12 081	10 363	7434	19 659

Our people

There are currently 194 people working on radio astronomy in the ATNF, including SKA. Five people identify as Indigenous and our gender breakdown is similar to previous years. Data in this section includes our staff and others receiving financial support from CSIRO for activities within the ATNF and the SKA, including joint appointments and, from 2020, those employed under contractor or labour hire arrangements. The data, captured on 30 June 2021, excludes honorary fellows and students.

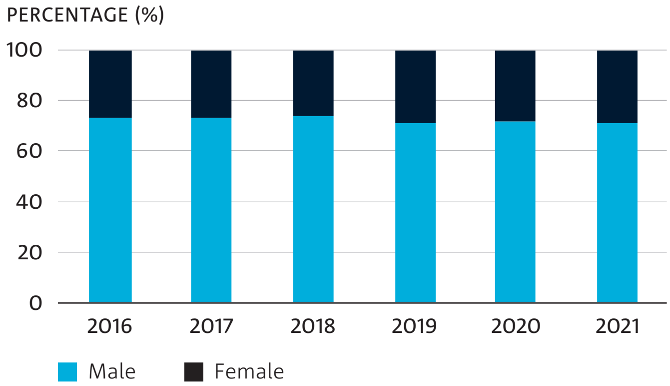


Figure 7: Gender breakdown of our people over time.

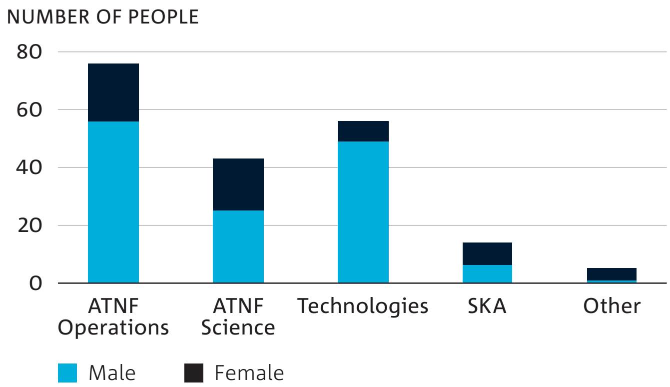


Figure 8: Gender breakdown by research program. Note: many staff working on SKA projects are based in other Programs, such as Technologies.

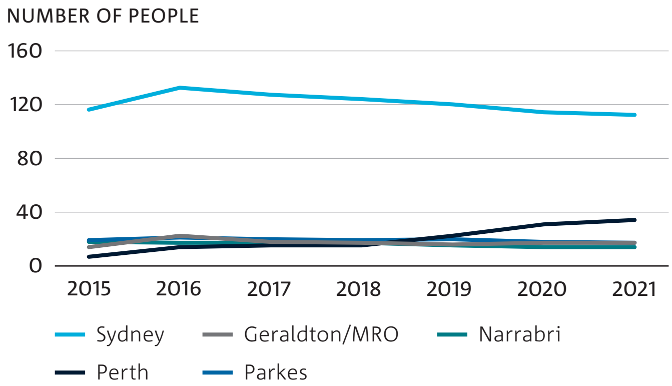


Figure 9: Our people by site.

Diversity and inclusion

We received a bronze Pleiades award from the inclusion, diversity and equity in astronomy chapter of the Astronomical Society of Australia in recognition of our commitment to ensuring a safe, respectful, inclusive and diverse working environment for our people, students and visitors.

Diversity Champion, Kevin Ferguson, and the Diversity and Inclusion Committee developed the first annual action plan. A highlight was interactive workshops to provide our people with strategies for responding to inappropriate behaviour in the workplace. Over 100 of our people attended one of these 'Speak Up!' workshops. We made changes to our recruitment, advertising by default roles with the option of being full-time, part-time, or job-share, to increase diversity in the applicant pool, and added a diversity statement to all position descriptions. In June, we opened a third culture survey and focus groups to help us understand where we are doing well, and which areas require attention to make our workplace more inclusive. Results from the survey and focus groups will inform next year's action plan.

Our Parkes radio telescope, and two other dishes at the observatory, were this year given Wiradjuri names by the region's traditional owners. This was the culmination of two years' work by Indigenous staff member, Stacy Mader, with Wiradjuri Elders, the NSW Aboriginal Education Consultative Group and the North West Wiradjuri Language & Culture NEST.

Awards and honours

Our award-winners this year included:

- Keith Bannister and 53 co-authors (21 from CSIRO) – Newcomb Cleveland Prize awarded by the American Association for the Advancement of Science for an outstanding paper published in *Science*.
- Keith Bannister – Astronomical Society of Australia Anne Green Prize for pioneering work on fast radio bursts.
- Vanessa Moss – International Union of Radio Science (URSI) 2021 Young Scientist award; the only Australian to receive this award in 2021.
- Sarah Pearce – elected a Fellow of the Australian Academy of Technology and Engineering.

Chenoa Tremblay volunteers her time at a school in Perth as part of the STEM Professionals in Schools program. Image: Harrisdale Primary School.

Health, safety and environment

Our safety culture continues to grow as we move to a proactive approach with more workplace inspections and audits. We are also fostering a positive 'prevention is better than cure' attitude by reporting incidents quickly so we can understand root causes, prevent further incidents and assist our people with a quick recovery. These data now reported in the same manner as CSIRO.

Our recordable injury frequency rates.

YEAR	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	

Frequency rate is per million hours worked. 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.

Financial summary

CSIRO funding for the ATNF this year was $40.5m: $3.1m for capital expenditure and $37.4m for operations, covering direct and indirect costs. This is supplemented with $18.1m from external sources such as sale of telescope time, funding for our SKA work and grants from the Australian Research Council. Also included is $1.6m for ASKAP operations from the National Collaborative Research Infrastructure Strategy, administered by Astronomy Australia Limited.

The table below summarises revenue and expenditure applied to CSIRO's radio astronomy activities. Notable factors affecting the financial results for this year include an increase to external revenue due to ARC grants for BIGCAT ($0.2m) and CryoPAF ($1.4m). CSIRO appropriation decreased largely in line with reduced travel due to COVID-19. Salary expenditure is down due to a revaluation of leave provisions and $1.3m of salary costs appear in ATNF's capital investment table.

OPERATING	YEAR TO 30 JUNE 2016	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
Revenue						
External	14 377	15 418	14 889	13 806	16 648	18 086
CSIRO direct appropriation	18 282	19 532	20 632	20 612	20 550	17 904
CSIRO indirect appropriation[1]	23 812	25 099	25 637	25 261	18 754	19 521
Total revenue	56 471	60 049	61 158	59 679	55 952	55 511
Proportion of appropriation funded	75%	74%	76%	77%	70%	67%
Expenditure						
Salaries	21 179	22 784	20 959	22 289	24 096	22 724
Travel	1 981	1 866	1 713	1 879	1 269	412
Other operating	8837	11 708	13 250	10 562	11 977	12 640
Overheads[2]	13 711	13 492	13 316	14 947	13 394	13 735
Depreciation	10 101	11 607	12 321	10 314	5 360	5 786
Total expenses	**55 809**	**61 457**	**61 559**	**59 991**	**56 096**	**55 297**
Operating result	662	-1408	-401	-312	-144	214

$'000s.

1. CSIRO indirect appropriation is funding for: overheads and depreciation.
2. Overheads include support services such as human resources, health and safety, 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 2016	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
ATNF	1 310	547	2 360	1 445	1 823	3 143
ASKAP	9 728	3 121	1 235			

Our Galactic near neighbours, the Large and Small Magellanic Clouds, over ATCA. Image: Alex Cherney.

ATNF management team

Director, Dr Douglas Bock

Deputy Director, Dr Sarah Pearce

Chief Scientist, Prof Elaine Sadler

Program Director SKA, Mr Antony Schinckel

Program Director Technologies for Radio Astronomy, Dr Tasso Tzioumis

Program Director ATNF Science, Dr Phil Edwards

Program Director ATNF Operations, Dr John Reynolds

Chief Operating Officer, Ms Kate Callaghan

Committee membership

ATNF Steering Committee

Chair

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

Australian astronomy community

Prof Sarah Brough, University of New South Wales
(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 30 April 2022)

Prof Tara Murphy, University of Sydney
(1 April 2020 to 31 March 2023)

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 30 April 2022)

Prof Xiang-Ping Wu, National Astronomical Observatories of China (1 April 2018 to 30 April 2021)

Australian stakeholder communities

Ms Catherine Livingstone AO
(1 January 2019 to 31 December 2021)

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

Ex-officio

Mr Brendan Dalton, Chief Information Officer, CSIRO

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

Secretariat

Nic Svenson, CSIRO

ATNF User Committee

Chair

Dr Ramesh Bhat, ICRAR/Curtin University
(January 2020 to December 2022)

Members

Dr Martin Bell, University of Technology, Sydney
(July 2020 to June 2023)

Dr Michelle Cluver, Swinburne University of Technology
(January 2020 to December 2022)

Prof Miroslav Filipovic, Western Sydney University
(July 2018 to June 2021)

Dr Bi-Qing For, ICRAR/University of Western Australia
(July 2018 to June 2021)

Dr Emil Lenc, CSIRO (July 2020 to June 2023)

Dr Nickolas Pingel, Australian National University
(July 2020 to June 2021)

Dr Ryan Shannon, Swinburne University of Technology
(July 2020 to June 2023)

Student members

Ms Philippa Patterson, University of Western Australia/
Macquarie University (July 2020 to June 2021)

Ms Yuanming Wang, University of Sydney
(July 2020 to June 2021)

Secretariat

Dr Cormac Reynolds, CSIRO

ATNF Time Assignment Committee

Chair

Dr Adam Deller, Swinburne University of Technology
(January 2021 to December 2022)

Dr Martin Meyer, ICRAR/University of Western Australia
(January 2018 to December 2020)

Voting members

Prof Geoff Bicknell, Australian National University
(January 2020 to December 2022)

Dr Jess Broderick, ICRAR/Curtin University
(January 2021 to December 2023)

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

Dr Katie Jameson, CSIRO (January 2020 to December 2022)

Dr Christene Lynch, ICRAR/Curtin University
(January 2018 to December 2020)

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

Dr Jongwhan Rhee, ICRAR/University of Western Australia
(January 2021 to December 2023)

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

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

Ex-officio

Dr Douglas Bock, CSIRO

Dr Jimi Green. CSIRO

Dr Jamie Stevens, CSIRO

Secretariat

Dr Hayley Bignall, Executive Officer, CSIRO

Mrs Amanda Gray, Administration, CSIRO

PhD theses

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

NAME	UNIVERSITY	MONTH AWARDED	THESIS TITLE
Dougal Dobie	University of Sydney	January 2021	Radio follow-up of gravitational wave events
John Lopez	University of New South Wales	June 2020	From one extreme to another: molecular clouds and star formation throughout the Milky Way Galaxy
Peter MacGregor (MRes)	Western Sydney University	August 2020	An investigation of the diffuse radio emission in the galaxy cluster Abell S1136
Aditya Parthasarathy	Swinburne University of Technology	January 2020	Timing properties across the pulsar population
Hao Qiu	University of Sydney	March 2021	Detecting fast radio bursts with the Australian Square Kilometre Array Pathfinder
Tristan Reynolds	University of Western Australia	July 2020	The effect of the environment on the neutral hydrogen content of galaxies
Shaungqiang Wang	Xinjiang Astronomical Observatory	June 2021	Emission variation study of radio pulsars
Naoyuki Yonemaru	Kumamoto University	March 2020	Study on direct detection of low-frequency gravitational waves with the pulsar timing array
Chao Zhang	National Astronomical Observatory of China	August 2020	Pulsar search with interpretable machine learning
Songbo Zhang	Purple Mountain Observatory	July 2020	Single pulses in the radio observation data sets
Andrew Zic	University of Sydney	August 2020	Cool stellar activity at low radio frequencies

Observing programs

Proposals allocated time on ATCA, Parkes and the LBA over the April 2020 – September 2020 and October 2020 – March 2021 semesters. A small number of 'target of opportunity' observations are not listed.

ATCA

OBSERVERS	PROGRAM	NO
Stevens, Edwards, Wieringa, Moss	ATCA calibrators	C007
Staveley-smith, Cendes, Gaensler, Indebetouw, Matsuura, Tzioumis, Zanardo, Ng	Supernova remnant 1987A	C015
Lundqvist, Perez Torres, Ryder, Bjornsson, Fransson, Filipovic, Kundu	Probing type Ia supernova progenitors with ATCA	C1303
Ryder, Kundu, Filipovic, Anderson, Stockdale, Maeda, Renaud, Kotak	NAPA observations of core-collapse supernovae	C1473
Hollow, Stevens	Summer student training and observing at the ATCA	C1726
Edwards, Stevens, Ojha, Kadler, Wilms	ATCA monitoring of Fermi gamma-ray sources	C1730
Possenti, Wieringa, Esposito, Israel, Rea, Burgay	Continuum radio emission from magnetars in outburst	C2456
Miller-Jones, Diaz Trigo, Migliari	The disc wind-jet connection in black hole transients	C2514
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
Aravena, de Breuck, Bethermin, Chapman, Jarugula, Marrone, Apostolowski, Malkan, Stark, Tothill, Vieira, Weiss, Litke, Spilker, Phadke	A legacy CO survey of the brightest dusty star-forming galaxies at z=2-7 discovered by the SPT	C2818
Piro, Ricci, Troja, Fiore, Piranomonte, Bannister, Wieringa, Gendre, Sanchez Ramirez	ATCA observations of the new class of ultralong GRBs: a local proxy of population III 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	Dense gas Across the Milky Way: the 'full-strength' MALT45	C3145
van Velzen, Miller-Jones, Anderson, Shappee, Jonker, Arcavi, Holoien, Gezari, Stein	Radio emission from stellar tidal disruption flares	C3148
Jackson, Barnes, Longmore, Contreras, Sanhueza, Hogge, Stephens, Whitaker, Walker, Smith, Krumholz, Kruijssen, Caselli, Cunningham, Ott, Allingham, Breen, Jordan, Killerby-Smith	A comprehensive ATCA census of high-mass cores	C3152
Popping, de Blok, Gannon, Heald, Koribalski, Lee-Waddell, Lopez-Sanchez, Spitler, Madrid, Moss, Meyer, Obreschkow, Pisano, Power, Rhee, Staveley-Smith, Wang, Westmeier, Wolf, Kaczmarek, Sardone, Vinsen, Elagali, Wong, Kleiner	Imaging galaxies intergalactic and nearby environment	C3157
McCarthy, Ellingsen, Breen, Voronkov, Chen	Investigating extragalactic star-formation through methanol maser emission	C3167
Ellingsen, Impellizzeri, McCarthy	A chemical map of the masers in the accretion disk of the Circinus galaxy	C3175
Anderson, Bell, D'antonio , Hancock, Lynch, Miller-Jones, Bahramian, Bannister, Kaplan, Murphy, Ryder, Macquart, Plotkin	ATCA rapid-response triggering on X-ray and gamma-ray superflares from the smallest stars	C3200
Anderson, Bell, Hancock, Miller-Jones, Bahramian, Rowlinson, Aksulu, Bannister, van der Horst, Macquart, Ryder, Plotkin, Wijers	ATCA rapid-response triggering on Swift detected short gamma-ray bursts: exploring the link with gravitational wave events	C3204

OBSERVERS	PROGRAM	NO
Shannon, Bhandari, Bannister, Mahony, Deller, Dodson, Flynn, James, Oslowski, Prochaska, Sadler, Tejos, Day, North-Hickey	Radio continuum emission from ASKAP-localised fast radio bursts	C3211
Chernyakova, Malyshev, van Soelen, Sobey, O'Sullivan, McKeague	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
Heald, Alexander, Anderson, Basu, Brown, Callingham, Carretti, Crawford, Farnes, Filipovic, Gaensler, Galvin, Harvey-Smith, Johnston-Hollitt, Kaczmarek, Landecker, Leahy, Lenc, Mao, McClure-Griffiths, Miyashita, O'Sullivan, Pasetto, Purcell, Riseley, Rudnick, Schnitzeler, Sobey, Sun, Thomson, Zhang	The QUOCKA survey	C3244
Dobie, Murphy, Kaplan, Lenc, Brown, Stewart, Hotokezaka, Bannister	Long term radio follow-up of GW170817	C3251
Troja, Piro, Ricci, Wieringa, Cenko, Lien, Sakamoto	Electromagnetic counterparts to gravitational wave events	C3262
Chomiuk, Ryder, Sokolovsky, Filipovic, Alsaberi, Manojlovic, Aydi, Linford	E-nova project monitoring of Nova Muscae 2018 and Nova Carinae 2018	C3279
Schulze, Bauer, de Ugarte Postigo, Hunt, Jonker, Klose, Malesani, Michalowski, Nicastro, Palazzi, Pellizzoni, Possenti, Tanvir, van der Horst, Wieringa, Bufano, Cavallaro, Ingallinera, Brocato, Kann, Lamb, Lekshmi, Lyman, Misra, Pian, Sànchez-Ramìrez, De Pasquale, Nicuesa Guelbenzu	The properties of compact-object mergers detected by LIGO and VIRGO	C3281
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